ARCHIVES OF CIVIL AND MECHANICAL ENGINEERING 18 (2018) 1092–1102

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: http://www.elsevier.com/locate/acme

Original Research Article

Evaluation of pre-treatment efficiency on sugarcane bagasse fibers for the production of cement composites

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ARTICLE INFO

Article history:
Received 22 November 2017
Accepted 23 February 2018
Available online

Keywords:
Fibers
Sugarcane bagasse
By-products
Cement
Composites

ABSTRACT

In the present study, physical, chemical, morphological, crystallographic analysis of the non-treated and treated (100 °C during 30 min) sugarcane bagasse fibers were examined. Sugarcane bagasse fibers pre-treatment effect on the Portland cement hydration was monitored by inhibition tests and differential scanning calorimetry in the first 24 h. Furthermore, 28 days age physical-mechanical properties of cement composite materials with sugarcane bagasse fibers were also evaluated. Inhibition index of treated sugarcane bagasse fibers was 5.9%, while for the non-treated sugarcane bagasse fibers it was 67.3%. Cement composites containing treated sugarcane bagasse fibers showed lower physical properties (water absorption and thickness swelling) than the cement composites reinforced with non-treated sugarcane bagasse fibers ($p < 0.05$). Likewise, mechanical properties under flexure (modulus of rupture, MOR, and modulus of elasticity, MOE) of cement composites with treated sugarcane bagasse fibers showed higher values than the cement composites with non-treated sugarcane bagasse fibers ($p < 0.05$), thus proving the pre-treatment efficiency on sugarcane bagasse fibers for cement composites.

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https://doi.org/10.1016/j.acme.2018.02.012

1. Introduction

Brazil is the world's largest producer of sugarcane, with an annual crop around 658.7 million tons [1]. Thus, a large amount of residual sugarcane bagasse by-products remains after crushing. The main compounds of sugarcane bagasse are cellulose, hemicellulose and lignin, which can be applied as a reinforcement in cement composites [2].

The major target of using vegetable fibers reinforcement in cement composites is to impart additional energy absorbing capability, by turning a brittle material into a pseudo ductile one. Vegetable fibers in cement composites can also contribute to reduce crack propagation [3]. Moreover, according to Mármol et al. [4], the use of the vegetable waste to produce cement composites is an interesting strategy to handle the environmental and social-economic issues generated by these by-products.

However, the use of sugarcane bagasse fibers as reinforcement for cement composites introduces challenges for manufacturing. The Portland cement (PC) hydration processes is more complex when the vegetable fibers are used as reinforcement of the composites.

PC is basically composed of tricalcium silicate (C_3S, alite), dicalcium silicate (C_2S, belite), tricalcium aluminate (C_3A) and tetracalcium aluminoferrite (C_4AF ferrite). After the water addition, C_3A reacts with water forming an aluminate rich gel. Thereafter, the gel reacts with the sulfate rich solution forming the ettringite (AFt), with a small rod-like structure [5]. Subsequently, C_3S and C_2S take part in a hydration reaction to form calcium silicate hydrate (C–S–H) gel and calcium hydroxide [$Ca(OH)_2$]. These phases are considered as the principal contributors to the mechanical properties of PC composites [5].

Nevertheless, all of these hydration reactions of the PC can be disturbed by the addition of sugarcane bagasse fibers, causing a deceleration of the setting time. Particularly, extractives and impurities may affect the PC hydration reaction equilibrium, resulting in low quality PC composites [6].

Previous studies [6,7] suggest significant decrease on the PC hydration due to the hydrophilic characteristics of the vegetable fibers due to the water uptake by the capillary porous, and subsequent water release during the curing period. Additionally, the released water can contain extractives leading to a protective layer on the cement grains blocking further hydration [8].

The most recent studies have shown that extractives effect in the PC hydration decrease is due to their absorption on the surface of the hydrating cement grains, or on the hydrated products. Chakraborty et al. [9] states that dissolved extractive may form a protective layer on the partially hydrated cement grains. This layer forms a temporary barrier on the cement grains for further hydration. In addition, extractives reduce the PC hydration temperature, acting as an inhibitor of the formation of hydrated products of PC [7]. As a measure to avoid this negative effect, Ferraz et al. [10] suggest to remove extractives and impurities from vegetable fibers by a hot water (100 °C) pre-treatment.

The aim of the present study is to evaluate the effect of hot water (100 °C during 30 min) pre-treatment efficiency on sugarcane bagasse fibers to produce PC composites. Pre-treatment effects will be investigated, either on the sugarcane bagasse fibers, as well as on the physical-mechanical properties of PC composites.

2. Material and methods

2.1. Materials

The Portland cement (PC) used for this research was a Type CP V-ARI PC (High Early Strength), according to the Brazilian Standards NBR 5733 ([11], ABNT, 1991) and equivalent to the PC Type III ASTM C150. High early strength PC contains 0–5% from mineral additions (blast furnace slag or pozzolans). It was selected because it minimizes the influence of those additions on the hydration reactions in conjunction with the sugarcane bagasse fibers. Chemical compositions (% by mass of oxides) of the PC were determined using X-ray fluorescence spectrometry and are presented in Table 1. The sugarcane bagasse used was collected from an industrial sugarcane mill plant located in the state of São Paulo, Brazil.

2.2. Sugarcane bagasse fibers processing and pre-treatment

Sugarcane bagasse was crushed using a mill (Model DPC-1, Cremasco) and then sieved with the aid of an automatic shaker (Model G, Produtest) to obtain approximately 8 mm of length fibers, (Fig. 1).

Pre-treatment of the processed sugarcane bagasse fibers were carried out according to the methodology described by Cabral et al. [2] as shown in Fig. 2. The water was heated up to 100 °C in a 30 L container capacity (Fig. 2a) and then, the sugarcane bagasse fibers were introduced in a ratio of 31.25 g per L of water (Fig. 2b). The immersed fibers were kept into the 100 °C water during 30 min (Fig. 2b). The recovered fibers were washed with tap water (at ~20 °C) (Fig. 2c). Finally, the fibers were placed in a 60 °C oven with forced ventilation for 72 h (Fig. 2d), until the moisture content reached ~8% by mass.

2.3. Chemical characterization

The methodology proposed by the French Standards NF V03-040 ([12], AFNOR, 1993) was followed in order to determine the cellulose, hemicellulose, lignin and extractives content from non-treated and treated sugarcane bagasse fibers. The determination of ash and humidity contents followed the procedures described by Morais et al. [13].

Table 1 – Chemical composition of PC (% by mass of oxides).

	Ca	Si	S	Fe	Al	K	Mg	Sr	Ti	Mn	Zn	Zr
PC[a]	78.73	6.72	4.75	3.9	2.3	1.8	0.9	0.26	0.25	0.10	0.07	0.01

[a] NBR 5733 (clinker + gypsum = 100–95% by mass; carbonate material = 0–5%).