Characterization of sugarcane bagasse ash under different beneficiation processes for application as solar selective surfaces

Ithyara Dheylle Machado de Medeiros[1], Raissa Venâncio[2], Gabriela Oliveira Galvão[3], José Félix da Silva Neto[4], Kelly Cristiane Gomes[5]

[1]ithyaramachado@gmail.com. Universidade Federal da Paraíba/Departamento de Engenharia Mecânica. [2]raissa.venancio@cear.ufpb.br. Universidade Federal da Paraíba/Departamento de Engenharia Mecânica. [3]gabrielagalvao1@gmail.com. Universidade Federal da Paraíba/Departamento de Engenharia Mecânica. [4]josefelix@cear.ufpb.br. Universidade Federal da Paraíba/Departamento de Engenharia de Energias Renováveis. [5]gomes@cear.ufpb.br. Universidade Federal da Paraíba/Departamento de Engenharia de Energias Renováveis.

ABSTRACT

The present study evaluated the influence of two sugarcane bagasse ash (SCBA) beneficiation processes (sieving and high-energy milling) as an alternative to evaluate its absorption potential for application as a raw material for the production of solar absorber films. It was noticed that the absorption levels of all the samples were higher than 90% and that the SBCA has predominance of SiO2 corroborated by the mineralogical analysis. The thermal behavior of all the samples was similar among each other, presenting a total mass loss corresponding to 8.5%. As the ash is able to maintain a thermal stability in the temperature range of 100°C to 1000°C, and the chemical and mineralogical composition favors the absorption of solar energy, SCBA has proven to be favorable for application as raw material of selective solar surfaces.

Keywords: Energy; Sugarcane bagasse ash; Solar absorber films.

RESUMO

O presente estudo avaliou a influência de dois processos de beneficiamento de cinzas de bagaço de cana (SCBA) (peneiração e moagem de alta energia) como uma alternativa para avaliar seu potencial de absorção para aplicação como matéria-prima na produção de filmes absorvedores solares. Observou-se que os níveis de absorção de todas as amostras foram superiores a 90% e que o SBCA tem predominância de SiO2, o que foi corroborado pela análise mineralógica. O comportamento térmico de todas as amostras foi semelhante entre si, apresentando uma perda de massa total correspondente a 8,5%. Como a cinza é capaz de manter uma estabilidade térmica na faixa de temperatura de 100 ° C a 1000 ° C, e porque a composição química e mineralógica favorece a absorção de energia solar, o SCBA se mostrou favorável para a aplicação como matéria-prima de energia solar seletiva. superfícies.

Palavras-chave: *Energia, Cinzas do bagaço de cana-de-açúcar; Filmes absorvedores solar.*

SUBMETIDO 21/10/2019 > APROVADO 14/09/2020

1 Introduction

The necessity of finding an applicability for industrial waste has been a current challenge. Although several types of waste have been the subject of studies, sugarcane bagasse ash (SCBA) has been neglected, probably due to its provenience from developing countries (TEIXEIRA; SOUZA; SANTOS, 2008).

SCBA is a by-product of the sugar industry and its production begins with the crushing of sugarcane, processed for juice extraction, where the rejected fibrous material of this process is designated bagasse, which is used as fuel in the cogeneration boiler. After burning, a residue is collected through a filter, the SCBA (BAHURUDEEN; SANTHANAM, 2015).

Brazil is the world's largest producer of alcohol and sugarcane (TEIXEIRA; SOUZA; SANTOS, 2008) the amount of sugarcane generated in 2018 was somewhat around 636.6 Mt, representing 158.9 Mt of sugarcane bagasse and 3.8 Mt of SCBA (COMPANHIA NACIONAL DE ABASTECIMENTO, ANALISES DO MERCADO AGROPECUÁRIO E EXTRATIVISTA, 2017).

