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On the influence of sugarcane bagasse ashes as a partial replacement of cement in compressive strength of mortars

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ABSTRACT

This paper presents an experimental program objectifying at investigating the potential of the use of sugarcane bagasse ash as a partial replacement of cement in the production of mortars. Sugarcane bagasse ashes from two origins were studied - one from sugarcane industry directly and other from pizzerias that uses this material replacing the wood in their ovens. The methodology followed the characterization of the material, where it was carried out through laboratory tests using X-ray diffraction (XRD) and X-ray fluorescence (WDXRF) and initial tests for the ideal quantification of cement substitution by residues. Results obtained indicated that both residues exhibited pozolanic features presenting about 60% of amorphous material in their composition and compressive strength tests at different ages showed satisfactory results. Concluding that residues played an important role in increasing short and long term compressive strengths.

Keywords: sugarcane bagasse ashes; compressive strength of mortars; replacement of cement.

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A influência das cinzas de bagaço de cana-de-açúcar como substituição parcial do cimento na resistência à compressão de argamassa

RESUMO

O artigo apresenta um programa experimental, objetivando investigar o potencial do uso das cinzas de bagaço de cana-de-açúcar como uma substituição parcial do cimento na produção de argamassas. As cinzas do bagaço de cana-de-açúcar de duas origens foram estudadas: uma oriunda diretamente da indústria de cana-de-açúcar e outra de pizzarias que utilizam este material em substituição a madeira em seus fornos. A metodologia seguiu com a caracterização do material, onde foi realizado através de testes de laboratório utilizando a difração de raios X (XRD) e a fluorescência de raios X (WDXRF) e testes iniciais para a quantificação ideal de substituição do cimento pelos resíduos. Os resultados obtidos indicaram que ambos os resíduos exibiram características pozolanas apresentando cerca de 60% de material amorfo na sua composição e testes de resistência compressiva em diferentes idades mostraram resultados satisfatórios. Concluindo que os resíduos desempenharam um papel importante no incremento das resistências à compressão a curto e de longo prazo.

Palavras-chave: cinza de bagaço de cana-de-açúcar; compressão de argamassa; substituição de cimento.

La influencia de las cenizas de bagazo de caña de azúcar como reemplazo parcial del cemento en la resistencia a la compresión de los morteros

RESUMEN

El artículo presenta un programa experimental, con el objetivo de investigar el potencial del uso de las cenizas de orujo de caña de azúcar como una sustitución parcial del cemento en la producción de morteros. Las cenizas del bagazo de caña de azúcar de dos orígenes fueron estudiadas: una oriunda directamente de la industria de caña de azúcar y otra de pizzerías que utilizan este material en sustitución de la madera en sus hornos. La metodología siguió con la caracterización del material, donde fue realizado a través de pruebas de laboratorio utilizando la difracción de rayos X (XRD) y la fluorescencia de rayos X (WDXRF) y pruebas iniciales para la cuantificación ideal de sustitución del cemento por los residuos. Los resultados obtenidos indicaron que ambos residuos exhibieron características de pozolanicidad presentando cerca del 60% de material amorfo en su composición y pruebas de resistencia compresiva en diferentes edades mostraron resultados satisfactorios. Concluyendo que los residuos desempeñaron un papel importante en el incremento de las resistencias a la compresión a corto y largo plazo.

Palabras clave: cenizas de bagazo de caña de azúcar; resistencia a la compresión de morteros; reemplazo de cemento.

1. INTRODUCCIÓN

Brazil is the most producer of sugarcane in the world and this commodity plays an important role in the country economy, especially in its northeastern region. This industrial sector is responsible for generating about 3.6 million direct and indirect jobs, besides being economically significant for the country in national and international trade relations, which account for 2.4% of gross domestic product (ALBINO et al, 2015).

These numbers shows the importance of the sector for the country economy and enhances the need for further research to enable rational use of the generated residue.

The most attractive waste from sugarcane industry is its bagasse, which can be used in several manners. One of these ways is the electric energy co-generation, a process that involves burning the bagasse at high temperatures that produces a significant amount of waste often referred as sugarcane bagasse ash. This type of ash is also generated in pizzerias that uses this material as a replacement of wood in their ovens. Recent researches indicates that the major chemical component of such ashes is the SiO_2 that exhibits great potential to be used as a mineral addition in concrete or mortars as pozzolanic aims.
The use of pozzolanic materials as a partial replacement of cement in mortar and concrete presents several advantages and the most important one is related with the reduction of CO_2 emissions because their obtention demands less energy than those involved in the clinker process.
Furthermore, researches regarding the production of mortar and concrete using sugarcane bagasse ashes residues as supplementary cementitious materials (SCM) has already proved to be an efficient procedure with no loss of compressive strengths of tested specimens.
In this context, the paper discusses about the possibilities of using sugarcane bagasse ash (SCBA) from pizzeria as a partial cement replacement of Portland cement to produce mortars used in several applications in building industry.

