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Production of cement slabs using sugarcane bagasse ash associated with expanded polystyrene

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Abstract - Civil construction is considered a major generator of urban solid waste and one way to mitigate this problem is to invest in modular construction systems, making room for lean and sustainable models. This paper evaluated the potential of Sugarcane Bagasse Ash (SCBA) as composites, combined with the inclusion of expanded polystyrene (EPS) in the production of cement slabs applied to civil construction. For the partial substitution of Portland Cement (PC) the chemical characterization of SCBA by fluorescence and X-ray diffraction was carried out and its production used concentrations from 6.8% to 25.5% of SCBA. In the cementitious plate, tensile strength tests were performed for flexure tensile strength, water absorption and permeability, in accordance to Brazilian guidelines. The results demonstrated the use of SCBA in partial substitution of PC in the proportion of 6.8% and 13.6% with absence of fine sand and 17% with addition of fine sand, allowing its use in a clean, modular and dry construction technology. It is possible to conclude, therefore, that the industrial residue of SCBA can be used in substitution of PC and that the inclusion of EPS in the studied product's formula increases its volume and decreases its apparent density.

Keywords: Industrial waste. Composite material. Sustainable construction system. Physical and mechanical properties.

Produção de placas cimentícias utilizando cinza do bagaço da cana-de-açúcar aliado ao poliestireno expandido

Resumo - A construção civil é considerada como um grande produtor de resíduos sólidos urbanos, uma forma de mitigar este problema é o investimento em sistemas construtivos modulares, dando espaço para modelos enxutos e sustentáveis. Este trabalho avaliou o potencial da cinza do bagaço da cana-de-açúcar (CBC) como compósitos, aliado a inclusão do poliestireno expandido (EPS) na produção de placa cimentícia aplicada a construção civil. Para substituição parcial do cimento *Portland* (CP) foi realizada a caracterização química da CBC por fluorescência e difração de raios - X e na sua produção utilizou-se uma concentração entre 6,8 % e 25,5% de CBC. Na placa cimentícia foram realizados testes de resistência à tração na flexão, absorção de água e permeabilidade de acordo com as diretrizes brasileiras. Os resultados demonstraram a utilização da CBC em substituição parcial do CP na proporção de 6,8 % e 13,6 % com ausência de areia fina e 17% com acréscimo de areia fina, permitindo sua utilização em uma tecnologia construtiva limpa, modular e a seco. Conclui-se, portanto, que, o resíduo industrial de CBC pode ser utilizado em substituição do CP e que, a inclusão do EPS na formulação do produto estudado aumenta seu volume e diminui sua densidade aparente.

Palavras-chave: Resíduo industrial. Material compósito. Sistema construtivo sustentável. Propriedades físicas e mecânicas.

Producción de losas de cemento con ceniza de bagazo de azúcar asociada con poliestireno expandido

Resumen – La construcción civil se considera una de las principales generadoras de residuos sólidos urbanos y una forma de mitigar este problema es invertir en sistemas de construcción modular, dando cabida a modelos esbeltos y sostenibles. Este trabajo evaluó el potencial de las cenizas de bagazo de caña de azúcar (SCBA) como compuestos, combinados con la inclusión de poliestireno expandido (EPS) en la producción de losas de cemento aplicadas a la construcción civil. Para la sustitución parcial del Cemento Portland (PC) se realizó la caracterización química del SCBA por fluorescencia y difracción de rayos X y su producción utilizó concentraciones de 6.8% a 25.5% de SCBA. En la placa cementosa se realizaron pruebas de resistencia a la tracción en flexión, absorción de agua y permeabilidad, de acuerdo con las directrices brasileñas. Los resultados demostraron el uso de SCBA en sustitución parcial de PC en la proporción de 6,8% y 13,6% con ausencia de arena fina y 17% con adición de arena fina, permitiendo su uso en una tecnología de construcción limpia, modular y seca. Es posible concluir, por tanto, que el residuo industrial de SCBA puede ser utilizado en sustitución del PC y que la inclusión de EPS en la formulación del producto estudiado aumenta su volumen y disminuye su densidad aparente.