Traditionally, SCBA has been discarded mainly as soil fertilizer. Due to its environmental impact, this form of elimination is far from being the most adequate (FARIA; GURGEL; HOLANDA, 2012; LIMA *et al*, 2012). As a result, studies (BAHURUDEEN; SANTHANAM, 2015; FARIA; GURGEL; HOLANDA, 2012; TEIXEIRA; SOUZA; SANTOS, 2008) have been carried with the objective of applying SCBA as a pozzolanic material. Pozzolan is an inorganic, natural or artificial, siliceous or aluminum-siliceous material, which may present binder properties when finely milled and in the presence of water and calcium hydroxide (CORDEIRO; TOLEDO FILHO; FAIRBAIRN, 2009). Studies on the influence of granulometric distribution and fineness on the pozzolanic reactivity of residual ash have been performed (CORDEIRO *et al*, 2011; KIATTIKOMOL, 2001).

Hobold *et al*. (2020) developed a study on the reuse of ash from SCBA, because studies show it is possible to apply ash in some specific areas, such as replacement of Portland cement, replacement of clay, as an adsorbent, in the treatment and stabilization of soils, in the pavement of road asphalt, among others. Santos *et al*. (2019) studied the addition of SCBA partially replacing the small aggregate (natural sand) in seft-compacting concrete. The experimental analyses showed a slight increase in tensile and compressive strength.

Despite the fact that most SCBA research has focused on its use as supplementary material in concrete (AKRAM; MEMON; OBAID, 2009; SRINIVASAN; SATHIYA, 2010), there is great potential for its use in other applications (MEDEIROS; GOMES; SILVA NETO, 2017; ALAVEZ-RAMIREZ *et al*, 2012). One of them is as precursor material for the production of selective solar surfaces (SSS) (MEDEIROS; GOMES; SILVA NETO, 2017). These surfaces are used to increase the efficiency of photo thermal conversion (NURU *et al*, 2014) so that, for a material to be used in its manufacture, it must demonstrate an absorption (**α**) greater than 85% in the solar spectral range (0.2 – 2.5 µm) and a low thermal emission (**ε** < 15%) in the medium and far infrared region of the electromagnetic spectrum (2.5 – 30 µm) (NUNES, 2018).

In view of what has been exposed above, the present study has the objective of evaluating the influence of two beneficiation processes of SCBA as an alternative to evaluate its absorption potential for application as raw material for the production of solar absorber films.

2 Experimental

2.1 Methodology

The SCBA used was provenient from the furnace filter of a production industry in the State of Paraíba (Brazil), and was thus considered fly ash. This material was dried in an oven at 100°C/1h and then subjected to two processes: sieving and milling.

The choice of the granulometry adopted in the sieving process occurred in function of the diversity of particle size of the SCBA in natura, due to its influence on its properties (BAHURUDEEN; SANTHANAM, 2015; MEDEIROS; GOMES; SILVA NETO, 2017), thus based on the work of Medeiros *et al* (2017), the 200 mesh sieve was chosen to standardize the granulometry of the raw material.

The sifted product was placed in a Frittsch Pulverisette 5 high-energy planetary mill with steel balls and jars. The milling parameters adopted were: ball:mass load of 5:1 and 10:1 and milling time of 20 and 30 min, at 250 rpm. To perform the milling, oleic acid and distilled water were added in order to avoid the agglomeration of the particles. Thus, 6 different milling conditions were obtained, denominated as samples S2 to S7, according to Table 1, and the sample S1 was the one which only passed through the sieving process.

Table 1 – Milling Parameters and Chemical Composition

Sample	Milling Parameters		Chemical Composition						
	Load ball:mass	Time (min)	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	K_2O (%)	CaO (%)	MgO (%)	Others (%)
S1	----	----	74.84	2.28	3.27	6.30	3.83	2.67	6.81
S2	5:1	20	67.51	2.85	3.65	9.66	4.82	3.51	8.00
S3	5:1	30	67.94	2.95	3.74	9.30	4.84	3.35	7.88
S4	10:1	20	70.00	3.03	3.81	8.34	4.55	3.23	7.04
S5	10:1	30	70.20	2.96	3.77	8.40	4.41	3.17	7.09
S6	15:1	20	67.87	3.08	3.83	9.20	4.85	3.39	7.78
S7	15:1	30	70.47	2.80	3.87	8.27	4.29	3.07	7.23

Source: Elaborated by the authors.

