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Recycling of construction and demolition waste for producing new construction material (Brazil case-study)

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HIGHLIGHTS

- Low-cost bricks were manufactured using construction and demolition waste (CDW).
- Lime and cement used as binding agents mixed with CDW and water.
- The bricks present better technological properties than standards.
- The use of this waste reduce the raw materials demands and environmental impacts.

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ABSTRACT

Construction and demolition waste corresponds to 50% of all urban solid waste, usually it is dumped in improper places. This work reuses this waste as substitute of natural aggregate to produce bricks. Lime and cement were used as binding agents and were pressed using a uniaxial hydraulic press. After 21 days curing were submitted to compression tests, the probes presented an average resistance greater than 4 MPa, which is higher than standards. Water absorption, apparent porosity and density were also determined. The results show that it is possible to produce low-cost bricks with excellent physical properties using CDW as aggregate and lime or cement as additive.

1. Introduction

Construction demolition waste (CDW) is a worldwide problem. The estimated CDW production in Brazil is higher than 70 Mt/year (around 500 kg/year per capita), but this amount is variable and has correlation with the human development index (HDI). CDW represents the largest amount of municipal solid waste (in mass). The illegally dumped waste in urban areas, nearby creeks, roads and other unprepared places has substantial environmental and economical impacts resulting in financial problems for the community and public administration. In the last years, governments have approved new policies about responsibilities, dumping and recycling of waste in general. As a result, the situation in the major cities is changing with the implantation of recycling plants, but nowadays only a small part of the CDW is recovered.

On the other hand, recycling has another environmental and economic advantages, since it reduces the consumption of natural resources. So, there is a comprehensive array of research on the social and financial cost, production, characterization and recycling of this waste [1–4]. CDW recycling plants have been proved to be economically viable [5,6] as well as having a positive environmental impact [7,8].

However, it is essential to absorb the output from these plants by the market. In other words, there is a strong need to diversify the industrial applications of this waste. CDW materials have been evaluated and successfully implemented in recent years in several countries [9,10], and generally, it is used as raw mineral materials in paving projects [11–14], footpaths [15] and pipe-bedding [16]. Some author have focused in recycling CDW for concrete production

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[17–20]. Moreover, others researchers have developed new application as concrete brick [21–22] and concrete block [21,23–25]. Mymrin et al. (2015) have developed a new construction material from CDW and waste from lime production industry with better mechanical properties that Brazilian standards establishes [26]. But there is still a great need for new products, processes and markets, to reduce the volume produced and to recycle most of the CDW [1,3].

In general, CDW mineral fraction is very heterogeneous (mortar, ceramics, concrete, rocks, natural gravel, masonry, sand, soil, etc.) and depends on the characteristics of each construction. Besides, the extent of economic development of each region defines the chemical composition of the waste [27]. Consequently, CDW presents a wide range of porosity and particles size (bulk specific gravity variability from 1.7 to 3.0 kg/dm^3 and water absorption variability from 0 to 20.6%). Essentially, these minerals are mainly made up of silicates from ceramic and natural rocks and carbonates from cement-based particles. Hydrated cement-based phases also must be present. Phyllosilicate content is more relevant in the size fraction below 0.15 mm due probably to soil incorporation [1,4]. Although, the CDW fraction below 4.8 mm obtained in most of the plants is, generally, not used and represents approximately 40% of the total mass [2]. The present work is focused and proposes an alternative use for this fraction.

In view of the above, the main objective of this work was to evaluate the possibility of producing bricks, using lime or cement as binders, to construct low-cost housing, with construction and demolition waste (CDW) with the fraction below 4.8 mm as substitute of natural aggregates. As secondary objective was to evaluate, in term of mechanical behaviour, the different composition of CDW (mixture 50:20:30 (TSC1) and other randomly obtained in a recycling plant (TSC2)). The physical and technological properties of probes were determined and compared with Brazilian, European and American standards, looking for commercial applications for this residue.

2. Materials and methods

2.1. Materials (CDW, cement and lime)

Representative samples of two different types of CDW (Class A) [28] were obtained from two different metropolitan regions of São Paulo State (SP) Brazil, in order to compare the heterogeneity of these samples evaluating the technological properties. Sample 1 (Presidente Prudente County) was collected from the transporting containers disposed at the work sites of construction and demolition. Sample 2 was collected from a CDW Recycling Plant (São José do Rio Preto County). The samples were grounded and sieved through a 4.8 mm mesh sieve and used only fraction <4.8 mm.

According to previous works [29,30], CDW in Presidente Prudente is mainly composed by ceramic (50%), concrete (20%) and mortar (30%). CDW shows a vast array of elements in its composition, majorly containing SiO_2 (40–70 wt.%), CaO (10–25 wt.%), Al_2O_3 (5–20 wt.%), Fe_2O_3 (0.5–8 wt.%) and K_2O (1–4 wt.%). Similar characteristics was also reported in other studies [31–33].