Palabras clave: Residuos industriales. Material compuesto. Sistema de construcción sostenible. Propiedades físicas y mecánicas.

Introduction

Given the current environmental scenario and the need to develop sustainable materials applied to the construction sector, several efforts have been promoted to reduce the use of natural resources and waste generation. The best way to decrease the use of these resources comes from the substitution of traditional methods by more efficient construction methods and the incorporation of waste (industrial and construction) as raw material (Marhani et al. 2012; Alwaeli 2013; Cordeiro et al. 2016; Zhang et al. 2016).

More efficient, modular and constructive methods should be applied on the construction site to mitigate waste, improve the process, make it possible to meet deadlines, reduce costs and maximize profits (Marhani et al. 2012; Gosling et al. 2016; Jamil and Fathi 2016). In this sense, prefabricated processes using wood frame, steel frame and reinforced concrete (industrial, commercial and residential) construction models can be applied instead of more traditional construction methods (Sarhan and Fox 2013; Bajjou and Chafi 2018; Martins et al. 2019; Bagheri and Doudak, 2020).

An ecologically sustainable alternative that is economically viable and has shown satisfactory results is the introduction of solid waste in mortars (Moretti et al. 2016; Favara and Gamlin 2017; Anjos et al. 2020; Matias et al. 2020). Thus, mortars produced from composites, represent an alternative to minimize cost, energy, reduce the volume of waste and improve their properties (Matias et al. 2020; Oliveira et al. 2020; Raheem and Ikotun 2020).

The inclusion of these residues (industrial and/or civil construction) in the production of composite materials allows the reduction of demand for extraction of natural resources and makes it possible to obtain materials with similar properties, resulting in innovative technologies (Castro and Martins 2016; Namrou and Kim 2016; Favara and Gamlin 2017; Oliveira et al. 2020).

Several studies using mainly Sugarcane Bagasse Ash residues (SCBA) are being developed on the inclusion of concrete mortars (Chen et al. 2013; González-López et al. 2015; Castro and Martins 2016; Lima et al. 2012;). Currently, most of the SCBA waste is dispensed with in the crops as an agricultural input, but there is another portion that does not receive such destination and corresponds to an environmental problem for the production chain and can be reused in the construction industry. Due to the high silica content (SiO_2) present in SCBA, this residue presents pozolic properties (Frías et al. 2011; Longarini et al. 2014; Bahurudeen and Santhanam 2015; Molin Filho et al. 2019) and can be used as a small aggregate or even in partial substitution of cement in concrete production (Frías et al. 2011; Lima et al. 2011; Lima et al. 2012; Raheem and Ikotun 2020).

Allied to the incorporation of SCBA, the addition of polymers such as expanded polystyrene (EPS) in the production of mortars makes it possible to produce a highly resistant material with properties of low thermal conductivity, making the cementitious plate more efficient as a thermal, acoustic, and waterproof insulator (Batayneh et al. 2007; Hong and Choi 2017; Matias et al. 2020). This material included in the concrete mortar composite reduces its incident load and makes it an excellent material for the manufacture of cementitious plates (Zhou et al. 2018; Jesus et al. 2019; Koksal et al. 2020).

Thus, the development of these composite materials must be related to the rheological characteristics in the establishment of resistance, fluidity, cohesion and segregation of phases and requires specialized research with appropriate tests and techniques (ABNT NBR 15823-1 2017). Aiming at the reuse of waste and sustainable development, the objective of this study was to produce a cement slab with the incorporation of different quantities of SCBA in partial substitution of cement, alongside the addition of EPS to the mortar.

