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Improved interfacial transition zone between aggregate-cementitious matrix by addition sugarcane industrial ash

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ABSTRACT

The aim of this study was to evaluate the influence of sugarcane industrial ash (SCIA) on mechanical properties of interfacial transition zone (ITZ) between aggregates and cementitious matrix by nanoindentation technical analysis. The sugarcane biomass (agroindustrial by-product) was used for generation of electricity by burning in a cogeneration power system. The results of nanoindentation analyses showed that the ITZ thickness varied significantly with the water/binder ratio. Each formulation used different water and binder ratio, with the inclusion of 20% silica fume (SF) or SCIA. In fact, the mineral additions caused a reduction of the thickness of the matrix-aggregate ITZ, and consequently increased the values of the indentation modulus and hardness in relation to aggregate-matrix interface of the reference concrete.

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1. Introduction

Brazil is the largest producer of sugarcane in the world, with a total of 632 mil tons/year (2015/2016). It is known that approximately 28% of the sugarcane production is bagasse i. e. for each tonne of processed sugarcane; there are about 270 kg of bagasse and straw, resulting in a significant amount of bagasse available for energy use in the coming years. This bagasse is composed of: cellulose (43 wt%), hemicellulose (26 wt%), lignin (24 wt%) and ashes (7 wt%) [1].

Currently, sugarcane bagasse has been considered mainly agroindustrial by-products, because this biomass is burned to produce electricity in a cogeneration power system at the sugar and ethanol industry [2,3]. The straw became another solid by-product with sugarcane mechanized harvesting. About 14%–18% of straw by tons of sugarcane produced [4]. The straw is composed of: water (15 wt%), ash (2 wt%), and biomass fibers (83 wt%) [5]. Several applications for this waste have been studied, such as the generation of cellulosic ethanol second-generation [6–8]. Furthermore, the straw also has been used as biomass to burn in a cogeneration power system. Therefore, the Brazilian sugarcane agroindustry generates a lot of solid by-products.

In addition, researchers have conducted studies using the sugarcane straw ash (SCSA) and sugarcane bagasse ash (SCBA) as mineral addition in cement matrix [9–12].

The use of these ashes can modify the particle size distribution of the mix designs, concrete rheology, increase pozzolanic activity and mechanical, chemical and physical properties of the cementitious matrix.

Cordeiro et al. (2009) [13] observed that blended cement with SCBA and rice husk ash (RHA) can interfere in the concrete rheological behavior and increase the resistance to penetration of chloride ions. This change was consequence of the pozzolanic activity of both ashes and the refinement in the pore size distribution in relation to the reference concretes [13]. Furthermore, SCSA for its greater reactivity with Portland cement can increase the mechanical strength of mortars [9], and can also increase the modulus of rupture and tenacity of fiber cement composite because the SCSA collaborated to protect the lignocellulosic fibers reducing alkalinity and improvement the interface with cementitious matrix. In this way, the pullout and bridging mechanisms are more efficient in the fracture process [14].

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In a previous work, researchers conducted the blended cement mixtures elaborated with SCBA and fly ash (FA), and they concluded that the shape and size distribution of the particles of the SCBA produced a pseudoplastic behavior (non-Newtonian behavior when the viscosity changes when the shear rate changes i.e. Higher shear rates = lower viscosity) and workable pastes and mortars i. e. a better rheological behavior than mixes without SCBA. The use of 20% of FA combined with 10% or 20% of SCBA was beneficial to produce lower yield stresses related to rheological behavior than those presented in a binary system – Portland cement with SF or Portland cement with SCBA [14].

Thus, the cement matrices can incorporate one or various mineral addition in order to manufacture binary, ternary or quaternary blended cements [15–17]. However, there are some challenges regarding the use of mineral addition in blended systems, as examples: most amount of water required, because the water normalizes the rheological behavior of a fresh cement paste that depends on particle size distribution, morphology of the particles, specific surface area, zeta potential among other characteristics of a mineral addition, and also, in some cases, such as pulverized fuel ash and metakaolin, the generation of larger amount of heat during hydration, which causes the undesirable increase of the temperature of the concrete [18,19]. Even that, with the presented problems, technical benefits with these systems in the cement matrix favor its use [13,15,20,21,22].