2. EXPERIMENTAL PROGRAM

2.1 Materials
High initial strength Portland cement (Brazilian standard CPV ARI - similar to type III of ASTM), with a specific mass of 3.17 g/cm3 and specific surface of 8924 cm^2/g was used according to NBR NM 16372 (2015) and ASTM C231 / C231M - 17ª (2003).
Two types of sugarcane bagasse were used: one from a sugarcane industry (SCGA-Ind) and other from a pizzeria that uses this material in replacement of wood in its oven (SCGA-Piz). The ash temperatures of the sugarcane bagasse are 400 ºC for the ash collected in the pizzeria and 500 ºC collected in the industry, respectively. According to Ribeiro (2012) and Cordeiro (2009), the best burning sugarcane bagasse burning temperature is the burning at 600 ºC, under controlled burning. It is worth mentioning that the ashes collected remained in natura, without any type of thermal treatment.
The SCBA-Ind was collected from a sugar and alcohol producer located in the state of Pernambuco in the northeast of Brazil and the SCBA-Piz was collected in a pizzeria in metropolitan region of Recife capital of the state of Pernambuco that uses pressed ashes blocks in replacement of wood in its ovens. Samples of ashes used in the research were dried by means of sieving process for 20 minutes at a speed of 70 rpm to obtain a fraction passing through the sieve opening 0.075 mm.
Both pulverized ashes specific mass and specific surface are: 2.37 g/cm^3 and 6539 cm^2/g for SCGA-Ind and 2.72 g/cm^3 and 6550 cm2/g for SCGA-Piz according NBR to NM 23 (2001) and ASTM D1298 - 12b (2017).
Tests used to assess the pozzolanic activity showed potential for both type of SCBA studied to be applied as pozzolanic admixture. The values obtained were also found by Nunes (2009), Cordeiro (2009) and Frias (2007). The chemical composition of bagasse ashes and Portland Cement used is presented in Table 1 and their and the crystallography in the diffractogram are shown in Figure 1 and Figure 2. These characteristic values with peaks at angles of 26.5º degrees SiO_2 were described by Ribeiro (2014). Both type of ashes are mainly composed by amorphous material according (BERENGUER, R.A; SILVA F.A.N. et.al. 2016).

Table 1. Chemical composition of studied ashes

Chemical element	Portland Cement	SCBA-Piz	SCBA-Ind
SiO_2	18.30 %	63.61 %	84.86%
CaO	63.40%	7.18%	2.96%
MgO	0.62%	6.85%	2.54%
Fe_2O_3	3.31%	6.63%	3.83%
SO_3	3.32%	4.43%	0.38%
K_2O	0.78%	4.03%	1.38%
Al_2O_3	4,01%	2.51%	1.91%
Cl	0.12%	1.81%	-
Na_2O	0.24%	1.04%	0.47%
P_2O_5	0.38%	0.87%	0.38%
TiO_2	0.21%	0.62%	0.75%
ZrO_2	-	0.14%	0.12%
MnO	0.08%	0.12%	0.19%
Cr_2O_3	0.02%	0.06%	0.05%
SrO	0.32%	0.05%	0.03%
ZnO	0.01%	0.04%	0.03%
Rb_2O	-	0.02%	0.015%

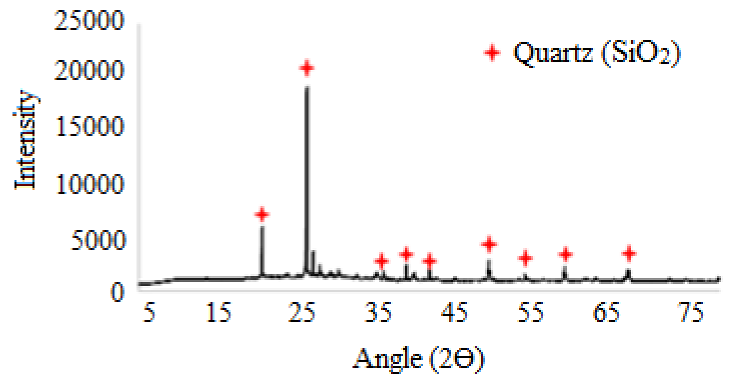

Figure 1. SCBA-Piz - XRD results. Font: Author (2016).