Materials and methods

For the production of the cement slab, raw materials available in the Brazilian market were used, such as Portland CPV-ARI cement, 4 x 4mm fiberglass mesh, expanded polystyrene (EPS), natural washed fine sand (silica) and expanded vermiculite. SCBA was supplied by a sugar-alcohol plant located in the Northwest of Paraná State - Brazil (Latitude 23°23’49.71 “S, Longitude 52° 5’37.21 “W).

All raw materials had their granulometric profile characterized (ABNT NBR 10004 2004; ABNT NBR 7211 2009; ABNT NBR 15900-1 2009; ABNT NBR 5752 2014; ABNT NBR 7181 2016) for a greater production control of the cementitious plate. SCBA was sieved and used with a granulometry of 0.044mm in the mortar mixture.

In the production of the mortar were used, expanded polystyrene of the EPS MARINGÁ brand with a diameter of 3mm in the form of a micro sphere (EPS-30) and the ADFORS Vertex brand fiberglass with a 4 x 4mm mesh, being applied in two stages, the first placed on the base of the form and the second fixed on the mortar.

Characterization of SCBA

The chemical composition of SCBA was determined by Wavelength Dispersive X-Ray Fluorescence (WDXRF) model S8 TIGER - Bruker (Tokyo, Japan). The sample was analyzed in He with a Rh X-ray source operating in the 30 - 60kV voltage range. Its morphological state (crystallinity) was determined by XRD in a Bruker AXS D8 Advance instrument, with Cu radiation Kα1, α2 operating at 40 kV and 40 mA, in the range of 5° to 80°. The diffraction patterns were collected in a plane geometry with 0.02° steps and accumulation time of 3s per step. The X-ray diffraction data of the powder was refined following the Rietveld method with the software TOPAS Academic V.5 ©.

Cement Plate Characterization

The quantity of inputs used for the production of the cementitious plate was sized as described in Table 1. The plates were produced in the dimensions of 600mm X 1200mm X 6mm, meeting all requirements according to the current legislation in Brazil (ABNT NBR 15.498 2016).

The preparation and production of the cement slab was performed with the mixture of cement, lime, sand and water, referring to each composition in study (Table 1) under mechanical agitation for 3 minutes. The other components were incorporated to the preparation adding SCBA, EPS and the adhesive (diluted in water) and kept in agitation for another 2 minutes, then vermiculite and the whole mixture was agitated for 3 minutes.

Table 1. Composition of the raw material mixture for the production of the cementitious plates

Samples	Cement (Kg)	(SCBA) (Kg)	Vermiculite (Kg)	Lime (Kg)	Sand (Kg)	EPS (Kg)	H_2O (Kg)
A	6,42	-	0,48	-	2,58	-	3,00
B	3,21	2,55	0,48	-	2,58	-	3,00
C	3,21	2,55	0,48	-	2,58	0,03	3,00
D	1,61	3,83	0,48	0,50	2,58	0,04	3,00
E	5,99	2,04	0,48	-	-	0,01	3,00
F	7,28	1,02	0,48	-	-	0,01	3,00

After the production of the cement plate, the specimens were divided into rectangular shapes to perform the tensile strength tests in simple bending, apparent density, water absorption index and permeability following the recommendation of the Brazilian legislation (ABNT 2016). The tensile strength test was carried out at the Universidade Tecnológica Federal of Paraná (UTFPR), Apucarana Campus - Brazil. For the test it was used the universal testing machine TIME-SHIJIM TIME WDW-300E, with loading rate between 20 and 50mm/min, supported with the face exposed in the installation facing up and load applied along the midline through the loading bar in the intervals of 10s to 30s.

The compositions of the raw material mixtures in the formation of the cementitious plate went through the multivariate statistical analysis PCA (Principal Component Analysis). The tests data were duly organized in tables in MS-Excel and loaded in the free software PAST (Paleontological Statistics Software Package for Education and Data Analysis) from the University of Oslo, Norway (https://folk.universitetetioslo.no/ohammer/past). After this, the analysis of the resulting PCA graphs was performed and their results are discussed in the next section.

