Ecological brick manufactured with addition of ceramic waste

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Abstract

Environmental legislation has placed constraints on the extraction of natural resources. As the construction industry is highly dependent on raw materials, more sustainable choices are required. This necessitates a cost-benefit analysis of the alternatives. Focusing on the benefits to the environment with the reduction of clay consumption, this work proposes an exploratory study on the production of unburned bricks with construction and demolition ceramic waste. The construction and demolition waste used was composed solely of ceramic brick remains, being crushed and sieved until reaching the desired granulometry to start the manufacturing process. Among three different properties, the bricks that obtained the best performance were those that incorporated higher content of construction and demolition ceramic waste.

Keywords: Brick; CDW; Ceramic Waste; Construction Materials; Recycling.

Introduction:

In recent years, with the evolution of the civil construction process, new methods and construction alternatives have been used, seeking to obtain economy, durability and sustainability. When dealing with the current environmental situation, there is an emphasis on the concern related to natural resources, concerns that have been growing rapidly. Despite this, the production of waste tends to increase **[1]**. According to Ö. Çimen **[2]** the necessary market mechanism to contribute to material circularity or manage the increased complexity of the construction when interacting across sectors is still needed. The cause of environmental impacts is related to the inadequate disposal of industrial waste; the waste produced by the civil construction industries, is responsible for thousands of tons produced annually, and is often discarded inappropriately, generating a serious environmental problem.

The Construction and Demolition Waste (CDW) is composed of several types of materials discarded during construction, which can vary according to the stage in which it is produced **[3]**. CDW can be composed of cement, mortar, bricks, blocks, wood, ceramics, concrete, soil, tile, steel, plaster, etc. and has a high recycling potential and can be reused in civil construction. The construction industry and construction-related site activities are the main contributor to waste material, landfills and up to 40% of urban solid wastes **[2]**. According to F.M. Grande **[4]**, the use of bricks in soil-cement brings several advantages, starting with the ease of manufacture, which makes use of

simple and more viable techniques. Among the advantages mentioned, the most relevant is the low impact on the environment by eliminating burning and minimizing waste/losses. In ceramic industries, a significant part of the losses in the manufacturing of ceramic elements is not returned to the production process **[5]**. However, among all policies and measures to expedite ceramic elements transformation, financial subsidies are still the most important driving factor, both at the corporate and individual levels in the construction industry **[2]**. Therefore, in order to contribute to sustainability, several studies demonstrate the feasibility of reusing ceramic waste **[3, 5, 6, 7, 8]**.
Thus, this work aimed to study the use of CDW from ceramics (bricks and tiles) for manufacturing soil-cement bricks. Their physical and mechanical characteristics are investigated through tests of compressive strength and water absorption. This work is an applied case study. Therefore, due to the high variability of global soils, the results cannot be directly extended to other soil types.

Material and methods:

(a) Characterization and preparation of materials

The argillaceous soil used to produce the bricks, extracted from a borrow pit, underwent a drying process exposed to air and sieving to remove any organic particles contained in it. The cement used for these experiments was the Brazilian Portland CP V-ARI because it is a high initial resistance cement and widely used in the manufacture of prefabricated materials such as masonry blocks, paving blocks, poles, among others.
Ceramic waste materials were crushed and ground, through a crusher to obtain a better uniformity of the mixture and used for the manufacturing the ecological bricks. A percentage of lime was added to replicate the mix compositions for the manufacture of bricks. Note that the mortar that contains lime in its composition has some advantages such as compressive strength and adherence, sufficient for laying and coating. Lime was also used to give plasticity to the mortar, in addition to better absorbing small movements in constructions, avoiding possible cracks. Figure 1 shows the sieving of the soil, the CDW from ceramics and the machine used for crushing.

Figure 1. Process of preparation of materials for the production of ecological bricks:
(a) Sieving soil, (b) Ceramic waste, and (c) Waste crushing.

The granulometry test was carried out based on the Brazilian standard NBR 7217 **[9]** and consisted of using a series of sieves from #4 to #200 with varying sizes to determine the ideal diameter of the aggregate to be used in making the bricks.
Once the test was started, a 1 kg sample was separated to carry out the sieving phase. With the sieves clean and already assembled with the mesh opening in ascending order from the base to the top, portions of the samples were placed on the upper sieve. Then, the material was stirred for separation and classification of the different grain

sizes. The top sieve was detached from the set and, with a lid and a fitted false bottom, was shaken with lateral and circular movements. Soon after, the grains that passed through the sieve were separated and the same was brushed to remove and separate the retained material. Subsequently, the next sieve was verified, with the material passing through the upper sieve being added, all being verified in the same way. Finally, the mass of retained material was determined. Figure 2(a) shows the aggregate of ceramic material waste that have already undergone the granulometry test.

