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Effect of partial replacement with thermally processed sugar cane bagasse on the properties of mortars

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ABSTRACT

Sugar cane bagasse is a residue of the sugar-alcohol industry, and its main destination is represented by burning boilers for power generation. The bagasse cogeneration of power produces a sugar cane bagasse ash (SCBA) residue that does not have a useful destination. Ashes are commonly studied as pozzolan in Portland cement production. International Standards indicate the use of pozzolan with up to 50% substitution. In the present work, we investigate the use of SCBA as an addition in Portland cement. For this purpose, Portland cement was prepared by substituting cement with 0, 10, 20, and 30% processed SCBA in volume. The ashes were processed by re-burning and grinding and were then characterized by scanning electron microscopy, X-ray diffraction, laser granulometry, X-ray fluorescence spectrometry, the Chapelle method, and pozollanic activity. To evaluate the cement with substitution, we used the mortar recommended by NBR 7215. The mechanical properties of the cements with replacement were analysed through tests of the compressive strength and flexural strength of mortars. The results appear interesting and support the possible use of SCBA in the production of cement from the aspect of mechanical properties evaluated.

Keywords: sugar cane bagasse ashes; cementitious composites; mechanical behaviour; sustainability.

1. INTRODUCTION

In 2013, Brazil produced approximately 70 million tons of cement [1]. Cement consumes 5.5 GJ of energy and releases approximately 1 ton of CO_2 per t of clinker, corresponding to between 5 and 8% of the total CO_2 emitted annually into the atmosphere [2]. Mineral additions are often employed to reduce the environmental impact of cements.

An alternative to mineral addition is represented by sugar cane bagasse ash (SCBA). The partial replacement of Portland cement with SCBA may result in an improvement of the mechanical properties of the composite and support the production of a more sustainable material. It is important to highlight that while the bagasse combustion releases CO_2, the CO_2 emission balance is essentially zero when the complete cycle is considered because photosynthesis restores the burned biomass in the next sugar cane crop. After the sugar cane combustion process, approximately 0.7% of the initial mass remains in the form of residual ash, the equivalent of 4.8 million tons in just 2009 [3]. Considering that only 93% of the bagasse is used as fuel in the boilers, the amount of residual ash would be approximately 0.58% of the sugar cane's total mass, which amounts to a production of nearly 4 million tons of ash [4]. It is believed that the percentage of residual ash

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generated in the bagasse combustion is variable, depending on the efficiency of the boiler burning process.

Studies conducted by Paula [5] show that compression tests over 7 and 28 days, performed on mortars with concentrations of SCBA between 0 and 30 wt%, indicate the possibility of substituting up to 20 wt% of cement with SCBA without reducing the resistance. The work of Ganesan et al. [6] highlighted that up to 20 wt% of Portland cement can be replaced by sugar cane bagasse ash, leading to a high initial mechanical resistance, a reduction in water permeability, and a sensitive resistance to chlorides, as well as improvements in the durability of concrete structures.

Ribeiro and Morelli [7] evaluated the pozzolanic activity of SCBA. The results showed the technical feasibility of using SCBA as a pozzolanic material in construction, which would provide an alternative to the proper disposal of this waste as well as products with high technical performance.

Although SCBA can be classified as a pozzolanic material, its activity strongly depends upon granulometry and fineness [8]. The first requirement for the effective application of SCBA to mortar and concrete production is the controlled use of grinding processes and classifications, enabling it to reach the fineness and homogeneity necessary to meet industry standards. The type of mill and grinding adopted, the particles size, and the specific surface area may influence the pozzolanic activity of the ashes produced. The pozzolanic activity of the ash is directly linked to its fineness [9].

Cordeiro, Toledo Filho, and Fairbairn [9] indicate that the temperature of calcination is an important parameter for the production of SCBA with pozzolanic activity. Furthermore, the SCBA produced with air calcination at 600°C for 3 h with a rate of heating of 10°C/min presents amorphous silica, a low carbon content, and a high specific surface area. The sample produced with these characteristics presents considerable pozzolanic activity according to both mechanical and chemical methods of evaluation. In this context, the aim of this study is to evaluate the effect of partial replacement (in volume) of Portland cement with thermally processed sugar cane bagasse ash on the properties of mortars.

2. MATERIALS AND METHODS

The sugar cane bagasse ashes were collected from Bem Brasil Alimentos SA, a company situated in the mesoregion of Alto Paranaíba and Triângulo Mineiro, Brazil. The ash examined in this study was obtained by processing the sugar cane bagasse through boiler burning. High early strength Portland cement, normalized sand, and tap water distributed by the public water supply network were employed in the research.

The ashes were oven-dried at temperatures of 100 ± 5°C for 24 h and then subjected to two procedures: re-burning and grinding. Burning was performed in a forced-draft muffle furnace at the temperature of 600°C for 3 h with a rate of heating of 10°C/min, as previously suggested [9]. Grinding was performed by high-performance ball milling for 10 min at 300 rpm using 16 spheres with a diameter of 10 mm and of the same material in a 500-ml zirconia container until a lower granulometry to 0.045 mm was obtained.

The re-burned and ground SCBA (SCBA RG) was characterized by scanning electron microscopy (SEM), X-ray diffraction spectrometry (XRD), X-ray fluorescence spectrometry (XRF), and laser granulometry (LG), and pozzolanic activity. The microscopy experiments were performed on a SEM with variable pressure with a magnification from 15 to 30,000 times and digital zoom factors of 2x and 4x, using an accelerating voltage of 15 kV and a BSE (backscattered electron) detector. The XRD measurements were performed on a copper X-ray tube with 40 kV accelerating voltage and a 30 mA current in a continuous scanning mode and a 2θ that varied between 5º and 90º at a 2°/min rate. XRF was performed with atmospheric air and a collimator of 10 mm. The LG was performed in a liquid medium with water as fluid, without a dispersive liquid, and with ultrasounds applied for 60 sec and an obscuration of 10%.