Results and discussions

Result of raw material characterization

Table 2 shows the composition of SCBA performed by X-ray fluorescence (XRF). Through the results, it is possible to observe the predominant presence of silicon dioxide (silica - SiO_2). This result is in accordance with the results described in the literature (Moisés et al. 2013; Gonçalves et al. 2017; Molin Filho et al. 2019) and the composition of SCBA characterized by WDXRF indicates the potential application of this residue in the zeolitization process.

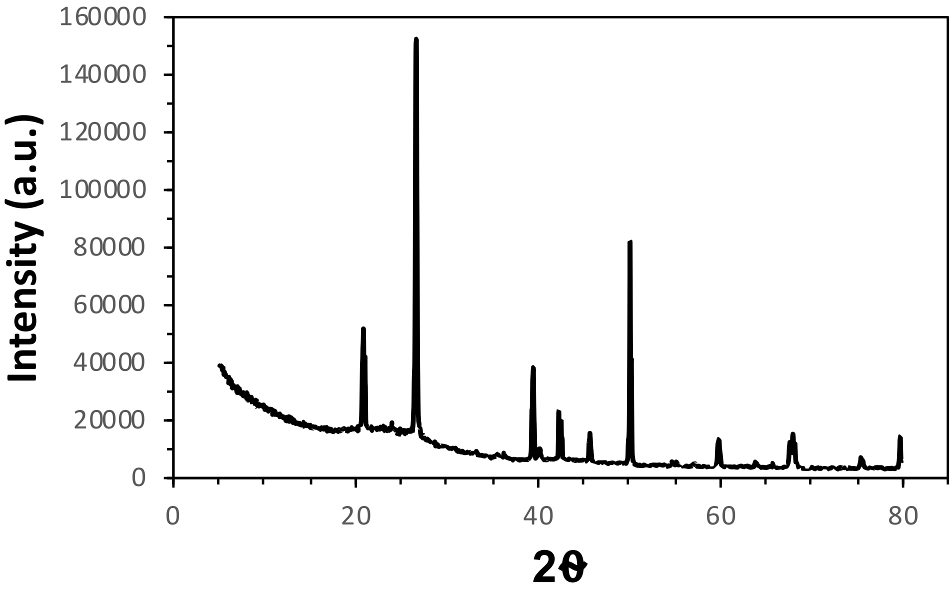
Table 2. Chemical composition of SCBA by X-ray fluorescence.

Composites	SiO_2	Al_2O_3	K_2O	CaO	Fe_2O_3	TiO_2	Others
Mass (%)	80,2	4,83	5,32	1,26	5,04	2,66	0,69

Figure 1 shows the X-ray diffractometer (XRD) obtained for the SCBA, in which it was possible to demonstrate peaks that characterize the material as crystalline. Through the comparison with the crystallographic reference sheets of pure materials (standard pattern number 02-0458 - International Centre for Diffration Data - ICDD database), it can be stated that there is a predominant presence (> 98%) of the crystalline structure of α-quartz and a small proportion (< 2%) of the mixture of trimidite and cristobalite.

Several authors (Lima et al. 2012; Cordeiro et al. 2016; Gonçalves et al. 2017; Molin Filho et al. 2019; Anjos et al. 2020; Chindaprasirt et al. 2020) have described the incorporation of sugarcane bagasse ash in materials applied to civil construction, instances in which they obtained promising results in terms of resistance to compression, diametrical compression, bending traction and water absorption. Thus, the incorporation of SCBA as a partial substitute for cement is relevant in view of the need to develop actions capable of contributing to the sustainability of the planet.