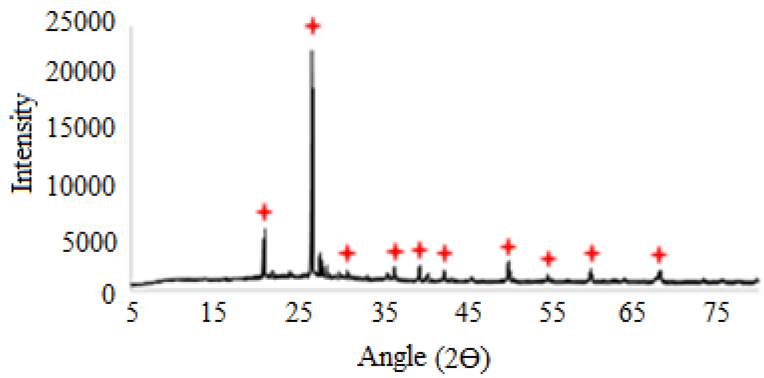

Figure 2. SCBA-Ind - XRD results. Font: Author (2016).

2.2 Mix designs

To find out the optimum amount of replacement of cement by both studied ashes six mixtures were produced: reference (REF), SCBA from pizzeria (SCBA-Piz-5%, SCBA-Piz-10%, SCBA-Piz-15%, SCBA-Piz-20%, SCBA-Piz-25% and SCBA-Piz-30%) and SCBA from sugarcane industry (SCBA-Ind-5%, SCBA-Ind-10%, SCBA-Ind-15%, SCBA-Ind-20%, SCBA-Ind-25% and SCBA-Ind-30%).

For each amount of substitution, six specimen were prepared to evaluate their compressive strengths after 28 days. Table 2 summarizes data of mortar mixtures used.

Table 2. Mortar mixtures used

SCBA (%)	Cement (kg)	Sand (kg)	Water (ml)	SCBA (g)
0	624,00	1.872	300	-
5	592,80	1.872	300	31,2
10	561,60	1.872	300	62,4
15	530,40	1.872	300	93,6
20	499,20	1.872	300	124,80
25	468,00	1.872	300	156,00
30	436,80	1.872	300	187,20

3. RESULTS AND DISCUSSION

Table 3 and Table 4 present results of compressive strengths performed in mortar-cylindrical specimens with dimensions of 50 mm in diameter and 100 mm in length in accordance to NBR 5739 (2007) and ASTM E9-89 00 (2000).

Table 3. Compressive strengths – SCBA from pizzeria

ID	REF	SCBA-Piz (5%)	SCBA-Piz (10%)	SCBA-Piz (15%)	SCBA-Piz (20%)	SCBA-Piz (25%)	SCBA-Piz (30%)
1	20,3	23,0	18,4	29,7	14,7	22,0	14,2
2	30,7	27,7	19,2	29,9	23,2	23,2	19,6
3	31,3	22,4	20,6	31,2	24,7	23,5	22,7
4	31,6	32,0	21,8	31,4	26,4	24,7	23,5
5	32,2	34,1	22,1	33,2	27,2	27,8	24,0
6	32,4	35,5	30,1	35,4	31,7	28,8	25,4
Average	**29,8**	**29,1**	**22,0**	**31,8**	**24,7**	**25,0**	**21,6**
SD (MPa)	**4,7**	**5,6**	**4,2**	**2,2**	**5,7**	**2,7**	**4,1**
COV (%)	**15,7**	**19,3**	**19,1**	**6,8**	**23,0**	**10,9**	**19,0**

Table 4. Compressive strengths – SCBA from sugarcane industry

ID	REF	SCBA-Ind (5%)	SCBA-Ind (10%)	SCBA-Ind (15%)	SCBA-Ind (20%)	SCBA-Ind (25%)	SCBA-Ind (30%)
1	20,3	14,8	24,9	34,8	26,9	25,7	22,5
2	30,7	28,8	25,4	35,1	28,6	26,0	23,0
3	31,3	29,3	29,1	35,5	29,0	26,8	23,5
4	31,6	36,6	37,0	35,8	29,7	26,9	24,7
5	32,2	38,4	37,5	36,1	30,5	27,1	24,9
6	32,4	39,5	38,9	36,3	30,7	27,4	25,3
Average	**29,8**	**31,2**	**32,1**	**35,6**	**29,2**	**26,7**	**24,0**
SD (MPa)	**4,7**	**9,2**	**6,4**	**0,6**	**1,4**	**0,7**	**1,1**
COV (%)	**15,7**	**29,6**	**19,9**	**1,6**	**4,8**	**2,5**	**4,8**