The SCBA had its pozzolanicity evaluated according to NBR 5752 [10] and NBR 15895 (Modified Chapelle method) [11]. The NBR 5752 [10] calls for two different mortars be prepared: (i) the mortar A should contain Portland cement only; and (ii) the mortar B must have part (35%) of the total volume of cement replaced by the pozzolanic material. For each type of mortar is recommended for molding three cylindrical test pieces of 50 mm x 100 mm. The determination of the setting times of Portland cement with SCBA was evaluated according to NBR NM 65 [12].

The mortars were prepared using normal sand with a constant cement/sand ratio of 1:3 in mass and constant water/cement in volume, substituting the high early strength Portland cement with SCBA RG at 10, 20, and 30% by volume. The replacement was done in volume following the procedure of NBR 5752 [10] using the relationship between specific mass. The ash amounts were determined to evaluate the corresponding amount of cement substituted in order to maintain the same volumetric ratio between fine aggregates and paste. Because of the specific masses difference of the Portland cement and of the SCBA, the removal of the mass of Portland cement was not the same mass of SCBA added. Usually, the water / cement ratio is determined by the mass of the splitting of water by the mass of the cement, but as the replacement of Portland cement with SCBA was performed in volume, thus altering the water / cement and water / binder (Portland cement + SCBA) for the same amount of water added for the different mortars. However, the replacement of Portland cement by volume SCBA keeps the water / binder at constant volume.

To calculate the exact amount of ash used, the specific masses of Portland cement and ashes were determined using the ABNT NM 23 [13] and are presented in Table 1. The difference between two individual results obtained from the same sample under test, by the same operator using the same equipment in a short period of time, did not exceed 0.02 g/cm³, given the parameters of ABNT NM 23 [13]. The loss on ignition of Portland cement and ashes were determined using the ABNT NM 18 [14] and are presented in Table 1.

Table 1: Specific mass and loss on ignition of the Portland cement and of the ashes.

Material	Specific mass (g/cm^3)	Loss on ignition (%)
High early strength Portland cement	3.106	3.75
SCBA in nature	1.720	49.16
SCBA RG (Re-burned and Ground sugar cane bagasse ash)	2.653	3.29

Following the measurement procedures established by the NBR 7215, it prepared five cylindrical specimens of 50 mm in diameter and 100 mm in height for the compressive strength test [15] and three prismatic specimens of 40 mm × 40 mm × 160 mm to evaluate the flexural strength [16]. For compressive strength and flexural strength tests, when the maximum relative deviation is greater than 6%, a new average is calculated, excluding the outlier value. Persisting fact, it was eliminated the bodies of the test piece of all ages, and the test has been completely redone [15-16]. The maximum relative deviation of the series of four results was obtained by dividing the absolute value of the difference between the average resistance and individual resistance which departs furthest from this average, more or less, the average resistance and multiplying this quotient by 100. The percentage obtained was rounded to the nearest tenth.

For the statistical evaluation of the results was used the method "Anova: Single Factor" with Microsoft Excel software support with allowable error of 5%. The results of the ANOVA was verified by the hypothesis compressive strength results of the various mortars are exactly equal in range, i.e., the results can be regarded as similar. The analyzes were taken into consideration source of variation between groups. For the test P value (P value) lower than the permissible error it was rejected equality between mortars. Another way was to analyze compares the value of the critical region boundary (critical F) and the value of F (F), that is, if "F" exceeds the "critical F" equal must be rejected.

To measure the flow of mortar was used the NBR 7215 [15] procedure but mixtures were conducted separately of the preparation of specimens. The mouldings were performed according to their respective standards, and curing of the specimens was carried out in water saturated with calcium hydroxide until the date of testing. After curing, the mortars had their water absorption and specific mass determined according to NBR 9778 [17] the mean of three values.

This research used high early strength Portland cement (CP V - ARI MAX), as this material has no significant additions. According to NBR 5733 [18], its concrete constitution has concentrations between 95 and 100% of clinker and calcium sulfate, with the addition of up to 5% carbonate material in the production of the agglomerate. Table 2 presents the results of the chemical characterization of Portland cement. Table 3 presents the results of the physical characterization of the Portland cement.

Table 2: Chemical characterization of high early strength Portland cement

Testing	Methodology	Unit	Result	Requirements
Insoluble residue	ABNT NM 15 [19]	%	0.57	≤ 1.0
Loss on Ignition	ABNT NM 18 [14]	%	3.75	≤ 4.5
Magnesium oxide	ABNT NM 21 [20]	%	1.48	≤ 6.5
Sulphur trioxide	ABNT NM 16 [21]	%	2.73	≤ 4.5
Anhydride Carbonic	ABNT NM 20 [22]	%	2.61	≤ 3.0

Table 3: Physical characterization of high early strength Portland cement.

Testing	Methodology	Unit	Result	Requirements
Specific area (Blaine)	ABNT NM 76 [23]	cm^2/g	4,507	≥ 3,000
Residue on sieve # 200	ABNT NBR 11579 [24]	%	0.06	≤ 6.0
Residue on sieve # 325	ABNT NBR 9202 [25]	%	0.87	-
Normal consistency water	ABNT NM 43 [26]	%	30.4	-
Setting times cement - Start	ABNT NM 65 [12]	Minutes	142	≥ 60
Setting times cement - End	ABNT NM 65 [12]	Minutes	191	≤ 600
Expandability	ABNT NBR 11582 [27]	mm	0,00	≤ 5.0

3. RESULTS

Figure 1 shows the granulometrical distribution of the Portland cement and of the SCBA RG after grinding for 10 min. The grinding process was continued for 2, 4, 6, 8, and 10 min. No significant decrease was observed in the average size of the ashes until 6 min of grinding had been completed; moreover, the granulometry results indicate a slightly finer granulometry for the ashes ground for 8 and 10 min. As the equipment manufacturer's test recommends 10 min of grinding for this type of material, it opted for this duration. Table 4 lists the particle size measured for the Portland cement and SCBA RG by laser granulometry. The SCBA RG particles are finer (Figure 1 and Table 4) and has lower specific mass (Table 1) than those of the cement used. The sieve analysis shows that the samples satisfy the ASTM C618 fineness criterion for fly ash and natural pozzolans, with less than 34% of the material retained on a 0.045 mm sieve [28].