Figure 1. CBC X-ray diffractogram



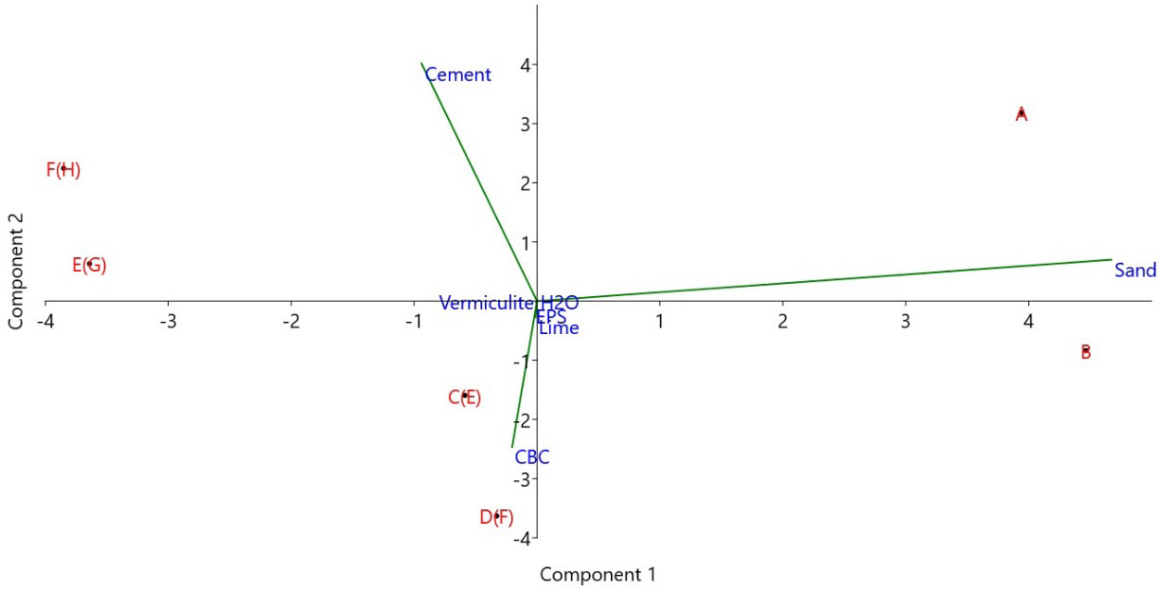
The different compositions (Tables 1) were prepared with the main objective of evaluating the effect of increasing the percentage of SCBA and the reduction of cement on the strength of the cementitious plate, as well as evaluating its physical and mechanical characteristics. To maintain the working capacity of the mixtures, a superplasticizer was used for high performance concrete.

According to the Brazilian technical standard (ABNT NBR 5752 2014), for a material to be evaluated as a pozzolanic material replacing Portland Cement, at least 80% of its particles must be smaller than 0.045 mm. Thus, the granulometric control was important for the reproduction of the physical and mechanical characteristics of the cement plate.

For the production of cementitious plates was used, SCBA with granulometry of 0.044 mm and EPS in the form of a microsphere with a diameter of 3 mm, specific mass 13 kg / m^3, 10% deformation under compression of 30 Kpa, thermal conductivity = 0.044 W.m^{-1}.K^{-1} and water absorption less than 5%.

Figure 2 presents the PCA analysis for evaluating the composition of the mixture. In this analysis we can observe that in sample A the cement is strongly associated with sand for the formation of the cement plate. With the incorporation of SCBA in the mixture, the most effective interaction by PCA analysis occurred for mixtures E and F, with SCBA percentages of 13.6 % and 6.8 %, respectively.

Figure 2. PCA analysis for the composition of the cement plate mixture.



Cement plate mechanical result

After the mechanical tests performed on the specimens, the results of resistance to traction in simple bending, deformity, density and water absorption index were obtained and presented in Table 3. These results help to adequately classify the fiber cement plate according to its application (ABNT NBR 15.498 2016), so due to its physical properties measured in Mega Paschoal (MPa) these plates can be applied in external or internal environments.