2.2 Characterization

The sifted and milled SCBA were characterized by X-Ray Diffractometer (D2Phaser, Bruker) using copper K**α** radiation, 30 kV voltage and 10 mA current, with a 2**θ** scan between 15° and 60°, with a pitch of 0.02°/s and a 1 mm slit. The absorption spectrum in the UV-Vis region was obtained by UV-Vis Spectrophotometer (UV-2600, Shimadzu) with the integrating sphere accessory. The morphology was observed through a Scanning Electron Microscope (Quanta 450, FEI). The quantification of the present oxides was determined by Sequential X-Ray Fluorescence Spectrometer (XRF-1800, Shimadzu). The thermal behavior was determined by the non-isothermal method of analysis (TGA/DTA 60H, Shimadzu) at heating rates of 5°C/min until 100°C and 10°C/min between 100°C and 1000°C, using an inert nitrogen atmosphere at a flow rate of 50 ml/min and a temperature range of 25°C to 1000°C.

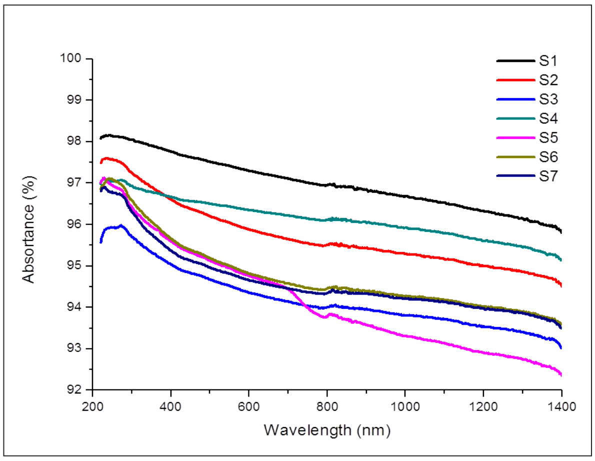
3 Results and discussion

Figure 1 shows the absorptance spectrum of sifted (S1) and milled (S2 - S7) ashes in the wavelength range between 220 – 1400 nm. The value of the absorptance was obtained through the equation:

$$\alpha = 1 - \rho \quad (1)$$

Where **α** and **ρ** correspond, respectively, to the values of absorptance and reflectance of the samples. The transmittance value was not considered because the ash is an opaque material at the wavelength range under analysis (CHEN *et al*, 2014; MEDEIROS; GOMES; SILVA NETO, 2017; NUNES *et al*, 2018).

Figure 1 – The absorptance spectrum of the samples.



Source: Elaborated by the authors.

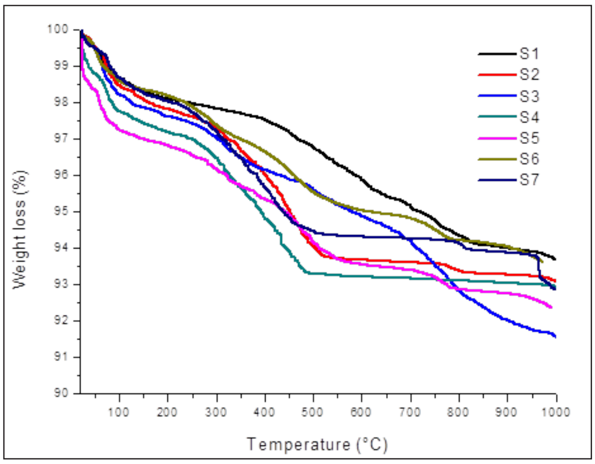
It can be seen from the analysis of Figure 1 that the absorption levels of all the samples were adequate for their use as raw material for SSS production, since they were higher than 90% (NUNES *et al*, 2018).