The agroindustrial ash affects the interfacial transition zone (ITZ) between aggregate and cement matrix by means of particle size distribution (decrease wall effect) and pozzolanic reactivity (increase quantity of calcium silicate hydrated). The ITZ is a usually region with a higher W/B ratio, and thus a higher porosity, than the bulk paste. The cement and mineral addition particles in paste, which are suspended in the mix water, cannot pack together as efficiently when they are in the close vicinity of an aggregate particle. It is known to be the weakest region with deficit of cement particles in concrete [23]. For concrete to possess good mechanical performance, it is essential that the ITZ is designed to be as dense as possible, resulting in a good bond between the aggregate and the matrix [24]. Several researches present results demonstrating that the mineral additions can produce a significant reduction in the thickness of the matrix-aggregate interfacial transition zone (ITZ), i.e. higher densification of such region, contributing to an improvement of the properties related to mechanical strength and concrete durability [25–27]. However, the influence of sugarcane (bagasse and straw) industrial ashes (SCIA) on the ITZ of concrete has been rarely reported, which constitutes an important line of research for the scientific community. The SCIA can decrease porosity in the ITZ because it has particles size distribution from nanometers to millimeters that filling voids among coarse particles mainly in the aggregate and matrix interface. Moreover, during hydration process the SCIA can mitigate voids by means of pozzolanic reaction that consequently can fill the voids with calcium silicate hydrated (C-S-H) phase. Therefore, the aim of this study was to evaluate the influence of the mix of cogeneration ashes from bagasse and straw sugarcane on mechanical properties of ITZ in concretes by nanoindentation technical analysis. Nanoindentation measures are being used as a good tool to evaluate properties micro and nanometer scale, such as hardness and indentation modulus in cement based materials [28–33].

Table 1
Mix design of the cementitious matrix of the concretes.

Series	W/B	SF/C (%) *(by mass)*	SCIA/C (%) *(by mass)*	SPA/B (%) *(by mass)*
1	0.35	–	–	0.1
2		20	–	0.2
3		–	20	0.2
4	0.55	–	–	–
5		20	–	0.1
6		–	20	0.1

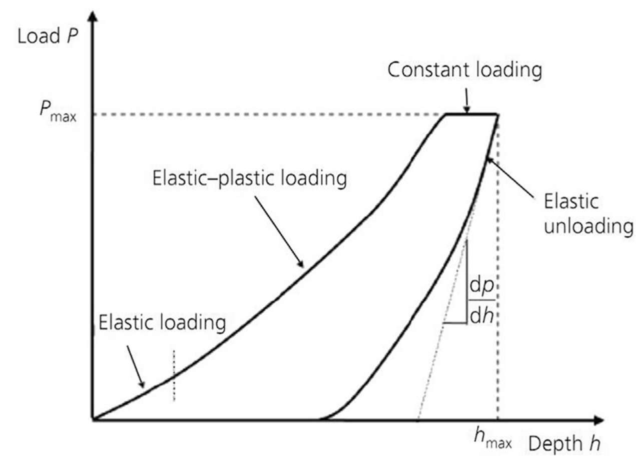

Fig. 1. A typical load-depth curve of the nanoindentation tests [42].

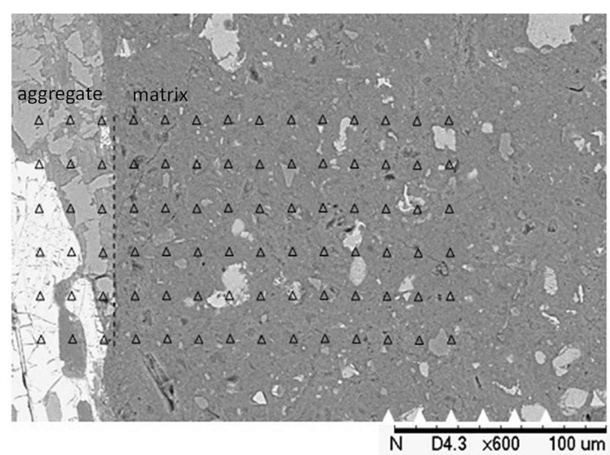

Fig. 2. Schematic diagram of indentation area of aggregate-matrix interfacial transition zone.

Table 2
Chemical composition by XRF of cement, SCIA and SF.

Element	Cement	SCIA	SF
SiO_2	19.1	60.14	84.50
Al_2O_3	4.44	12.53	0.97
Fe_2O_3	2.68	10.35	2.62
MnO	<0.10	0.20	0.27
MgO	2.32	2.10	0.60
CaO	63.5	3.11	2.93
Na_2O	0.36	0.16	0.15
SO_3	2.63	0.11	–
K_2O	1.10	6.06	1.04
TiO_2	0.24	2.73	0.10
P_2O_5	0.21	1.47	0.14
SrO	0.14	–	–
LOI	3.52	1.03	7.53

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