Portland cement (type I) and hydrated lime (HL III) were used as binder. Portland cement type I is composed of clinker and gypsum [34]. Portland cement contains mainly CaO, SiO_2, Al_2O_3 and Fe_2O_3 (60–67, 17–25, 3–8 and 0.5–6 wt.%, respectively) as stated by the Brazilian standards (NBR) [35] and the U.S. National Bureau of Standards (NBS) [36]. The Hydrated Lime (CH III) is a high quality dolomitic lime, meeting the technical requirements of ABNT 7175 [37]. According to Brazilian building quicklime requirements [38], lime had a CaO and MgO content higher than 88–90 wt.%, and contained appreciable amounts of carbon dioxide (up to 12 wt.%).

2.2. Testing samples (TS) preparation

A total of three series of mixtures were prepared in the laboratory trials as test specimens (TS). Series I and series II mixtures were prepared for producing concrete bricks using CDW from Sample 1 and 2 respectively; series III mixtures were prepared for making lime bricks with CDW Sample 1. The details of these three series of mixes are given in Table 1. The mix notations indicate the different types of mixes (with TSC for concrete bricks and TSL for lime bricks), the notations of CDW aggregates (Sample 1 and 2), and the percentages (by weight) of the additive (cement or lime) in the total amount. The materials were mixed manually, moistened and homogenized. The cylindrical TS (ϕ = 30 mm, h ≈ 60 mm), were pressed in triplicate, utilizing a uniaxial manual hydraulic press and load of 7 tonf (tons-force).

Table 1
Composition of the different tests.

	CDW/additive (wt.%)	Water (wt.%)[c]	Nomination
CDW[a] – cement	90–10	13	TSC1-10
	80–20		TSC1-20
	70–30		TSC1-30
CDW[b] – cement	90–10	13	TSC2-10
	80–20		TSC2-20
	70–30		TSC2-30
CDW[a] – lime	80–20	12	TSL1-20
	75–25		TSL1-25
	70–30		TSL1-30
	65–35		TSL1-35

[a] Using classified CDW (50/20/30).
[b] CDW with randomly composition from a recycling plant.
[c] wt% of solid mass.

2.3. Methods

The particle size analysis of CDW was performed by a mechanical shaker using sieves Granutest model (2.40 mm; 1.00 mm; 0.60 mm; 0.30 mm; 0.15 mm and 0.075 mm). The identification of the mineral phases was analysed by the XRD technique (X-ray diffraction) in a Shimadzu diffractometer model XRD 6000, using Cu κα radiation working at 1.2 kW (40 kV e 30 mA). Data were recorded in the 5–60° 2θ range (step size equal to 1°/min).

Major and trace elements were analysed by Energy Dispersive X-ray Fluorescence (EDXRF) with a Bruker spectrometer S2 Ranger LE equipped with an X-ray tube of 50 W (50 kV, 2 mA), anode of Pd, XFlash® Silicon Drift Detector with resolution <135 eV for Mn Kα and 100,000 cps, with cooling system type Peltier (without need for liquid nitrogen) and tool changer primary filters with 9 positions available.

The behaviour of TS was evaluated on the basis of water absorption (WA), apparent specific mass (ASM) and apparent porosity (AP), according to the Archimedes method. The specimens were dried at a temperature of 110 °C for 24 h after immersion in a container of water during 24 h. The TS were weighed dried (dry mass), wet (wet mass) and immersed (mass immersed) using an analytical balance. According to the following equations:

$$WA\ (\%) = \frac{(m_w - m_d)}{m_d} \times 100 \tag{1}$$

$$AP\ (\%) = \frac{(m_w - m_d)}{(m_w - m_i)} \times 100 \tag{2}$$

$$ASM\ (g/cm3) = \frac{m_d}{(m_w - m_i)} \tag{3}$$

where m_w is the wet mass, m_d is the dry mass and m_i is the mass immersed in water.

Compressive strength (σ) was measured using an EMIC apparatus, model DL-2000 on ten test specimens for the three series of TS, with a cell for small test specimen compression.

$$\sigma = \frac{F}{S} \tag{4}$$

where F is the applied force (Kgf) on the test specimen and S is the cross section area (cm^2).

3. Results and discussion

3.1. Materials characterization

CDW elemental composition, shown in Table 2, indicates that this waste is mainly composed of Si (71.74 wt.% as SiO_2), Al (14.17 wt.% as Al_2O_3) and Fe (12.11 wt.% as Fe_2O_3). These results are similar to those reported in other previous studies [29–33]. It is also observed a high concentration in other elements as Mg (3.67 wt.% of MgO), Ca (3.44 wt.% of CaO), Na (2.86 wt.% of Na_2O) and K (2.68 wt.% of K_2O) according to the mineralogical composition. The trace elements are present at concentrations below