Figure 2. (a) Aggregate of waste ceramic materials passing through the sieve 16, and (b) Mixing raw materials before molding.

For molding the ecological bricks, the mixture of its components (soil, cement, lime, waste of ceramic materials and water) was carried out in order to obtain the most homogeneous mass possible, with the aid of a hoe and a trowel (Figure 2(b)). The ecological bricks have two hollow sections that allow the passage of pipes for electrical and hydraulic installations embedded in the masonry avoiding tears or mending.

Three mixes were performed to produce specimens for the compressive strength and for the water absorption tests. The variation of the CDW of ceramics and soil portion in the three compositions as shown in Table 1, sought to produce different bricks to identify which material would affect the compressive strength and water absorption. The reason for 15% variation assessments in soil and CDW was to achieve a wider range of analysis in this preliminary study.

Table 1. Compositions used for making and testing ecological bricks (in % of mass).

Composition	Soil	CDW from ceramic waste	Cement	Lime	Total
T1	50	15	20	15	100
T2	35	30	20	15	100
T3	20	45	20	15	100

(b) Production of bricks

The mixture workability test was also performed, necessary to identify the amount of water needed to reach the ideal plasticity. The test consisted of squeezing a part of the mass that was already moist, this should show the marks of the fingers, and when dropped to the ground, it should dissolve **[10]**. The bricks manufactured have two holes and sockets and have an area of 10 x 20 centimeters and 5 centimeters thick. Using a manual press, capable of manufacturing a brick by pressing, the molding and production of hollow bricks was followed. After the mixing was carried out, the mass was moistened to be submitted to the manual pressing process. Once the moistened material was pressed, it was removed and stored in a place without direct sunlight. The fabrication resulted in nine specimens for each composition. Figure 3(a) and (b) show the press used and the brick after pressing, respectively.

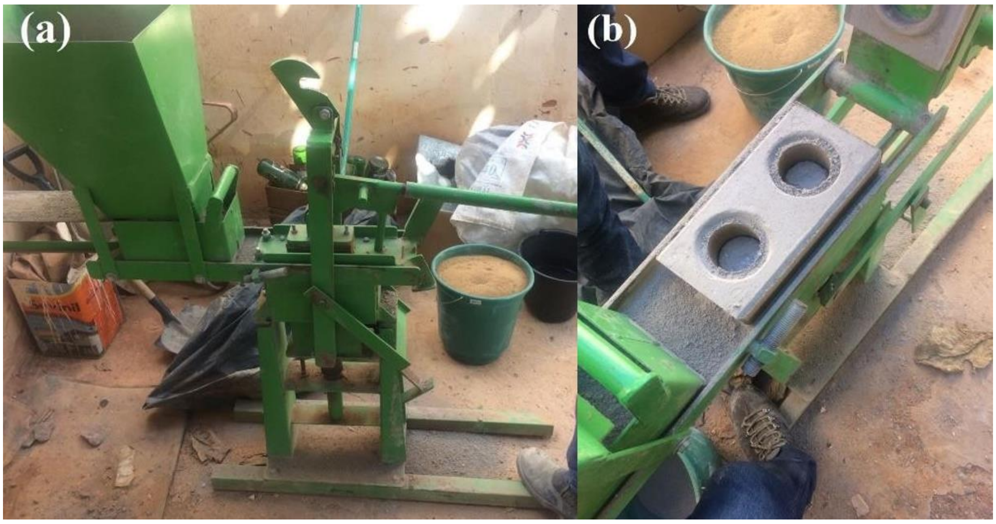

Figure 3. Production equipment: (a) Manual press for manufacturing ecological brick, (b) Ecological brick after pressing.

(c) Compressive strength tests

After a period of 28 days for the complete curing of the specimens, they went through the capping process, required by the Brazilian standard NBR 10836 **[11]**, which consists of regularizing the faces with Portland cement paste or very plastic mortar with purpose to obtain flat surfaces and evenly distribute the load during the test. A mortar composed of cement and sand in the proportion of 1:3 by-mass was made, this was distributed with the aid of a trowel on a plywood surface, ensuring the leveling of the coated faces. After the hardening of the capping, the blocks were submerged in an immersion tank for 24 hours to initiate the compressive strength test of the specimens. The compressive strength tests of the specimens were carried out using a hydraulic press, where the material was subjected to an axial load, expressed in tons, until its rupture. Figure 4 (a), (b) and (c) show the steps of preparation of specimens for the performance of the compression test.