Figure 2 illustrates thermal analysis graphs through thermogravimetric curves (TGA). Three events were identified through the technique. The first is associated with weight loss of the SCBA relative to the reduction of adsorbed water in the residual powder up to the temperature of 200°C (MOISÉS *et al*, 2013; TEIXEIRA *et al*, 2014). At around 500°C there was another weight loss related to the combustion of volatile substances and of remaining organic material (FARIA; GURGEL; HOLANDA, 2012; TEIXEIRA *et al*, 2014). The last event corresponds to the reduction of weight after 600°C caused by the release of CO_2 from carbonates, the decomposition of organic matter and the prolongation of the volatilization process (FARIA; GURGEL; HOLANDA, 2012; TEIXEIRA *et al*, 2014). Similar events were identified by Moises *et al* (2013) and Teixeira *et al* (2014) in their studies on thermal degradation of SCBA.

The thermal behavior of all samples were similar to each other. The ash is capable of maintaining a thermal stability in the temperature range of 100°C to 1000°C, favoring its application as SSS (CHEN *et al*, 2014).

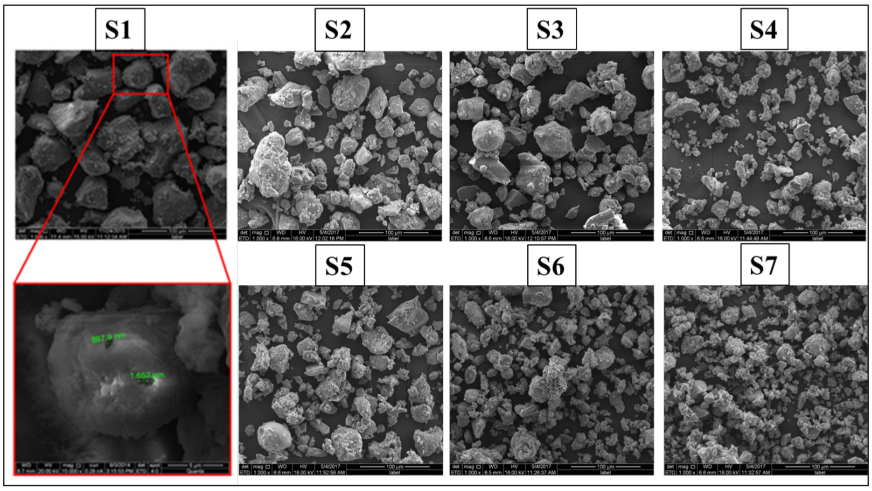
The morphological aspects of SCBA particles can be observed in Figure 3. Note that the samples are rich in angular shaped particles, which are probably composed of silica, besides containing cylindrical porous plates due to the incomplete burning of the bagasse (FARIA; GURGEL; HOLANDA, 2012).

Figure 2 – TG curves for the samples.



Source: Elaborated by the authors.

Figure 3 – Micrographs of the samples.



Source: Elaborated by the authors.

Bahurudeen and Santhanam (2015) analyzed the influence of different processing methods on the pozzolanic performance of sugarcane bagasse ash and observed that the ashes consist of fine burnt particles and fibrous unburnt particles, with irregularly shaped grains rich in silica.

In the present work, t is observed that the increase of the ball:mass load decreased the grain size and provided its agglomeration, due to the temperature of the milling process and the impact with the balls (BAHURUDEEN; SANTHANAM, 2015).

Figure 4 shows that SCBA has a predominance of quartz (standard pattern numb er 03-1228: ICSD database) as crystalline material (ALAVEZ-RAMIREZ *et al*, 2012; SOUZA *et al*, 2011), which can be confirmed by the chemical analysis in Table 1. The work of Moisés *et al* (2013) that aimed to synthesize zeolite NaA from sugarcane bagasse ash proved the majority presence of quartz, this fact was also evidenced by the research by Souza *et al.* (2011) who reused SCBA for the production of ceramic materials. In addition, the following crystalline structures were found: microcline (standard pattern number 10-0495: ICSD database) and cristobalite (standard pattern number 75-300: ICSD database). Cristobalite was also identified by Alavez-Ramirez *et al* (2012) when studying the application of SCBA to improve the durability and mechanical properties of compacted soil blocks.

