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Construction material from construction and demolition debris and lime production wastes

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HIGHLIGHTS

- New construction material from construction and demolition debris.
- Lime production waste was used as binder material.
- Uniaxial resistance strength on the 3 day was 4.0 MPa, on the 60th day 15.3 MPa.
- Established by XRD, SEM and EDS methods ceramics production.
- Utilization of industrial wastes has high economical and environment efficiency.

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ABSTRACT

It was developed a construction material from construction and demolition debris (CDD) and lime production waste (LPW). Beyond it is a viable solution for the utilization of the large amount of lime output residues generated, having in mind that was also found nothing similar in the world literature. There were studies on the parameters of chemical and mineralogy compositions of initial components and final product, axial resistance strength, water resistance and water absorption. The LPW was characterized by a high excess of $CaCO_3$. The medium compression resistance of the samples, cured in air conditions during 3 days is 4.0 MPa, on the 60th day arrived to 13.4 MPa and to 17.1 MPa on the 365th day. The XRD and SEM studies explain the growth of the samples resistance by the transformation of the initial mineral mixture into carbonates of calcium, carbonates of magnesium, between other carbonates, which led to the growth of amorphous and crystalline new formations. The main advantage expected from these materials is the environmental conservation they afford, represented by the use of CDD and LPW.

1. Introduction

The construction industry is one of the oldest known industries, and since the early days of mankind, construction was performed by hand, creating a large amount of mineral debris as a byproduct. Since then, among construction waste, a large amount of modern construction and demolition debris (CDD) has appeared. These materials include aggregates, such as bricks, concrete, plaster, ceramics, glass, asphalt, tiles, gypsum wallboard, wood, metals, different types of plastics, etc. CDD is being produced in enormous quantities and often with significant amounts of different organic and inorganic pollutants (oily materials, heavy metals, etc.).

The Construction & Demolition Recycling Association (CDRA) estimates [1] that in the USA, more than 325 million tons of CDD is generated annually, where 25–45% of the waste goes to US landfills, which thus contributes to reduced life and increased environmental impacts across the country. Rodrigues et al. [2] estimated that CDD represents approximately 31% of all waste produced in the European Union. Poon et al. [3] stated that in Hong Kong in 1998, the daily CDD generation CDD was approximately 32,710 tons.

Many researchers have shown that CDD is polluting the environment, not only mechanically but also chemically. Tolaymat et al. [4]

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found that among samples from CDD recycling facilities in Florida, 11 contained elevated leachable heavy metal concentrations in the ground, particularly arsenic and lead. Jang and Townsend [5] also found a process of gypsum dissolution of wallboard and that sulfate leaching from CDD drywall particles CDD in fine soil was impacting the environment. Additionally, using a leaching method, Engelsen [6] identified increased contents of only the major components of CDD – Al, Ca, Fe, Mg, Si and SO_4.

The most common and viable solution for disposing of CDD is to incorporate it into the base and sub-base of road construction [7].

Arulrajah et al. [8] compared the properties of CDD bricks with the properties of crushed brick blends for the Australian pavement sub-base system. Acchar et al. [9] confirmed that approximately 50% of CDD can be incorporated into red ceramics, such as brick and tiles without a decrease in their quality. Bricks with CDD inclusions were also developed by Dondi [10]. In the opinion of Jonh et al. [11] and Mymrin [12], CDD can be used as the primary component (up to 85% by weight) in composites with many other industrial and municipal wastes to produce various construction materials, such as solid bricks and hollow bricks, building blocks, road and airfield bases, etc.

According to [13], to implement these methods on an industrial scale in the USA, the amount of CDD could correspond to more than 30% of the initially applied materials, which would thus avoid the accumulation of these wastes in the environment.

The binder material used in the present research was lime production waste (LPW), which is poorly burnt carbonate for quicklime production that occurs when the sufficient temperature could not be reached during the combustion process; thus, LPW can also be formed as a result of quicklime storage in unsuitable conditions (without sufficient insulation air and humidity).

LPW can also be used for different purposes. Bhatty et al. [14] used LPW as raw material for Portland cement industries; Hansen [15] recycled concrete aggregates in combination with fly ash to produce new concrete. Correa and Mymrin [16] used LPW as a binder for rejected concrete. Mymrin [12] used LPW as a binder for many types of industrial wastes: phosphor-gypsum, pulp from paper production, sludge from wastewater treatment plants, wood and coal ash, iron slag, asbestos tiles, porcelain, waste from natural rocks, etc. Al-Sayed [17] and Do et al. [18] found that using LPW increases the physical and chemical properties of asphalt mixes. Arce et al. [19] used LPW to reduce waste generated during the painting process. Al-Khaja et al. [20] studied the use of LPW in various mineral aggregate mortar mixtures. Bulewicz et al. [21] reached over 70% desulfurization of flue gases from a coal-burning power plant that used LPW in the oven. Kumar [22] and Marinkovic and Kostic-Pulek [23] used LPW as raw material to manufacture bricks.