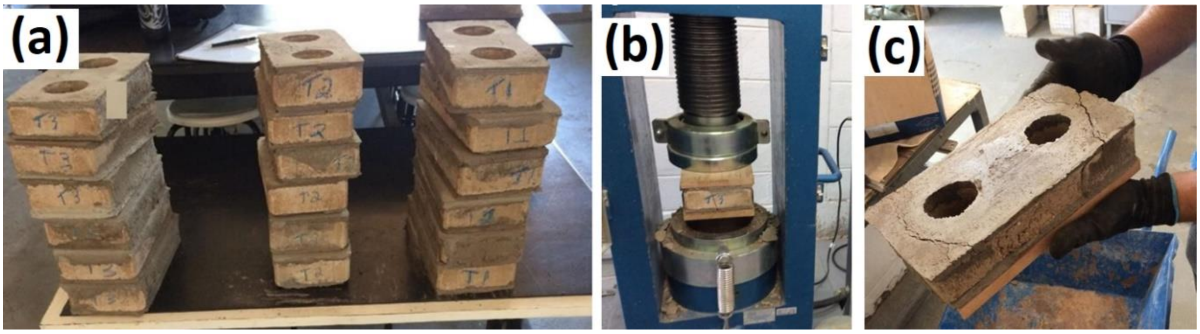

Figure 4. (a) Identified and capped bricks, (b) Pressing the brick using a hydraulic press, and (c) Cracks caused after rupture.

(d) Water absorption

For the water absorption test, a scale was needed to verify the mass of the analyzed specimen. An electric oven that maintains the temperature between 105 and 110 ºC was also used in this test. The first step was to find the dry mass, placing the bricks in the oven and after 24 hours they were weighed, obtaining the dry mass. After checking the dry mass of the bricks, they were submerged for a period of 24 hours in an immersion tank to later check the saturated mass. The difference between the mass of the bricks' absorption value is noted, calculated according to the Brazilian Standard NBR 10836 **[11]**. Figure 5 (a), (b) and (c) show, respectively, the drying and weighing processes of the bricks to obtain the dry mass and the wet mass.

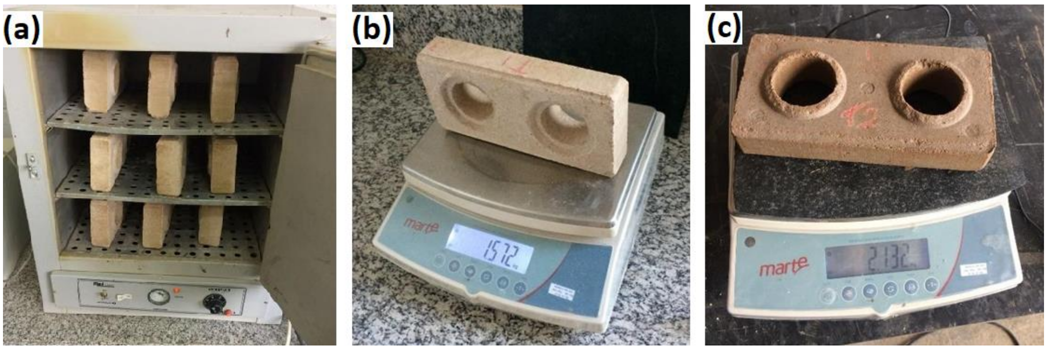

Figure 5. (a) Drying; and weighing processes of the bricks to obtain (b) the dry mass, and (c) the wet mass.

Discussion:

(a) Particle size test

The particle size curve is represented in Figure 6. After obtaining the aggregate particle size distribution, it was suggested the fraction between sieves #1.19 mm and #2.00 mm to carry out the experiment. After that, results of Cu (1) and Cc (1) have shown a uniform granulation of the material. By this fraction of grain-size-distribution curve, the material is classified as coarse sand.

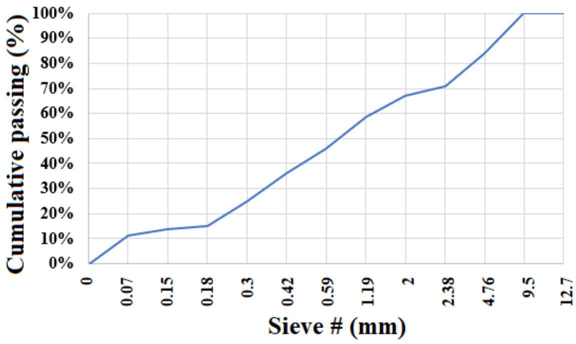

Figure 6. Cumulative particle size distribution.