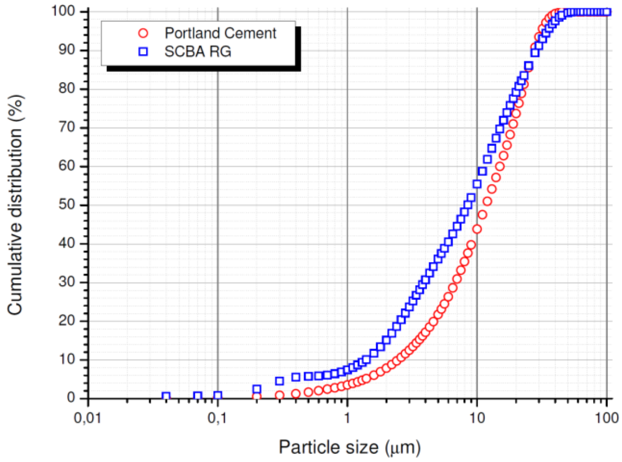
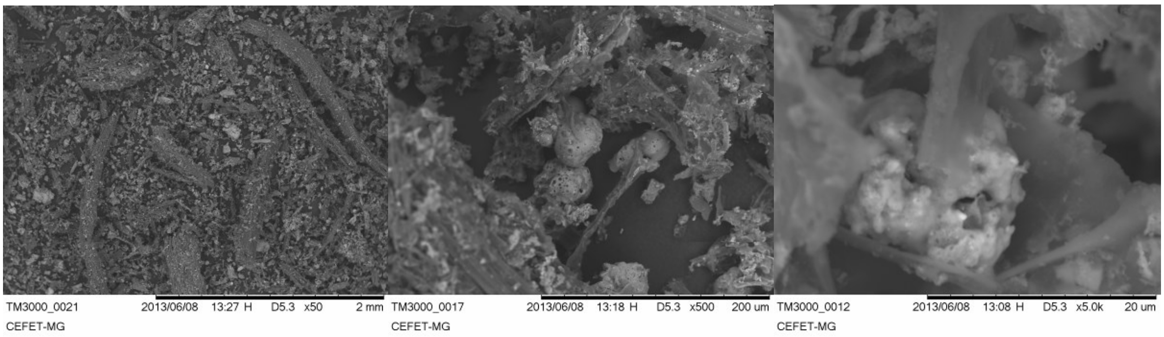


Figure 1: Particle size distribution of Portland cement and re-burned and ground sugar cane bagasse ashes (SCBA RG).

Table 4: Laser granulometry (particle sizes in μm) of Portland cement and re-burned and ground sugar cane bagasse ashes (SCBA RG), with d10, d50, and d90 denoting the particle size at 10, 50, and 90% of the cumulative distribution.

Cumulative distribution	Portland cement	SCBA RG
d10	2.46	1.39
d50	11.70	8.47
d90	27.50	28.62
Average size	13.66	11.88

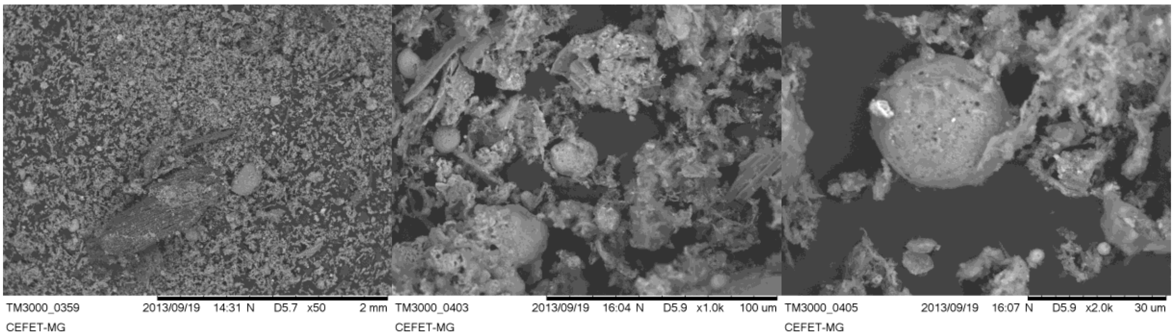
Figure 2 shows images of the SCBA in natura (SCBA) magnified 50 (a), 500 (b), and 5,000 (c) times. Various SCBA fibres can be observed in Figure 2(a).



(a) (b) (c)

Figure 2: Images of re-burned sugar cane bagasse ashes before grinding.

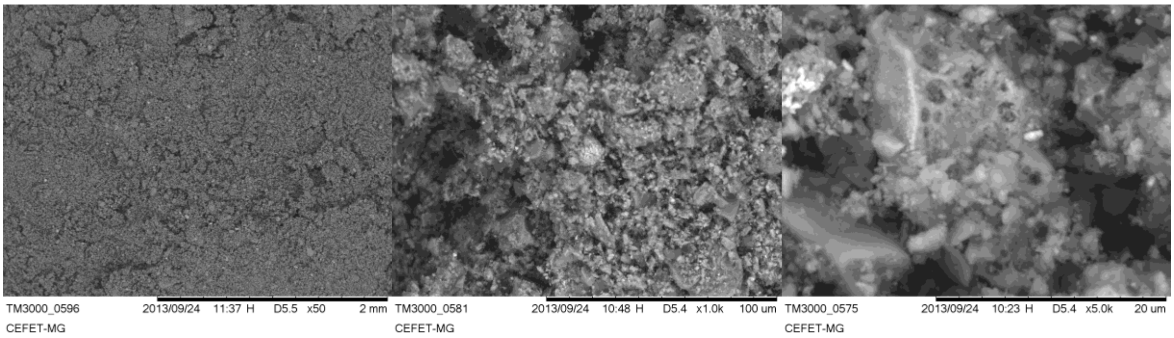
Figure 3 shows images of the SCBA re-burned and before grinding (SCBA R) magnified 50 (a), 1,000 (b), and 2,000 (c) times. While some residual SCBA fibres can still be observed in Figure 3(a), equidimensional particles with a spherical form are visible in Figure 3(b) and (c).



