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Banana leaves ashes as pozzolan for concrete and mortar of Portland cement

Rodrigo C. Kanning [a], Kleber F. Portella [b,*], Mariana O.G.P. Bragança [b], Marcelle M. Bonato [a], Jeannette C.M. dos Santos [c]

[a] Programa de Pós Graduação em Engenharia, Universidade Federal do Paraná, P.O. Box 19011, CEP: 81531-990, Curitiba, Paraná, Brazil
[b] Departamento de Engenharia Civil, Instituto de Tecnologia para o Desenvolvimento, P.O. Box 19067, CEP: 81531-980, Curitiba, Paraná, Brazil
[c] Departamento de Novas Ligações, Companhia de Eletricidade da Bahia, Av. Edgard Santos, 300, Narandiba, Salvador, CEP: 41181-900, Brazil

HIGHLIGHTS

- Banana leaf ash was assessed as pozzolanic materials in concrete and mortar products.
- Banana leaf ash demonstrated pozzolanic activity index with a strength of 7.900 MPa.
- Worldwide productions of banana may generate up to 10 million tons of ashes from their leaves.

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ABSTRACT

The worldwide productions of banana were bigger than 95 million tons, which resemble to, approximately, 10.22 million tons of ashes. Additions of these residues or banana leaf ash (BLA) in mortars were investigated by ratios of 0–10% in replacement to weight of the Portland cement as pozzolanic materials. The products were characterized by chemical compositions, SEM, rheology and pozzolanic activity index. Hardened materials were characterized by tearing it in walls. The mechanical and chemical resistance performances of 10% and 20% BLA concrete samples were also evaluated by artificial ageing chambers. The BLA was considered a pozzolan material.

1. Introduction

The application and use of mineral admixtures in mortar and concrete have been widely studied in recent decades to improve the resistance and durability of their composites and reduce the cement consumption, because of the substitution of this material in rates of 8–10% [1–9]. In addition, unusual and wasted materials in concrete may prove to be technically feasible solutions to improve good performance, diminishing costs of production and reducing local environmental impact [3,7,10]. As examples, two cases of important natural materials assessed in Brazil to the civil engineering areas as pozzolan can be cited: the first one is the bagasse ashes, investigated by Cordeiro et al. [11] which identified their high pozzolanic activity, attributed to the presence of amorphous silica in small particle size, with high surface area and low loss on ignition; and, the second, by Pedrozo [12], whose researched the utilization of 15% and 25% ratios of residual rice rush ashes in structural concrete for long life span on chloride environment exposition. Their products performances had decreased the cement consumption, had increased the mechanical and chemical resistances of Portland concrete and had reduced the consequent environmental impact in agriculture and construction areas.

A pozzolan material is defined by ASTM C 125-13 [13] as a product that has chemical structure based on siliceous or siliceous and aluminous material, with little or no portions of cement but that will, in finely divided form and with water, it reacts chemically with calcium hydroxide at ordinary temperatures to form compounds that has cementitious properties. The pozzolanic activity arises from the reaction of amorphous silica with $Ca(OH)_2$ to form calcium silicate hydrate gel as the basic reaction presented in the Eq. (1).

$$x\mathrm{SiO_2} + y\mathrm{CaO} + z\mathrm{H_2O} \leftrightarrows x\mathrm{CaO} \cdot y\mathrm{SiO_2} \cdot z\mathrm{H_2O} \quad (1)$$

* Corresponding author. Tel.: +55 41 3361 6220; fax: +55 41 3361 6141.
E-mail address: kfportella@pq.cnpq.br (K.F. Portella).

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From these, banana leaf ash (BLA) was assessed as pozzolanic materials in concrete and mortar products. Once a time, in 2012, were produced more than 95 million tons of banana and plantain (*Musa* spp.) [14,15]. These worldwide productions resemble to, approximately, 10.22 million tons of ashes and residues from banana plant [10]. Then, the purpose of this research was investigated the influence of the addition of banana leaf ash in cement mortar and concrete, in proportions of 0%, 5%, 7.5% and 10%, in terms of fresh and hardened state.

2. Experimental

2.1. Materials

Filler-modified Portland cement (type CPII F-32) and pozzolan-modified Portland cement CPII Z 32, both of them with a compressive strength of 32 MPa at 28 days, were casted for the production of mortars and concrete samples, respectively. Fine and coarse aggregates of washed natural medium sand and crushed basalt stone with a maximum nominal size of 4.8 and 20 mm, respectively, were used and tested according to the recommendations of ACI Education Bulletin E1-07 [16] and Brazilian standards [17].

Banana leaf ash (BLA) was obtained after burning at 900 °C for 24 h in air, based on the parameters, experiments and data from the literature [8,10,18,19,20]. The temperature and the time in the oven were defined for decreased grayscale or close to white tones of the BLA powders to facilitate the public acceptance and to maintain a higher percentage of amorphous reactive phases [10]. Then, the material was ground in a Marconi ball mill with a capacity of 35 l at 55 rpm for 30 min.

The physicochemical characterization of the cement and the natural and artificial aggregates was performed before their use in the mixtures. The elementary chemical composition and the chemical phases were obtained from energy dispersive spectroscopy (EDS), X-ray fluorescence (XRF) and X-ray diffraction (XRD) methods. PW 2400 Philips fluorescence equipment was used to determine the elemental chemical composition. The XRD of specimens was performed using a Philips (X'Pert MPD) diffractometer with Cu Kα radiation operating at 40 kV and 30 mA, with a 2θ scan between 3° and 70°, an angular step of 0.02°, a step time of 0.5 s, and a divergent slit of 1/2°. The diffraction patterns from ICDD were used to identify the chemical phases of the specimens.