Finally, taken into account data from Table 3 and Table 4, the sugarcane bagasse ash from industry showed a better behavior with a very low coefficient of variation – 1.6%. More than 15% replacement caused a decreasing in compressive strengths of the mortars studied.
After choosing the optimum amount of replacement of cement by sugarcane bagasse ashes, new test specimens were produced in order to investigate compressive strengths at ages of 28, 63 and 91 days. Reference mortar mixture was designed to exhibit an average compressive strength of 40 MPa at 28 days.
Average compressive strengths and dispersion measurements are presented in Table 5.

Table 5. Average compressive strengths result and dispersion measurements

Mixture	Age (days)	Average compressive strengths (MPa)	Standard Deviation (MPa)	Coefficient of variation (%)
Reference	28	40,110	1,402	3,496
	63	41,699	1,919	4,603
	91	43,829	1,716	3,914
SCBA-Piz-15%	28	40,126	1,804	4,496
	63	42,678	1,820	4,265
	91	44,128	0,612	1,405
SCBA-Ind-15%	28	39,686	0,853	2,150
	63	41,179	1,446	3,511
	91	43,201	0,869	2,012

The statistical parameters and coefficients of variation obtained confirm that there is a consistent increase in the average strength with age for all mixtures studied. The coefficients of variations were all below 5% in all cases and this fact highlight the excellent control procedures of the preparation, molding and testing of specimens.
Results obtained showed that mortars made with replacement of cement mass by ashes from pizzeria and from sugarcane industry exhibited a good performance in terms of average compressive in all ages studied. This is specially important when one consider that mortar mixes made with ashes had a cement content lesser than those made using only cement as an agglomerating agent. This means that both ashes studied played a role as binder and as pozzolanic material. In fact, the increase in compressive strength at 91 days was approximately

8% for the mortars made with sugarcane bagasse ashes while for the mortar without replacement the increase was only 5%, at the same age.
These results encourage the use of sugarcane bagasse ashes as cement replacement in several applications in civil engineering field with the added advantage of producing two important and beneficial side effects: (a) reduction of environmental impact of the disposal of this agroindustrial waste in nature and (b) decrease in cement consumption with consequent significant reduction of CO_2 emissions per ton of cementitious materials.
In order to assess tensile strengths of the mortar studied, splitting tensile tests were performed at the same ages of the compressive tests and the results are summarized in Table 6.

Table 6. Average tensile strengths results and dispersion measurements

Mixture	Age (days)	Average tensile strengths (MPa)	Standard Deviation (MPa)	Coefficient of variation (%)
Reference	28	4,460	0,885	19,85
	63	4,082	0,103	2,52
	91	4,400	0,228	5,18
SCBA-Piz-15%	28	4,346	0,342	7,86
	63	4,034	0,083	2,06
	91	4,421	0,126	3,86
SCBA-Ind-15%	28	4,409	0,281	6,38
	63	4,067	0,154	3,80
	91	4,500	0,282	6,50

As it can be seen, tensile strengths of mortar made with sugarcane bagasse ashes exhibited almost the same values obtained for the reference mortar for all ages. This means that the use of such ashes cause no undesirable effect on tensile strengths of mortars.

4. CONCLUSION

Based on the procedures and equipment adopted in this research to asses compressive and tensile strengths of mortar, it was verified that the replacement of a content of 15% of cement mass by SCBA from pizzeria and sugarcane industry generated a binder an pozzolanic effect on mortars.
The increase in compressive strength at 91 days was approximately 8% for the mortars made with sugarcane bagasse ashes while for the mortar without replacement the increase was only 5%, at the same age.
No undesirable effect in tensile strengths of the mortars made with sugarcane bagasse ashes was observed.
Furthermore, 30% of SCBA had performed as a pessimum content in this study for all strengths determinations.
The chemical composition of the ashes associated with its large surface specific and high degree of amorphousness explain this behavior.
Obtained results encourage the use of sugarcane bagasse ashes as cement replacement in several applications in civil engineering field with the added advantage of producing two important and beneficial side effects: (a) reduction of environmental impact of the disposal of this agroindustrial waste in nature and (b) decrease in cement consumption with consequent significant reduction of CO_2 emissions per ton of cementitious materials.

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