Construction and Building Materials 82 (2015) 31–38

Contents lists available at ScienceDirect

Construction and Building Materials

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

Sugarcane bagasse ash sand (SBAS): Brazilian agroindustrial by-product for use in mortar

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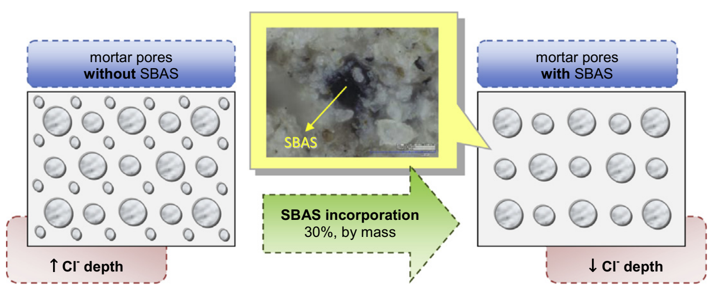
HIGHLIGHTS

- The incorporation of SBAS fills mortar pores with diameters below 150 μm.
- The use of SBAS does not affect the compressive strength of mortars.
- The carbonation depths of mortars containing 0% and 30% SBAS are equivalent.
- The use of SBAS increases the chloride penetration resistance of mortars.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 2 October 2014
Received in revised form 19 January 2015
Accepted 18 February 2015
Available online 5 March 2015

Keywords:
Sugarcane bagasse ash sand
Mortars
Porosity
Accelerated carbonation
Chloride penetration

ABSTRACT

SBAS (sugarcane bagasse ash sand) is the term used for the residue left over from burning sugarcane bagasse. Large amounts of this agro-industrial by-product are generated in Brazilian sugar and ethanol plants, and its disposal is an environmental problem. The application of SBAS as a fine aggregate in mortars can add value to this waste and also reduce the use of natural sand. The growing need to extract natural sand from Brazilian rivers has caused environmental problems. In this article, the effect of SBAS on mortars was investigated, specifically its compressive strength, porosity, carbonation depth and chloride penetration. The present study fills the gap in knowledge on the durability of mortars using different levels of SBAS. The substitution of natural sand by SBAS, especially with content of 30%, can lead to maintenance of mechanical properties, micropore clogging and improvement of the durability of mortars, in comparison with a reference mixture.

1. Introduction

Sugarcane production is a major agricultural activity in Brazil. Sugarcane bagasse ash sand (SBAS) is one of the major by-products from the processing of sugarcane to produce sugar and ethanol. In Brazil, 4 million tonnes of SBAS are generated per year [1,2]. SBAS is usually disposed of in crops, despite lacking adequate nutrients for its use as fertilizer [3].

SBAS has high silica (SiO_2) content (above 60% by mass), with variable and coarse particle size distribution [4]. The large amount of silica present in SBAS is due to the presence of sand from the growing and harvesting processes [3].

SBAS is the crude residue generated after the burning of sugarcane bagasse. This residue is collected from boilers at plants and has low levels of pozzolanic reactivity. SBAS shows a predominantly crystalline quartz structure, which impairs its pozzolanic activity [5]. Pozzolanicity in SBAS can be achieved by controlling the burning of bagasse (via burning temperature and burning/cooling time) and/or SBAS grinding conditions. After these treatments,

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http://dx.doi.org/10.1016/j.conbuildmat.2015.02.039
0950-0618/

the by-product is called sugarcane bagasse ash (SBAS [4,6], SBA [7] or BA [8,9]).

The reactivity of sugarcane bagasse ash is directly dependent on the conditions when burning the bagasse. Maximum reactivity can be achieved by burning bagasse at around 500 °C [6]. Sugarcane bagasse is burned in plants at temperatures between 700 °C and 900 °C, depending on its moisture content [4]. Thus, pozzolanicity in SBAS is not obtained by the uncontrolled burning of bagasse in plants.

In addition, sugarcane bagasse ash can become reactive by ultrafine grinding. Product obtained by grinding to values of D80 (80% passing size) below about 60 μm and Blaine specific surface areas above 300 m^2/kg can be classified as pozzolans [4,9,10]. Pozzolanicity can also be obtained from sugarcane bagasse ash by combining controlled burning with grinding the ash [8,11]. However, grinding and/or controlled burning require energy, and treating large volumes of SBAS using these processes is costly.

The low pozzolanic reactivity of SBAS does not prevent its use in construction materials [5,7,12–15]. An alternative would be to use it as a fine aggregate in mortars. The extraction of natural sand causes environmental impacts, such as the removal of vegetation cover, siltation of rivers and degradation of waterways [16]. The use of SBAS as a fine aggregate can reduce the use of natural sand and decrease the volume of waste disposed of in the environment.

The aim of this paper was to evaluate the use of SBAS (without grinding and without controlled thermal treatment) as an alternative aggregate substitute for natural sand in the production of mortar. To do so, the influence of SBAS on the mortar was investigated through measuring the compressive strength and analysing the porosity, carbonation depth and chloride penetration.