Table 3. Results of the mechanical test

Samples	Tensile Strength (MPa)	Deformity (mm)	Density (g/cm^3)	Water Absortion (%)	(SCBA) used in the Mortar (%)
A	1,9342	0,8413	1,13	28,42	0,00
B	13,5758	3,3568	1,20	25,00	17,0
C	1,7466	15,1209	0,70	51,61	17,0
D	1,3041	10,0821	0,71	53,12	25,5
E	4,1976	10,0844	0,71	39,39	13,6
F	5,2863	10,0832	1,12	22,73	6,8

Table 3 shows that all samples presented plastic properties when submitted to the tensile strength test, thus increasing their performance, since they did not present sudden ruptures, allowing a displacement of deformity and thus avoiding immediate shearing. The application of fiberglass as a canvas at the base of the form contributed to fixing and compacting the mortar and consequently increasing the surface resistance of the cementitious slab. Several authors (Sales and Lima 2010; Arenas-Piedrahita et al. 2016; Arif et al. 2016; Namrou and Kim 2016;) have also succeeded in their experiments with high mechanical performance through the incorporation of SCBA in the production of mortar and/or concrete.

The best tensile strength performances in single bending (Table 3) were obtained by samples B, E and F. Samples E and F were above the minimum required (ABNT NBR 15.498 2016), in addition to achieving relevant variables such as initial adhesion, plasticity, consistency, water retention, start and end of grip for materials produced from cement matrix (Cintra et al. 2014). Samples C and D had the lowest tensile strength in simple bending (Table 3), this result is due to the higher volume of SCBA incorporated in the composite and in sample C to the EPS incorporated in the composition of the mortar (Table 1).

The sample that presented the best result for deformity was C, but samples D, E and F obtained very expressive results for simple tensile deformity (Table 3). The specimen with the least deformity was sample A, this result can be attributed to the absence of SCBA and EPS in its composition (Table 1). After the incorporation of SCBA in the mortar composition allied to the addition of EPS it is possible to observe the increase in plasticity (Table 3), this result is corroborated by the work of Carvalho and Motta (2019) who evaluated the properties of concrete with the addition of EPS for use in load-bearing walls and by the work of Strecker et al. (2014) who related the inclusion of EPS for the production of cementitious plates.

After the mass density test (Table 3), the matrix that obtained the highest density result was sample B, reaching 1.20g/cm^3, the highest proportion of fine sand in its composition is attributed to this performance. This sample also presented the highest performance in the tensile strength test. Samples C, D and E showed the lowest density, since the composition of sample C has the lowest proportion of fine sand than samples D and E this performance is due to the presence of EPS and absence of fine sand in its composition (Cintra et al. 2014). Thus, the incorporation of EPS in the mortar contributes to the reduction of the mass density of the cementitious plates.

Water absorption is characterized as a physical process by which the concrete retains water in its pores, therefore, the smaller the amount of water absorbed by the plate, the greater the impermeability (Zareei et al. 2018). After analyzing the results (Table 3), it was observed that specimens C and D reached the highest water absorption rates, this result was due to the high volume of EPS in the mortar composition (Table 1) that increased its void index. Although the EPS volume between samples E and F described in Table 1 are the same, sample F obtained a better result in the water absorption index because it contains in its mortar higher PC volume and was better hydrated, increasing its workability, agglutination of the elements and filling the voids.