(b) Water absorption test

The Brazilian standard NBR 10834 **[12]** determines the average absorption limit of soil-cement bricks, being 20%. The Table 2 reports the individual values of the water absorbed after 28 days.

Table 2. Water absorption at the age of 28 days.

Composition	Dry Mass [g]	Wet Mass [g]	Absorption [%]
T1	1.592	2.061	29.46
	1.510	1.992	31.92
	1.572	2.043	29.96
		Absorption Average [%]	30.44
		Absorption Standard Deviation [%]	1.30
T2	1.672	2.132	27.51
	1.674	2.138	27.72
	1.648	2.119	28.58
		Absorption Average [%]	27.93
		Absorption Standard Deviation [%]	0.57
T3	1.643	2.109	28.36
	1.624	2.088	28.57
	1.644	2.111	28.41
		Absorption Average [%]	28.44
		Absorption Standard Deviation [%]	0.11

The average values found for the executed compositions T1, T2 and T3 were respectively 30.44%, 27.93% and 28.44%, which are also above the limit of the standard and for the standard deviation were 1.30, 0.57 and 0.11%.

(c) Compressive strength

Along with the water absorption values, the Brazilian standard NBR 10834 **[12]** specifies the minimum strength for soil cement bricks without structural function, being 1.7 MPa for individual values and an average of 2.0 MPa, at the age of 28 days. The Brazilian standard NBR 6136 **[13]** subdivides cored concrete blocks into 4 classes, with the classes A, B and C with compressive strength of 6, 4 and 3 MPa, respectively, being considered structural. Class A blocks are used in elements above and below ground level, while the others are only for above-ground masonry. In the Brazilian standard NBR 15270-2 **[14]** it is stated that the compressive strength of structural ceramic blocks must be considered 3 MPa. With the addition of the CDW, individual compressive strength values were obtained as shown in Table 3.

Table 3. Individual values of the compressive strength.

Specimen	T1 [MPa]	T2 [MPa]	T3 [MPa]
1	5.5	5.8	7.1
2	5.0	6.4	6.3
3	5.6	5.9	7.2
4	5.5	5.7	6.8
5	5.6	5.0	6.2
6	5.3	5.6	6.9
Average	5.41	5.72	6.75
Standard deviation	0.245	0.433	0.425

With the individual values found, it was possible to accept the brick by presenting required compressive strength specified by the standard. On average, the mixes T1, T2 and T3 presented, respectively, strength values of 5.41, 5.72 and 6.75 MPa and a standard deviation of 0.245, 0.433 and 0.425 MPa, and they also have a strength higher than that required by the standard for non-structural bricks. It was also possible to notice that the bricks manufactured with a higher percentage of CDW of ceramic waste presented higher strength than the others.

With these results, sustainable applications in civil construction can be considered. Ecological bricks, using recycled material, can replace conventional ceramic bricks. The environmental benefits range from the reduction in the exploitation of natural deposits to the reduction of waste generated by civil construction. The circular economy consists precisely in returning the waste of one industry to the production process of another as raw-material, enhancing the sustainability of the planet.

Conclusions:

From the present exploratory research about the manufacture of ecological brick with CDW from ceramic waste it can be concluded:

- The values found for compressive strength at the age of 28 days were satisfactory and they are higher than those specified by the Brazilian standards for soil-cement bricks without structural function, and even being similar to ceramic blocks and of concrete with structural functions.
- The water absorption tests showed that compositions performed presented values that were not acceptable according to the Brazilian standard NBR 10834 **[12]**. Probably, the factor related to this was

the addition of lime in the mixture. Despite having several advantages, the lime also has high water retention, which is considered a disadvantage.

- The manufacture and use of soil-cement bricks with the addition of waste ceramic materials, in addition to presenting ideal compressive strength, helps the environment due to the reuse of CDW, which is a relevant factor for environmental issues.

Acknowledgments:

The authors are grateful to technical staff of Construction Technology Laboratory of Faculty of Santo Agostinho, at Montes Claros-MG-Brazil. This work is financially supported by: Base Funding – UIDB/04708/2020 of the CONSTRUCT – Instituto de I&D em Estruturas e Construções - funded by national funds through the FCT/MCTES (PIDDAC). This work is funded by national funds through FCT – Fundação para a Ciência e a Tecnologia, I.P., under the Scientific Employment Stimulus – Institutional Call – CEECINST/00049/2018.

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