(a) (b) (c)

Figure 3: Images of re-burned sugar cane bagasse ashes before grinding.

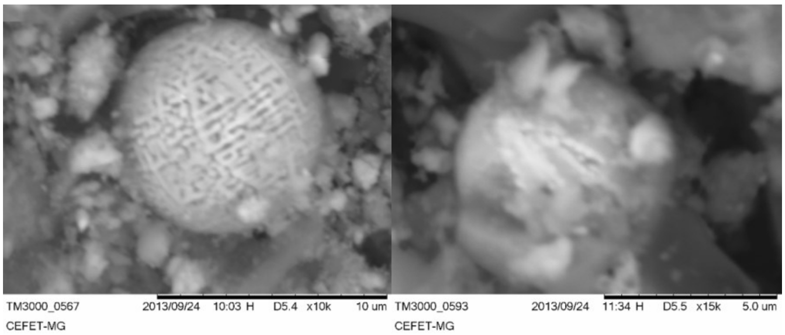
Images of the SCBA RG magnified 50 (a), 1,000 (b), and 5,000 (c) times are shown in Figure 4. The image in Figure 4(a) denotes a significantly more homogenous SCBA, from a granulometrical and morphological point of view, whereas in Figure 4(b) and (c), one can observe equidimensional particles exhibiting sharper edges and some degree of heterogeneity in the granulometry. However, unlike the SCBA R, the SCBA RG presented a very homogenous particle shape. Comparing the images of the SCBA in natura with images of SBCA RG, it is observed that the ash apparently became more homogeneous and decreased in particle size.



(a) (b) (c)

Figure 4: Images of re-burned and ground sugar cane bagasse ashes (SCBA RG).

Figure 5 shows images of the SCBA RG magnified 10,000 and 15,000 times, highlighting that the SCBA RG consisted of particles of a spherical shape with sizes smaller than 10 μm. Oertel et al. showed that amorphous silica have spherical primary particles [29]. Thus, it is believed that the spherical particles found in the SCBA are composed of silica in an amorphous form.



(a) (b)

Figure 5: Images of re-burned and ground sugar cane bagasse ashes magnified 10,000 and 15,000 times

The diffractogram of the SCBA RG is presented in Figure 6. The peaks can be associated with the crystalline phases of silicon dioxide. Previous results have also demonstrated the presence of quartz [30]: for instance, Cordeiro et al. [31] found quartz and cristobalite in SCBA. Table 5 presents the chemical composition of the SCBA RG in terms of the main oxides identified by XRF. The main oxide present in the ash was SiO_2, followed by Al_2O_3 and Fe_2O_3, in agreement with previous results [30, 31]. The cumulative amount of these three oxides is 80.26%. It is worth noting that the SiO_2 found by the XRD technique is necessarily in crystalline form, and as showed by XRF, it can present crystalline or amorphous.

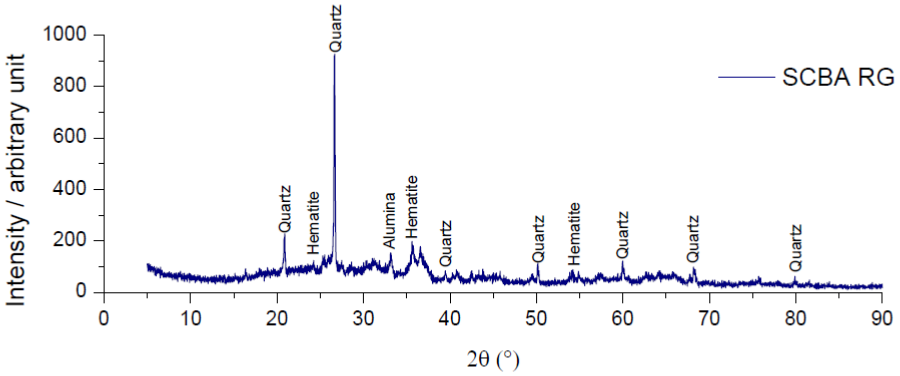


Figure 6: X-ray diffractogram (XRD) of re-burned and ground sugar cane bagasse ashes.

Table 5: Chemical composition (%) of sugar cane bagasse ash (SCBA) determined by X-ray fluorescence (XRF).

Material	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	TiO_2	P_2O_5	Na_2O	K_2O	MnO	LOI
SCBA	40.47	24.76	15.03	3.82	2.34	4.38	1.64	0.43	3.71	0.11	3.29

The results of SCBA pozzolanic activity are shown in Table 6. The Brazilian normalization [10] indicates that for a material to be considered pozzolanic, a sample with a partial cement replacement by the study material should have at least 75% of the sample resistance of one in which nothing was replaced. Thus, the SCBA analysed can be considered to be pozzolanic once, with a mean compressive strength of 38.17 MPa, it reaches 88.6% of the average resistance found for samples prepared without the use of ash (average strength of 43.08 MPa). The Modified Chapelle test according to NBR 15895 [11] for SCBA indicates that for the average results of two analyses to be equal to 382 mg/g of calcium hydroxide fixing and have pozzolanic activity, the sample must be fixed with at least 330 mg of calcium hydroxide [32].

Table 6: Pozzolanic activity with Portland cement according to NBR 5752 [10].