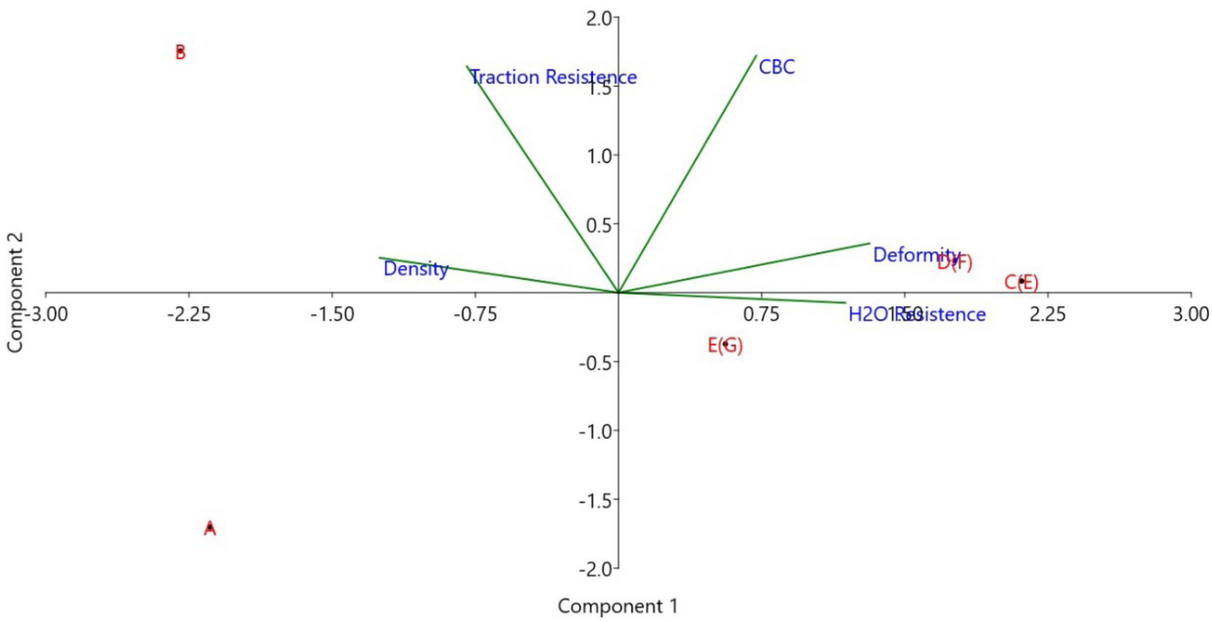
In the mortar composition for samples E and F (Table 1) the percentage of vermiculite was kept constant and the volume of EPS and SCBA decreased, which promoted an increase in tensile strength in the simple bending of the materials (Table 3) and a decrease in their water absorption rates. The hydration of the cement interferes both in the behavior of the mortar in its fresh state and affects the properties in its hardened state. The mortar needs a large part of the percentage of water to be retained so that the chemical reactions of hardening of binders occur in an appropriate manner so that the properties in the hardened state are satisfactory (Cintra et al. 2014).

Vermiculite can be used in civil construction as a small aggregate in the formulation of mortar for thermal and acoustic insulation or for waterproofing roof slabs (Ugarte et al. 2008). After analysis in the samples, it was found that the higher the concentration of EPS in the mortar composition the higher the water absorption index, due to the increased porosity of the material.

And the vermiculite, being a mineral formed by hydrated silicates, can help in waterproofing these materials, thus helping in the formulation of mortars that seek thermal, acoustic and permeability performance.

PCA analysis was applied to evaluate the mechanical tests (Figure 3). The main components PC1 (axis 1) and PC2 (axis 2) of the PCA analysis of these samples explain approximately 89% of the tests. We observed in the mechanical tests that the tensile strength is a very significant element in sample B, however, although this sample does not present sudden ruptures, it allows a small displacement of deformity with little expressive density. Sample F shows the opposite behavior, presenting less resistance, but a greater displacement of deformity and with less probability of ruptures when compared with sample B. The sample presents resistance and density properties similar to sample F, but with increased water absorption. The other samples A, C and D presented little relevant mechanical properties.

Figure 3. PCA analysis of the mechanical tests on cementitious plates.