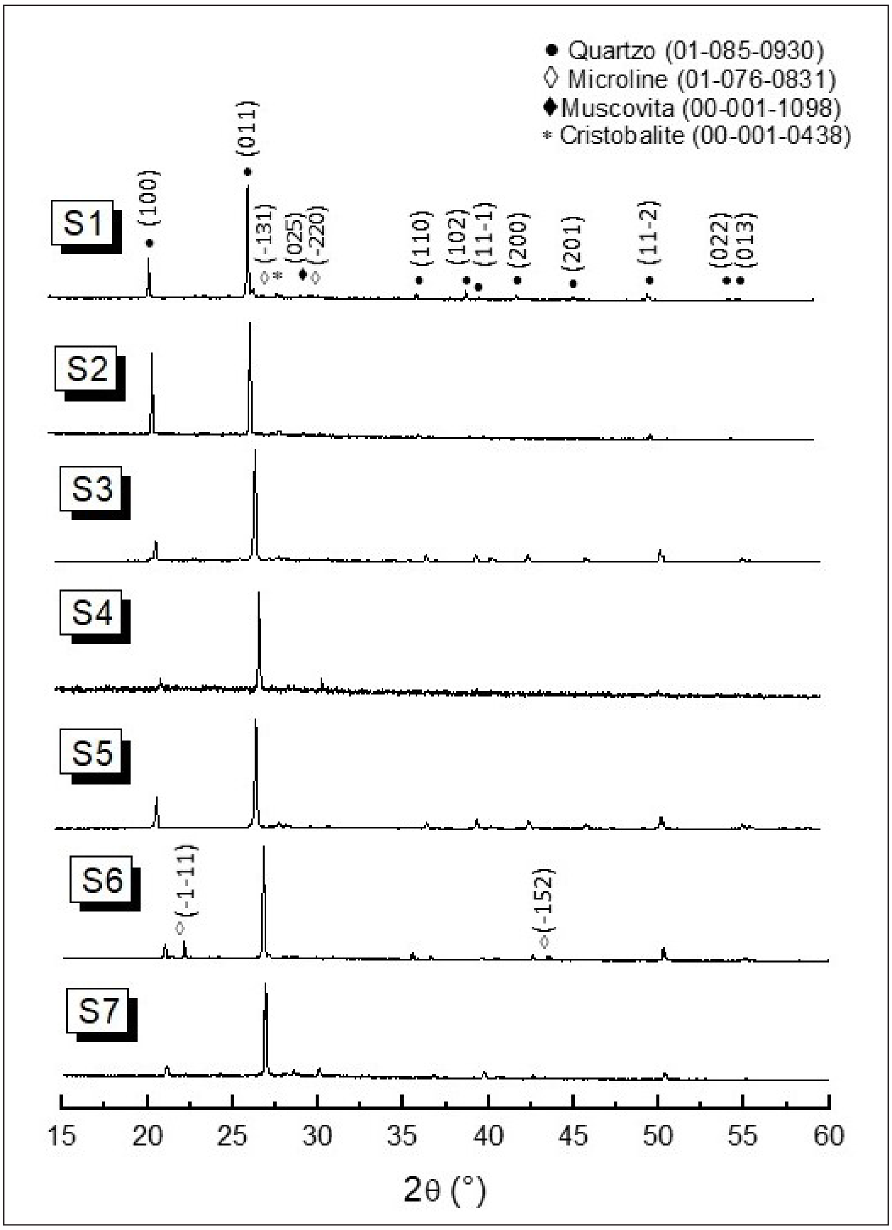
The silica found comes from the uptake of the soil by the roots of sugarcane, and also from the field sand, which is not completely removed when the cane is washed before processing, remaining in the ash after the bagasse combustion (SALES; LIMA, 2010).