	Flow (mm)	Water (g)	Compressive strength (MPa)	Pozzolanic activity (%)
Mortar A (Portland cement)	225.0	162.7	43.08	88.6
Mortar B (SCBA 35%)	225.0	179.4	38.17	

The setting times of the cement are presented in Table 7. Partial substitution of the cement by the SCBA RG did not affect the setting cement. The flow table, specific mass, and water absorption results of the mortars are presented in Table 8. Partial substitution of the cement with the SCBA RG led to a reduced workability of the mortars, as measured by the flow table tests. The table also shows that the specific mass was slightly increased and the water absorption slightly reduced (above 20%), despite the slightly reduced workability, which would hinder the densification of the specimens. Due to the smaller particle size, the SBCA requires a greater amount of water for the same workability. The inclusion of SCBA in mortar mixes increased both yield stress and viscosity, which caused a lower percentage of fluidity [33]. The results for the water absorption of the mortars indicate a possible decrease in open porosity. The increase in specific mass may be given due to the formation of microstructural phases denser or reduction of closed porosity, or refinement of open pores.

Table 7: Setting times of cement.

Addition	Substitution (%)	Setting times cement (min)	
		Start	End
Reference	0	142	191
SCBA RG	10	141	188
	20	143	191
	30	143	190

Table 8: Flow, specific mass and water absorption of mortars.

Addition	Substitution (%)	Flow (mm)	Specific Mass (g/cm^3)			Water Absorption (%)			
			Unit	Average	Standard deviation	Unit	Average	Standard deviation	Coefficient of variation
Reference	0	172.5	2.169	2.168	0.003	6.68	6.65	0.08	1.14
			2.169			6.56			
			2.164			6.70			
SCBA RG	10	166.5	2.164	2.169	0.010	7.05	6.79	0.47	6.93
			2.162			7.08			
			2.181			6.25			
	20	166.5	2.162	2.171	0.008	6.54	6.24	0.28	4.43
			2.176			6.00			
			2.175			6.17			
	30	166.0	2.177	2.178	0.006	6.15	6.10	0.14	2.23
			2.173			6.21			
			2.184			5.95			

Table9 and Figure 7 shows the results of the mortars prepared from mixtures with high early strength Portland cement substituted by 0, 10, 20, and 30% SCBA RG. Comparing the results obtained for the mortars with and without the substitution of Portland cement with SCBA RG, it is possible to observe that at an age of 3 days the compressive strength was reduced with an increasing substitution percentage, with reduction of up to 14%. Whereas at ages of 7, 28, and 91 days, the results from the different mortars became more similar to each other, with increase of up to 6.5%. Cordeiro et al. [8] evaluated the pozzolanic activity of SCBA as established from a comparison with an insoluble material at the same packing density. In that case, a different behaviour was verified in relation to the compressive strength of mortars produced with the mineral admixtures SCBA and quartz. After 28 days of curing, the compressive strength of the SCBA mortar was 31% higher than the strength of the mixture with quartz. Given that the quartz studied by Cordeiro et al. [8] has only a filler effect and that the SBCA studied in this work had an approximately equal compressive strength as the cement mortar, it is believed that the pozzolanic activity it was significant, other than the filler effect. It is believed that the same occurs with the mortars of this work, once the pozzolanic reaction is slower than the reaction of Portland cement.

Table 9: Compressive strength of mixtures.

Mortar	Substitution (%)	Age (days)	Compressive strength (MPa)					Average (MPa)	Standard deviation (MPa)	Variance (%)	Percentage of control (%)
			Specimen 1	Specimen 2	Specimen 3	Specimen 4	Specimen 5				
Control mortar (Reference)	0	3	33,16	33,30	33,47	34,64	34,86	33,89	0,80	0,64	100,00
		7	35,21	36,42	37,48	37,48	37,92	36,90	1,10	1,20	100,00
		28	40,73	41,21	41,51	44,40	44,88	42,55	1,94	3,76	100,00
		91	50,51	50,92	51,36	53,17	54,90	52,17	1,83	3,36	100,00
Mortar with SCBA RG	10	3	33,78	33,88	35,44	36,27	36,60	35,19	1,32	1,73	103,86
		7	35,35	35,80	36,10	36,79	36,99	36,21	0,68	0,47	98,11
		28	41,67	42,40	42,77	43,15	43,79	42,76	0,80	0,63	100,49
		91	42,52	44,7	45,29	46,18	46,21	44,98	1,51	2,29	86,21
	20	3	30,13	30,62	30,66	30,89	31,27	30,71	0,42	0,17	90,64
		7	34,91	35,94	37,67	38,13	38,85	37,10	1,63	2,65	100,54
		28	42,94	43,26	45,31	47,26	47,78	45,31	2,22	4,93	106,50
		91	46,22	46,42	47,88	48,56	50,12	47,84	1,61	2,59	91,70
	30	3	27,91	27,92	29,47	29,52	29,87	28,94	0,95	0,90	85,40
		7	34,95	36,50	37,06	36,71	37,91	36,63	1,08	1,17	99,25
		28	39,60*	42,06	44,57	44,85	45,25	44,18	1,44	2,08	103,85
		91	45,15*	48,41	48,42	48,62	51,48	49,23	1,50	2,25	94,37

* values are eliminated by more than 6% of the average.