The material was also analyzed by the following procedures: (i) determination of the particle size with a # 325 mesh sieve and determination of the particle size distribution by laser equipment from CILAS, model 1064, according to the dispersion of the material in water without a dispersing agent, (ii) bulk density by the Le Chatelier method, (iii) specific surface by the Blaine method [21], (iv) squeeze flow, (v) water retention index [22], and (vi) pozzolanic activity index – PAI (Eq. (2)) [23,24]. These tests were developed with mortar reference specimens of (50 × 100) mm in the proportions of 104: 936 g (CaO: sand) and a consistency of (225 ± 5) mm, as verified by the flow table test. The BLA was added to the reference mortar and then analyzed.

$$\mathrm{PAI} = 2 \cdot (\delta_{poz} \cdot \delta_{cal}) \cdot 104 \quad (2)$$

where PAI is the pozzolan activity index, δ_{poz} is the pozzolan specific mass (kg m^{-3}), and δ_{cal} is the lime specific mass (kg m^{-3}).

Modified Chapelle's method [23] was done to the determination of calcium hydroxide fixed by BLA materials. For the mechanical strength tests, the materials (BLA, lime, water and sand) were homogenized in a closed vessel during 2 min and prepared as previously recommended in a press Toni Technik/ToniNORM, with a loading speed of 500 N s^{-1} [10,25].

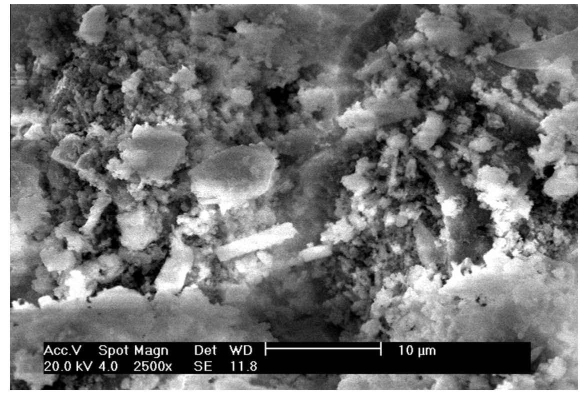

Fig. 2. SEM micrograph of BLA powder at a magnification of 2500×.

2.2. Dosage of mortar and concrete

The mortar reference mix proportions were 1:3 (cement CPII F 32: sand) by mass (w/w).

BLA mortars were casted adding X = 0,5,7.5 and 10% of banana leaf ashes as the %weight/binder, at a reference composition of 1:3:X. To all the samples were added 0.625% (%weight/cement) of polyfunctional additive based on lignosulfonate with specific mass of 1.18 g cm^{-3}. The compositions of BLA and reference samples were based on experimental procedures and literature data [5,10,26–28]. The binder content and the water to binder (W/B) ratio of all types of mortar were 0.59%, 0.58% and 0.57%, respectively.

BLA concrete with X = 0,10 and 20% (%weight/binder weight) cement substitution was casted with a 0.5% (W/B) ratio and a slump results of 300 mm. The basic proportion was 1:1.6:2.56:0.5:X:1.0 (cement:sand:gravel:water:BLA: additive). The CPII-Z 32 cement consumption was 425 kg m^{-3}, because this composition was based on the experimental results and on the trace utilized in poles for power distribution energy networks made by the local manufacturers of concrete and it is in accordance to the literature, which indicates cement consumption between 400 and 500 kg m^{-3} for concrete with silica fume additions [29]. The reference-concrete, 0% BLA, was also produced from each concrete mixture. A super plasticizer based on modified polycarboxylic ether with a specific mass of 1.04–1.08 kg m^{-3} was used.

2.3. Mortar specimens

The compressive and flexural strengths of the mortars were determined at ages of 28,56 and 91 days using six-dimensional specimens of (40 × 40 ×160) mm for each composition, in accordance with NBR 13279 [30]. The tests were performed in a press EMIC universal testing DL30000 with a loading speed of 500 N/s.

The water absorption index by the capillarity method was determined in prismatic molds with dimensions of (160 × 40 × 40) mm at 28 days of age according to NBR 13259 [31].

The compositions based on 0,5,7.5 and 10% of BLA mortar were tested for adhesive strength at ages of 28, 56 and 91 days. For these tests, the materials were cast as masonry on ceramic block walls of (90 × 140 × 190) mm. The masonry surface was coated with roughcast that was initially rolled. After 7 days of curing, the BLA mortar and the reference were applied to the wall with a thickness of 15 mm and finished with a wood trowel.

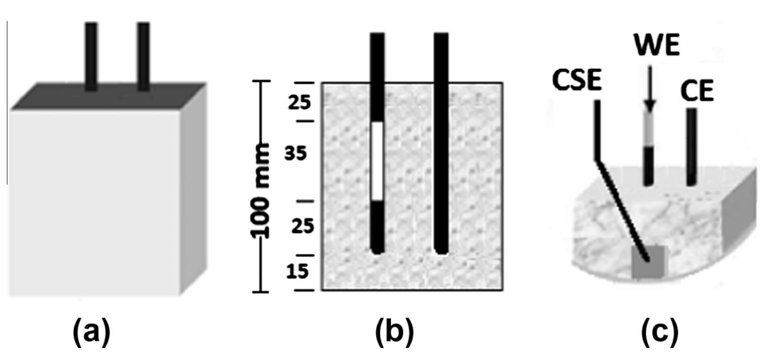

Fig. 1. (a) Schematic drawing of the prismatic reinforcing bar; (b) view of the metal and graphite bars and their dimensions (mm); and (c) electrochemical electrodes (WE – carbon steel CA-50; CE – graphite electrode; and CSE – reference electrode).