Even this brief review of the literature shows that the development of methods to dispose of CDD has been conducted many years ago and in many directions. However, despite this, the fact remains that the amount of non-recyclable CDD continues to grow in all countries. Therefore, there remains a need to develop more attractive, more efficient methods and to create compositions that more efficiently use CDD, which could solve the environmental problem of how to recycle CDD.

Therefore the objectives of this research are the following: to develop new construction material from CDD and LPW with predetermined mechanical properties that are better than those established by Brazilian standards. Only two industrial wastes, CDD and LPW are used as raw material in an extremely simple production process, which is economically and technologically attractive. The second objective is to investigate the physicochemical processes of these materials' structure formation to predict the behavior of the material during its service in structures.

2. Materials, methods and test sample preparation

The CDD and LPW samples were obtained from companies in the metropolitan region of Curitiba, Brazil. The CDD was dried at 100 °C for 24 h and was sieved through a 1.18-mm sieve. After homogenization of both wastes with different percentage compositions (Table 1), the wastes were hydrated at a defined percentage of water and set aside for 40 min before being compacted. After compacting with a loading of 10 MPa, the test samples (TSs) were stored in open air.

The raw materials (CDD and LPW) and TSs were characterized by various complementary methods. To determine a chemical composition it was used Spectrometer of X-Rays Fluorescence Philips/Panalytical model PW2400. Samples' preparation for XRF method included the following operations: drying, milling, confection the compressed tablet confection the compressed tablet with organic wax, assay loss on ignition at 1000 °C for semi-quantitative analysis. Results' interpretations were realized by Software Super-Q. These studies of mineralogical compositions of raw and final materials were done by X-Rays Diffractometer Philips, model PW1830, Generator Settings 40 kV, 30 mA with monochromatic wavelength λCu-Kα, at 2θ range of 2–70°, step size (2θ°) 0.02°, scan step time 0.5 s. Results were interpreted with software Super-Q for interpretation X'Pert High Score, database PDF-2. Morphological structures – by scanning electron microscopy (SEM) on FEI Quanta 200 LV; wet samples of raw materials were dried in a vacuum unit. Dried samples of raw materials and TSs were glued by conductive adhesive to the samples' holder, were sputtered by layer of gold and examined in SEM with accelerating voltage 50 kV. Chemical micro analyses were executed by method of energy dispersive spectroscopy (EDS) on Oxford (Penta FET-Precision) X-ACT and by micro-mass analyses through laser micro-mass analyzer LAMMA-1000, model X-ACT; solubility and lixiviation of metals from liquid extracts – by method of atomic absorption spectrometry (AAS) on Perkin Elmer 4100 spectrometer; granulometric composition – by laser diffraction particle size distribution analysis on Granulometer CILAS 1064, Brazil; mechanical resistance – by three-point flexural strength (FS) on EMIC universal testing machine. Water absorption coefficient by immersion was determined on Instrutherm BD 200 according to NBR 13818/1997. Linear shrinkage of TSs was determined with digital caliper of DIGIMESS. Were controlled also the changes of apparent specific gravity after TSs at different ages. Bulk density measurements were performed; the carbonates weight content was determined by a calcimeter via the weight method.

The values of all mechanical properties and standard deviations were obtained as an average of 10 TS measurements.

3. Calculations

The water resistance coefficient (C_{WR}) was determined from the axial resistance strength of the TSs on the 28th and 90th day, which were saturated after a total immersion in water for 24 h (R_{SAT}), and the strength of the dry TSs (R_D) following the standard in [24], was calculated using the following equation:

$$C_{WR} = R_{SAT}/R_D \quad (1)$$

Water absorption coefficient (C_{WA}) tests were also performed on the 28th and 90th day of curing following the standard in [25], which uses the equation:

$$C_{WA} = [(M_{SAT} - M_D)/M_D] \times 100 \quad (2)$$

where M_{SAT} = the mass of the test specimen saturated after total immersion in water for 24 h. M_D = the mass of the test specimen.

Table 1
Substantial compositions of TSs under study.

N°	Compositions, wt.%	
	CDD	LPW
1	90	10
2	85	15
3	80	20
4	75	25
5	70	30