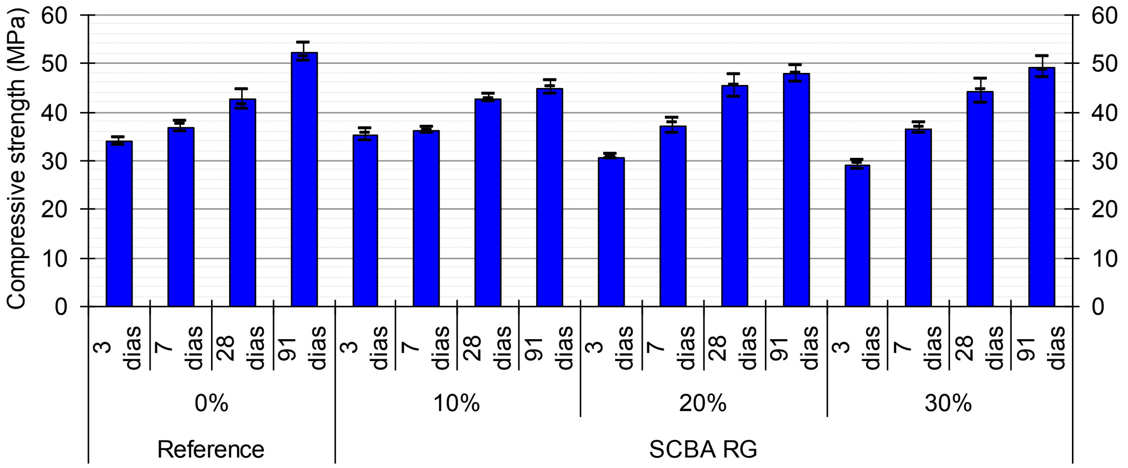


Figure 7: Compressive strength of mixtures.

Analyzing the Tables 9 and 10 it can be seen that the compressive strength results for the age of 3 days were considered statistically different, with the replacement of 10% presented the results averaged 3.86% higher and substitution of 20 and 30% They presented the results averaged 9:36 and 14.60% lower than the reference mortar (0% substitution), respectively. To the age of 7 and 28 days, the compressive strength results were considered statistically equivalent, it indicates that even the replacement of 30% of Portland cement with SCBA RG did not influence the results, and this substitution represents savings of 30% of Portland cement and embedding the same amount of a residue without loss of compression resistance of the mixture. It is believed that based on the mechanical behavior of mortar is possible to use sugar bagasse ash for the manufacture of Portland cement. It is worth noting that the compressive strength results presented by mortars with cement replacement by SCBA RG 28 days were higher than the control mortar in all percentages. The compressive strength results for the age of 91 days were considered statistically different and despite mortars with substitutions 10, 20 and 30% present reductions of 13.79, 08.30 and 5.63 in relation to reference mortar, respectively, all the mortars had compressive strength gain compared to the results achieved at 28 days, but the gains presented for the reference mortar was higher. While the mortar with 10, 20 and 30% SCBA showed compression strength increase of 5, 6 and 11%, respectively, the reference mortar showed a resistance gain at 23% compression, higher compressive strength gain between ages presented by mortars in all ages.

Table 10: Statistical analysis of the results of compressive strength.

Age	Source of variation	SQ	gl	MQ	F	P value	critical F	Evaluation
3 days	Between groups	123,2716	3	41,09053	47,78579	3,29E-08	3,238872	Statistically different
7 days	Between groups	2,250135	3	0,750045	0,5474	0,657011	3,238872	Statistically similar
28 days	Between groups	24,9923	3	8,330765	2,870387	0,07135	3,287382	Statistically similar
91 days	Between groups	133,6861	3	44,56205	16,82503	4,59E-05	3,287382	Statistically different

To analyse the measured compressive strength resistance, it was compared to the cement consumption by MPa of the compressive strength at 28th days. The data are presented in Table 11. Table 11 was considered as binder: (i) Portland cement; (ii) Portland cement with 10% substitution of high early strength Portland cement with SCBA RG; (iii) Portland cement with 20% substitution of high early strength Portland cement with SCBA RG; and (iv) Portland cement with 30% substitution of high early strength Portland cement with SCBA RG. It can be observed that the consumption of the Portland cement per cubic meter of composite was reduced with an increasing addition of ashes. Correlating the results of the compressive strength at 28 days and the consumption of cement per cubic meter, it can be noticed that the cement consumption per cubic meter of composite divided by the compressive strength in MPa was reduced with the addition of ash. Similarly, the cement consumption was reduced by 10% without losing the compressive strength. It is believed that the better performance shown by the sample with 20% SCBA RG substitution is related to the optimal content of $SiO_2 + Al_2O_3 + Fe_2O$ in the hydration reactions (Pozzolanic activity) and to the achievement of a better packing factor, through the filler effect. It is worth noting that the amount of water added in all mortars was the same. Due to the reduction of Portland cement, the water / Portland cement has changed significantly. Still, the mechanical behavior of mortars remained satisfactory. The ratio between water and Portland cement replacement with the SCBA (in volume) remained constant.

Table 11: Comparison between the cement consumption-agglomerate by MPa of acquired compressive strength at the 28th day, obtained from mixtures.

Mixture	Substitution (%)	Consumption (Kg/m^3)			Water/ binder in mass	Water/binder in volume	fc28 (MPa)	Consumption (Kg/MPa)	
		Cement	Addition	Water				Cement	Binder
Reference	0%	513.8	0.0	247.0	0.481	1.493	42.55	12.08	12.08
SCBA RG	10%	462.4	43.9	247.0	0.488	1.493	42.76	10.81	11.84
	20%	411.0	87.8	247.0	0.495	1.493	45.31	9.07	11.01
	30%	359.6	131.6	247.0	0.503	1.493	44.18	8.14	11.12

Figure 8 shows the flexural strength results for mortars with 0, 10, 20, and 30% substitution of high early strength Portland cement with SCBA RG. The mortars with 20 and 30% substitution presented substantially greater traction resistance compared to the control sample, with increase of up to 16%. Whereas the mortar with 10% substitution presented flexural strength equivalent to the control sample. The results of the flexural strength were statistically different between the mortar, which indicates that the SCBA RG positively influenced this property.