2. Experimental methodology

2.1. Materials

Sugarcane bagasse ash sand (SBAS) was used as a fine aggregate in partial substitution for natural sand (at levels of 30% and 50%, by mass) to produce mortar. SBAS samples were collected from sugar and ethanol plants in the state of São Paulo, Brazil. These SBAS samples were standardised by sieving (mesh of 4.8 mm) and grinding for three minutes at a mechanic mill (mortar/pestle) [14]. The appearance of the SBAS before and after the standardisation process can be seen in Fig. 1.

The characterisation results of the SBAS and natural sand are presented in Table 1. The particle size distribution of the SBAS, natural sand and mixture (SBAS + natural sand) is shown in Fig. 2. The composition of the mixture (SBAS + natural sand) was classified according to the usable area as a fine aggregate, considering levels of 30% and 50% by mass [17].

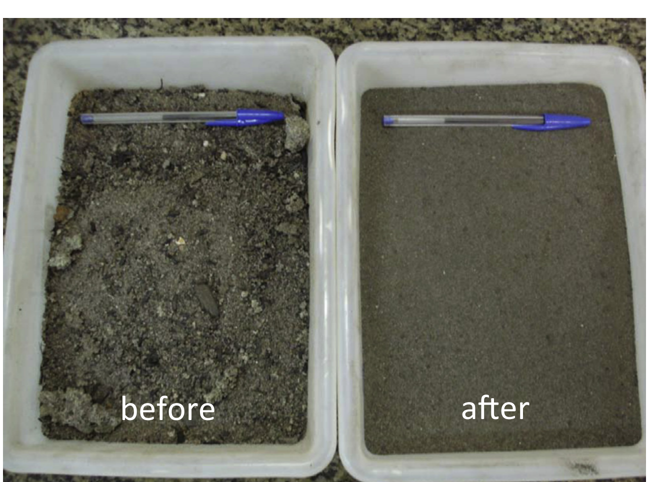

Fig. 1. SBAS appearance: before and after the standardisation process.

The SBAS used in this experimental programme had a predominantly crystalline structure of $SiO_2\alpha$-quartz, as determined by X-ray diffractometry in other studies, which revealed the absence of an amorphous halo in the diffractograms [14]. The values obtained by chemical analysis (before and after standardisation) are presented in Table 2. Also, the chemical composition of the sugarcane bagasse ash (SBAS treated) studied by other authors are shown in Table 2. The SBAS showed low pozzolanic reactivity, according to the results of the modified Chapelle test. In this test, 48 mg of CaO were consumed per gram of SBAS. The minimum consumption of CaO for a mineral addition to be considered pozzolanic is 330 mg of CaO.

The binder used was a Portland-composite cement with blast-furnace slag (CP II E 32). The chemical composition of the cement is shown in Table 3.

2.2. Production of mortars

Three series of mortars with different SBAS contents were produced, with 0% (reference mortar, RM), 30% (M30) and 50% (M50) substitutions of natural sand (by mass). The proportions of materials used in each series of mortar were the same proportions as determined by other studies [14], considering a mortar content of 51.3%. The amount of water in each series was adjusted to maintain the same levels of mortar consistency. The increase in SBAS content led to an increased water/cement ratio (w/c) in the mixture. The proportion of materials used in each series of mortar is shown in Table 4.

The materials used to produce the mortar were mixed in a mechanical mixer to obtain a homogeneous mass. Each mortar was moulded in cylindrical dimensions of 50 × 100 mm (diameter × height). The samples were kept in a humid chamber for 28 days (relative humidity of 95% ± 5%) [18].

2.3. Physical and mechanical characteristics of the mortars

The compressive strengths of the mortars were tested by applying a load at an average speed of 0.25 MPa/s, in accordance with ABNT NBR 7215:1996 [18].

The physical properties of the mortars were verified by testing their water absorption, void ratio and dry bulk density [19]. The mortar specimens were also characterised via optical microscopy (OM) in order to analyse the mean pore diameter. OM was carried out in a HIROX Digital Microscope KH-7700 equipped with a digital image acquisition system and dark and bright field illumination techniques. The OM technique was adequate for observing the effect of varying the porosity of the mortars, as a function of average pore size and pore distribution.

The results of these tests were submitted to analysis of variance (ANOVA) and Student's *t*-test at a significance level of 5%.

Table 1
Characterisation results of the SBAS and natural sand.

Properties	Unit	SBAS	Natural sand
Specific gravity	g/cm^3	2.57	2.45
Unit weight	kg/m^3	1,424.94	1,531.32
Water absorption	%	0.9	0.5
Maximum dimension	mm	1.18	6.3
Fineness modulus	–	1.15	2.32
Amount of powdery material finer than 75 μm (n° 200) sieve by washing	%	16.2	–