The permeability test was applied only to samples B, E and F, being these samples the ones that presented the highest performance in the tensile strength test in simple bending and the lowest percentage of water absorption (Table 3). The other samples did not reach the minimum required resistance of 4 MPa according to Brazilian guidelines (ABNT NBR 15.498 2016). In this test, for samples B, E and F the results were satisfactory and did not present dripping, but sample E presented humidity on the lower face of the plate after 24 hours.

A comparison between samples B, E and F with the 4 (four) most marketed cement plates in Brazil was made to measure the density performance and mechanical performance. In addition to these comparisons, the classification of each plate fits the norms (ABNT NBR 15.498 2016), since the "A" classification refers to plates with external applications subject to the direct action of sun, rain, heat and humidity and "B" classification stands for internal and external applications not subject to the direct action of sun, rain, heat and humidity (Table 4).

Regarding the mechanical characteristics of the samples if compared with the main commercial plates in the Brazilian market, sample B obtained the best performance, this result may have occurred due to the packing of the particles that cause this physical effect (Cordeiro et al. 2016). It is noted that for the commercial plates used as reference, the resistance in saturated state decreases, while for samples B, E and F, it had an increase in its resistance when in saturated state (Table 4).

Table 4. Comparison of density performance and mechanical performance in relation to industrialized and commercialized slabs in Brazil.

Plates	Bending Strength (MPa)		Apparent Density (g/cm³)		Water Absorption (%)	Weight (Kg/m³)	Classification*
	Equilibrium	Saturated	Equilibrium	Dry			
Comercial 1#	17	11	1,70	1,40	30,0	20,40	A3
Comercial 2#	12	-	-	1,25	30,0	15,41	B2
Comercial 3#	14	11	1,70	1,40	26,0	20,40	A3
Comercial 4#	12	8	1,70	1,54	24,0	15,41	A3
Sample B	13,60	16,70	1,25	1,21	25,0	15,30	A4
Sample E	4,20	6,71	0,76	0,71	39,3	12,51	A2
Sample F	5,00	6,71	1,18	1,11	22,7	18,00	A2

* Brazil (ABNT NBR 15.498 2016); # Cement Plates sold in Brazil.

In this comparison it can be highlighted that samples B, E and F presented an apparent density slightly lower than the commercial plates. As for the water absorption test, samples B and F showed lower rates of water absorption (Table 4).

Samples B, E and F presented the demanded parameters (ABNT NBR 15.498 2016) for all requirements related to strength, density, water absorption and permeability, with sample B achieving the best tensile strength classification in simple bending (Table 4). According to the ABNT NBR 15.498 (2016), the plates are classified in categories according to their resistance to traction in flexion, and the plate with classification A2 presents resistance to traction in flexion from 4 to 7 Mpa, A3 resistance from 7 to 13 Mpa and A4 resistance higher than 13 Mpa. The B2 classification demonstrates that the plate under analysis had a resistance of 7 Mpa in the result of traction in simple bending as can be observed in Table 4.

Conclusion

In this paper we studied different mixtures characterized by the partial substitution of Portland Cement for Sugarcane Bagasse Ash, with rheological properties expected in the production of cement slabs. It was demonstrated that we can use SCBA in substitution of Portland Cement (PC) in the proportions of 6.8 and 13.6% with the absence of fine sand and the substitution of 17% of PC with the addition of fine sand, generating a significant reduction in cement consumption and the addition of small amounts of EPS contributed to the reduction of mass density in the production of cementitious slabs, confirming data from the literature that indicate the use of SCBA in substitution of PC. These values show an excellent alternative for the reuse of sugarcane bagasse burning residues, both for recycling and for the possible development of a product with quality comparable to those in current use. Furthermore, this application enables an adequate technical destination for SCBA and has the potential to promote the deceleration of natural resources consumption, such as cement. Thus, advances are presented in the development of new products that can contribute directly to the advancement of socio-environmental values, both for generating plants and for use in civil construction for the advancement of buildings. Although the studies have shown possibilities of replacing the usual compositions, new studies in the hardened state are recommended for the final proof of the proposed idea.

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