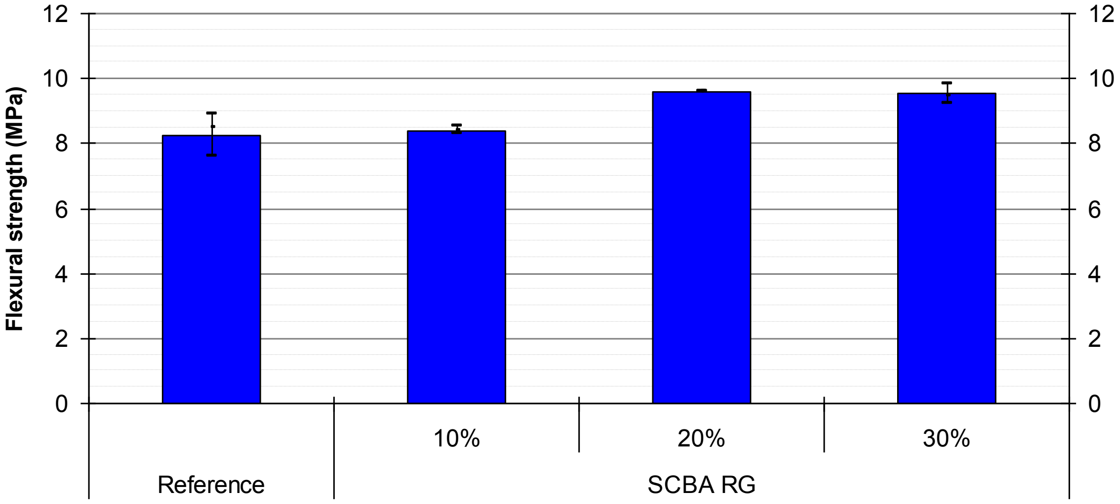


Figure 8: Flexural strength of mixtures

4. DISCUSSION AND RESULTS

The SEM shows SBCA with particles in a spherical form, indicating the presence of a non-crystalline structure. The composition results of the SCBA RG obtained by XRF corroborated the results of the XRD. Evaluating the results of the particle size of SCBA RG, it is perceived that the presented size of particles smaller than those of the Portland cement used has met the parameters of ASTM C618 [28]. The smaller particles may have significantly contributed to the increased reactivity of the SCBA RG, mainly due to the increased surface area caused by the reduction in particle size. This analysis confirms the results of compressive and flexural strength.

Some studies have noted that reducing the particle size of additions may improve the filling effect and compactness (filler effect) of cementitious composite (mortars and concretes). The filler effect fills voids of the cement paste that contribute significantly to increased resistance to compressive stresses, but the filler effect does not contribute significantly to the flexural strength of mortars and concretes. For the filling of pores by the filer effect directly impacts the compressive strength by reducing the porosity, but as there is no significant reactivity in the materials that work only as a filler, there is formation of new chemical bonds and or new constituents significantly to adhere the particles. As the compressive strength gain of mortars SCBA did not exceed 6.5% and the gain in flexural strength reached 16%, more than double the gain (150% higher), it is believed that with the addition was SBCA of forming new chemical bonds between particles and the formation of new or more adhesive components together. Thus, it is believed in clear pozzolanic reaction SCBA, since the pozzolanic reaction is characterized by calcium hydroxide reaction released in the cement hydration reaction of Portland and oxide silicon on non-crystalline form, and others (SiO_2 + Al_2O_3+Fe_2O) present in the pozzolan.

An analysis of the specific mass showed that the results were superior, and the results of water absorption were lower with the addition of the SCBA RG. These results correlated with better performance in the compressive and flexural strength of the mixtures with the addition of the SCBA RG, which was not only due to the effect of filler action but is believed to also be due the pozzolanic effect because the compressive and flexural strength has increased. The positive influence of the burning of sugarcane bagasse ash is confirmed in the literature [34].

5. CONCLUSIONS

Re-burning followed by grinding resulted in an apparently more homogenous morphology of the ash (SCBA RG) and reduced its granulometry. However, the re-burning process reduced loss on ignition and significantly increased the specific mass of the material (Table 1). The flexural strength tests of mortars substituted with 20 and 30% SCBA RG showed values superior to 0% (reference); as this test is intimately related to the attraction/bonding between particles, confirmed the pozzolanic activity of ash. From a mechanical point of view, the results evidenced the viability of the substitution of Portland cement at percentages of 10, 20, and 30%. Blends with 20 and 30% have water absorption lower than the reference mortar, indicating a lower open porosity to water, which is one of the factors for increased durability. The mortar with 10% SCBA RG presented approximate water absorption of the reference mortar. The mortar with 20 and 30% substitution showed slightly higher values of specific mass. It is believed that the increase in specific mass may be given due to the reduction of closed porosity or refinement of open pores, in both cases it leads to an increase of mechanical properties. The change in microstructure may also increase the specific mass, in some cases microstructure change can lead to increased mechanical strength. The workability of the mortar obtained through the flow was affected by the replacement of Portland cement by SCBA RG. However, the use of Portland cement significantly reduced without loss of mechanical strength. In this context, this study concludes that the partial replacement (by volume) of Portland cement with sugarcane bagasse ash thermally processed is possible. It is valid to point out that the cliquer reduction for the production of Portland cement or reduction of Portland cement for the production of mortar and concrete contributes to the reduction of CO_2 emissions and the carbon footprint in the construction industry.

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7. BIBLIOGRAPHY

[1] SINDICATO NACIONAL DA INDÚSTRIA DO CIMENTO, http://www.snic.org.br/numeros_dinamico.asp, accessed on January 2014.

[2] ISAIA G. C., GASTALDINI A. L. G., MORAES R., “Physical and pozzolanic action of mineral additions on the mechanical strength of high performance concrete”, *Cement and Concrete Composites*, v. 25, pp. 69-76, 2003.

[3] CORDEIRO G. C., *Use of ultrafine ash from sugarcane bagasse and rice husk as mineral additives in concrete*, Thesis of D.Sc., COPPE/UFRJ, Rio de Janeiro, RJ, Brazil, 2006.