Silva *et al*. (2019) evaluated the influence of grinding process in the pozzolanic activity of SCBA by XDR analysis and observed that the samples presented the same crystalline phases, with quartz the most intense.

Table 1 shows that ash samples presented the SiO2 as the major oxide (BAHURUDEEN; SANTHANAM, 2015; ALAVEZ-RAMIREZ *et al*, 2012; SALES; LIMA, 2010; TEIXEIRA; SOUZA; SANTOS, 2008), which is pertinent to its application as an absorber film due to its optical properties (excellent absorption of the radiation in the range of interest) and stability between 300°C and 500°C (SONG *et al*, 2017).

This result was confirmed the research of Faria *et al* (2012) that investigated the recycling of SCBA as a method to provide raw material for clay brick bodies, and observed that the ash is mainly composed of silicon, aluminum iron and potassium oxides, which was also corroborated by X-ray diffraction analysis.

Figure 4 – XRD patterns of the samples.



Source: Elaborated by the authors.

4 Conclusion

The SCBA that presented the best absorption result was the ash that only went through the sieving process (S1). This was a favorable result, since that sample required a lower preparation cost, in order to financially benefit the productive process of SSS. In addition to this, the semi-hollow shape enables the entrapment of the radiation contributing to a better absorptivity of the final product. However, S1 presents a larger grain size for the application in thin films, which may influence the final thickness of the layer. In this sense, it is necessary to search for a grinding process that will optimize the particle size, without, however, modifying its current morphology, for this reason the grinding process is the most suitable for the optimization of ash morphology and its properties. So, the study showed that the SCBA presented promising performance for application in solar absorber films. The results in chemical, thermal and optical terms present considerable performance, thus attributing an application to SCBA.

Based on the present study, the perspective for future work is to use SCBA as a raw material for the production of SSS through the alkaline activation of this material. Studies, such as the one developed by Falk *et al*. (2019) show that nanoparticles of SiO2 were synthesized via sol-gel route using SCBA as a silica source, what makes possible a work based on the use of SCBA as an anti-reflective layer in solar absorber films of different compositions.

ACKNOWLEDGEMENTS

The authors thank LABFILM, TECNOM and LSR Laboratories for technical support and Brazilian institutions CNPq (Universal no.472793/2013-6) and CAPES for financial support.

REFERENCES

ALAVEZ-RAMIREZ, Rafael *et al*. The use of sugarcane bagasse ash and lime to improve the durability and mechanical properties of compacted soil blocks. **Construction and building materials**, v. 34, p. 296-305, 2012.

AKRAM, Tayyeb; MEMON, Shazim Ali; OBAID, Humayun. Production of low cost self compacting concrete using bagasse ash. **Construction and Building Materials**, v. 23, n. 2, p. 703-712, 2009.

BAHURUDEEN, A.; SANTHANAM, Manu. Influence of different processing methods on the pozzolanic performance of sugarcane bagasse ash. **Cement and Concrete Composites**, v. 56, p. 32-45, 2015.

CHEN, Jianlin *et al*. Microstructure, optical and electrical properties of CrAlN film as a novel material for high temperature solar selective absorber applications. **Materials Letters**, v. 133, p. 71-74, 2014.

Companhia Nacional de abastecimento, Analises do mercado agropecuário e extrativista. **CONAB**. 2017. Disponível em: https://www.conab.gov.br/info-agro. Acesso em: 13 jun. 2019.

CORDEIRO, Guilherme Chagas; TOLEDO FILHO, Romildo Dias; FAIRBAIRN, Eduardo de Moraes Rego. Caracterização de cinza do bagaço de cana-de-açúcar para emprego como pozolana em materiais cimentícios. **Química Nova**, v. 32, n. 1, p. 82-86, 2009.