[4] FEDERAÇÃO DAS INDÚSTRIAS DO ESTADO DE SÃO PAULO. “Energy supply expansion from biomass (bagasse from cane sugar)”, In: *Centro das Indústrias do Estado de São Paulo*, FIESP/CIESP, 2001. (In Portuguese)

[5] PAULA M. O., *Potential of sugarcane bagasse ash as a partial replacement of Portland cement material*, Dissertation of M.Sc., Universidade Federal de Viçosa, Viçosa, MG, Brazil, 2006.

[6] GANESAN, K., RAJAGOPAL, K.,THANGAVEL, K., “Evaluation of bagasse ash as supplementary cementitious material”, *Cement and Concrete Composites*, v. 29, pp. 515-524, 2007.

[7] RIBEIRO D. V., MORELLI M. R. “Effect of Calcination Temperature on the Pozzolanic Activity of Brazilian Sugar Cane Bagasse Ash (SCBA)”, *Materials Research*, v. 17, pp. 974-981, 2014.

[8] CORDEIRO G. C., FILHO R. D. T., TAVARES L. M., *et al*., “Pozzolanic activity and filler effect of sugar cane bagasse ash in Portland cement and lime mortars”, *Cement and Concrete Composites*, v. 30, pp. 410-418, 2008.

[9] CORDEIRO G. C., FILHO R. D. T., FAIRBAIRN E. M. R., “Effect of calcination temperature on the pozzolanic activity of sugar cane bagasse ash”, *Construction and Building Materials*, v. 23, pp. 3301-3303, 2009.

[10] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS (2012). Materiais pozolânicos – Determinação da atividade pozolânica com cimento Portland: NBR 5752. Rio de Janeiro

[11] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS (2010). Materiais pozolânicos - Determinação do teor de hidróxido de cálcio fixado - Método Chapelle modificado: NBR 15895. Rio de Janeiro

[12] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS (2003). Cimento Portland - Determinação do tempo de pega: NBR NM 65. Rio de Janeiro.

[13] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS (2000). Cimento portland e outros materiais em pó - Determinação da massa específica. NBR NM 23. Rio de Janeiro.

[14] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS (2012). Cimento Portland - Análise química - Determinação da perda ao fogo: NM 18. Rio de Janeiro

[15] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS (1996). Cimento Portland – Determinação da resistência à compressão – Método de ensaio: NBR 7215. Rio de Janeiro.

[16] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS (2005). Argamassa para assentamento e revestimento de paredes e tetos - Determinação da resistência à tração na flexão e à compressão NBR13279. Rio de Janeiro

[17] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS (2009). Argamassa e concretos endurecidos - Determinação da absorção de água, índice de vazios e massa específica: NBR 9778. Rio de Janeiro

[18] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS (1991). Cimento Portland de alta resistência inicial: NBR 5733. Rio de Janeiro

[19] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS (2012). Cimento Portland - Análise química - Determinação de resíduos insolúveis: NM 15. Rio de Janeiro

[20] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS (2012). Cimento Portland - Análise química - Método para determinação de dióxido de silício, óxido de alumínio, oxido de ferro, oxido de cálcio e oxido de magnésio: NM 21. Rio de Janeiro

[21] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS (2012). Cimento Portland - Análise química - Determinação de Trióxido de enxofre: NM 16. Rio de Janeiro

[22] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS (2012). Cimento Portland e seus materiais constituintes - Determinação de dióxido de carbono por gasometria: NM 20. Rio de Janeiro

[23] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS (1997). Cimento Portland - Determinação da finura pelo método de permeabilidade ao ar (Método Blaine): NM 76. Rio de Janeiro

[24] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS (2013). Cimento Portland — Determinação do índice de finura por meio da peneira 75 µm (nº 200): NBR11579. Rio de Janeiro

[25] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS (1985). Cimento portland e outros materiais em pó - Determinação da finura por meio da peneira 0,044 mm (n° 325): NBR 9202. Rio de Janeiro

[26] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS (2003). Cimento portland - Determinação da pasta de consistência normal: NM 43. Rio de Janeiro

[27] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS (2016). Cimento Portland - Determinação da expansibilidade Le Chatelier: NBR 11582. Rio de Janeiro

[28] ASTM C618-12a (2012) Standard specification for coal fly ash and raw or calcined natural pozzolan for use in concrete.

[29] OERTEL T., HUTTER F., HELBIG U., *et al.*, "Amorphous silica in ultra-high performance concrete: First hour of hydration", *Cement and Concrete Research*, v. 58, April 2014, Pages 131-142

[30] SOARES M. M. N. S., POGGIALI F. S. J., BEZERRA A. C. S., *et al.*, "The effect of calcination conditions on the physical and chemical characteristics of sugar cane bagasse ash", *Rem: Revista Escola de Minas*, v. 67, pp 33-39, 2014.

[31] CORDEIRO G. C., TOLEDO FILHO R. D., TAVARES L. M., *et al.*, "Ultrafine grinding of sugar cane bagasse ash for application as pozzolanic admixture in concrete", *Cement Concrete Research*, v. 39, pp. 110-115, 2009.

[32] RAVERDY, M., BRIVOT, F., PAILLÈRE, A. M., *et al.*, "Appréciation de l'activité pouzzolanique des constituants secondaires", In: 7e. Congrés International de la Chimie des Ciments, v. III, n. 36, Paris.1980.

[33] JIMÉNEZ-QUERO V. G., LEÓN-MARTÍNEZ F. M., MONTES-GARCÍA P., *et al.*, "Influence of sugar-cane bagasse ash and fly ash on the rheological behavior of cement pastes and mortars", *Construction and Building Materials*, v. 40, pp. 691-701, 2013.

[34] FERREIRA, R. T. L., NUNES, F. M. M. P., BEZERRA, A. C. S. *et al.*, "Influence of Reburning on the Pozolanicity of Sugar-Cane Bagasse Ashes with Different Characteristics", *Materials Science Forum* (Online), v. 869, p. 141-146, 2016