CORDEIRO, Guilherme Chagas *et al*. Influence of particle size and specific surface area on the pozzolanic activity of residual rice husk ash. **Cement and Concrete Composites**, v. 33, n. 5, p. 529-534, 2011.

FALK, G. *et al*. Synthesis of silica nanoparticles from sugarcane bagasse ash and nano-silicon via magnesiothermic reactions. **Ceramics International**, v. 45, n. 17, p. 21618-21624, 2019.

FARIA, K. C. P.; GURGEL, R. F.; HOLANDA, J. N. F. Recycling of sugarcane bagasse ash waste in the production of clay bricks. **Journal of Environmental Management**, v. 101, p. 7-12, 2012.

HOBOLD, Monique Carrer *et al*. A study on the reuse of ash from sugarcane bagasse. **Revista Brasileira de Ciências Ambientais (Online)**, p. 1-11, 2020.

KIATTIKOMOL, Kraiwood *et al*. A study of ground coarse fly ashes with different finenesses from various sources as pozzolanic materials. **Cement and concrete composites**, v. 23, n. 4-5, p. 335-343, 2001.

LIMA, Sofia A. *et al*. Analysis of the mechanical properties of compressed earth block masonry using the sugarcane bagasse ash. **Construction and Building Materials**, v. 35, p. 829-837, 2012.

MEDEIROS, I. D. M.; GOMES, K. C.; SILVA NETO, J. F. Viability of Sugarcane Bagasse Ash as Precursor Material to Solar Absorbers Films. **Materials Science Forum**, p. 427-432, 2017.

MOISÉS, Murilo Pereira *et al*. Synthesis of zeolite NaA from sugarcane bagasse ash. **Materials Letters**, v. 108, p. 243-246, 2013.

NUNES, Rogério Antônio Xavier *et al*. Selective surfaces of black chromium for use in solar absorbers. **Materials Research**, v. 21, n. 1, 2018.

NURU, Z. Y. *et al*. Microstructural, optical properties and thermal stability of MgO/Zr/MgO multilayered selective solar absorber coatings. **Solar Energy**, v. 111, p. 357-363, 2015.

SALES, Almir; LIMA, Sofia Araújo. Use of Brazilian sugarcane bagasse ash in concrete as sand replacement. **Waste Management**, v. 30, n. 6, p. 1114-1122, 2010.

SANTOS, V. C. *et al*. Estudo do comportamento da argamassa autoadensável com cinza do bagaço de cana-de-açúcar no estado fresco e endurecido. **Revista IBRACON de Estruturas e Materiais**, v. 12, n. 1, p. 179-198, 2019.

SILVA, Emerson José da *et al*. Avaliação por análise de DRX da influência do beneficiamento de moagem na atividade pozolânica da cinza do bagaço de cana-de-açúcar. **Matéria**, v. 24, n. 4, 2019.

SONG, Ping *et al*. The investigation of thermal stability of Al/NbMoN/NbMoON/SiO2 solar selective absorbing coating. **Solar Energy Materials and Solar Cells**, v. 171, p. 253-257, 2017.

SOUZA, A. E. *et al*. Reuse of sugarcane bagasse ash (SCBA) to produce ceramic materials. **Journal of Environmental Management**, v. 92, n. 10, p. 2774-2780, 2011.

SRINIVASAN, R.; SATHIYA, K. Experimental study on bagasse ash in concrete. **International Journal for Service Learning in Engineering, Humanitarian Engineering and Social Entrepreneurship**, v. 5, n. 2, p. 60-66, 2010.

TEIXEIRA, Silvio Rainho *et al*. Valorization of sugarcane bagasse ash: producing glass-ceramic materials. **Journal of Environmental Management,** v. 134, p. 15-19, 2014.

TEIXEIRA, Silvio Rainho *et al*. Sugarcane bagasse ash as a potential quartz replacement in red ceramic. **Journal of the American Ceramic Society**, v. 91, n. 6, p. 1883-1887, 2008.