INFLUENCE OF SUGARCANE BAGASSE ASH IN THE EXPANSIONS OF MORTARS AFFECTED BY ALKALI-SILICA REACTION

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Abstract

This work presents the results of an experimental research concerning the influence of the partial replacement of cement by sugarcane bagasse ash (SCBA) in mortars subjected to alkali-aggregate reaction (AAR). Adaptations were made in a standard test of long term expansion to conduct evaluations and comparisons of expansions measurements of mortar cylindrical specimens produced with cement mass substitution of 0%, 8% and 12% bagasse ash sugarcane and 8% also by silica fume. Expansion tests were conducted using equipment (robot), designed and manufactured to perform automatic reading of volumetric deformations in free expansion tests. After curing for 28 days, the specimens of each mixture were maintained at temperature of 40 ± 2 °C, immersed in sodium hydroxide 1N solution for a period of 425 days. The mortar with substitution of 8% silica fume did not provide expansions from 45 days mitigating ASR expansion. The reference mortar (0%) and those with substitution of 8% and 12% of cement per sugarcane bagasse ash showed high expansions and about 0.20%, 0.35% and 0.19% of average volumetric expansion at 360 days of testing, respectively, indicating that under the conditions adopted sugarcane bagasse ash cannot mitigate ASR. The anisotropic behavior of expansions could be found in this research from major expansions measurements than 0.03%. The anisotropy factor, ratio between longitudinal and diametrical expansions steps, with no addition varies from 1.3 to 2.2 respectively to the 275 days and 425 days after immersion in the alkaline solution. The factors anisotropy of mortars with substitution of 8% and 12% of cement per sugarcane bagasse ash clearly show different values, with variations between 0.7 and 1.1.

Keywords: Alkali-silica reaction, sugarcane bagasse ash, volumetric deformations.

1 INTRODUCTION

This work presents the results of an experimental research concerning the influence of the partial replacement of cement by sugarcane bagasse ash (SCBA) in mortars subjected to alkali-aggregate reaction (AAR). Adaptations were made in a standard test of long term expansion to conduct evaluations and comparisons of expansion measured of mortar cylindrical specimens produced with cement mass substitution of 0%, 8% and 12% by bagasse ash sugarcane and also 8% by silica fume. Expansion tests were conducted using equipment (robot), designed and manufactured to perform automatic reading of volumetric deformations in free expansion tests at cylindrical specimen.

The mixture with no admixture and the one with cement substitution by 8% of silica fume serve as references.

The limitation of the alkali content in cement and the use of pozzolan in cement mortars may reduce or eliminate expansion due to alkali-silica reaction (ASR). The use of mineral admixtures, particularly pozzolanic materials, alters alkali available in the system and can produce chemical and physical effects on the microstructure of the mixture. The addition of adequate amounts of fly ash, blast furnace slag, silica fume and metakaolin, are among the most effective preventive measures to control the expansion of the ASR when a reactive aggregate is used in concrete [1]. The efficiency of mineral admixtures depends on their mineralogical and chemical composition, the percentage used as

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a substitute for cement, reactive aggregate and concrete alkaline content [2]. Silica fume is a pozzolanic material that with lower replacement levels produces greater reduction in alkalinity of the pore solution. The silica fume in replacing cement, percentage of 8-10%, has shown significant reduction or even mitigation of expansions in mortar or concrete affected by alkali-silica reaction [3].

Hasparyk and others [4] found that incorporating 12% of silica fume was sufficient to reduce expansion below 0.10% after 14 days of curing in alkaline solution, using reactive quartzite aggregate and superplasticizer in the mixture..

Furthermore, the use of pozzolanic materials into partial replacement of Portland cement generates significant reduction of CO_2 emissions per ton of cementitious materials [5], since their preparation uses less energy compared to the clinker process and the possibility of using industrial manufacturing byproducts. Studies on production of concrete and mortar seeking for the use of agro-industrial waste to reduce cement consumption has proven the efficiency of sugarcane bagasse ash as supplementary cementitious materials [6] [7] [8] [9]. Cordeiro [6], in their experimental research, have shown that the use of partial replacement of cement by sugarcane bagasse ash in the levels of 10%, 15% and 20% have kept the mechanical properties of concrete with lower consumption of Portland cement and with reduced release of heat.

Fairbairn et al. [10] show the benefit of clinker production reduction with the use of partial replacement of cement by sugarcane bagasse ash and got, in simulation for the south-east region of Brazil, an estimated reduction of CO_2 emissions of about 519 kton / year.

The available research on the use of sugarcane bagasse ash as filler in mortars show the great variability of chemical composition of the material and potential differentiated as pozzolan, depending on the collection site and conditions burning and grinding [6] [7] [8] [9] [11].

The unique internationally bibliographic reference found on the use of SCBA as a mitigator of AAR is from Macedo [12]. The experimental program developed in Macedo research [12] includes collection, characterization and processes of grinding sugarcane bagasse ash for use in mortars as partial replacement of fine aggregate. Tests for potential alkali reactivity of aggregates (ASTM C1260 [13]) were performed by replacing the cement CP V ARI in concentrations of 0%, 5% and 10% by volume bagasse ash. The mortars were considered potentially reactive, however obtaining an expansion reduction of about 15% in relation to the control mixture at 30 days.

Many are the standardized tests in several countries to detect the alkali-silica reactive potential in mortar or concrete and assessing the efficiency of pozzolanic materials. However, several researchers [3] [14] [15] conclude that these methods do not meet an optimum performance for the test, with some deficiencies such as excessive leaching of alkalis, contradictory results between laboratory and field with two common kinds of error, false positive or false negative. Thomas [15] points out that although the ASTM C1567 test [16] to investigate ASR mitigation of combinations of cementitious materials with aggregates is the most widely used, it does not completely address the phenomenological studies.

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 3.07 g/cm^3, specific surface of 4640 cm^2/g and D50 of10 μm was used. The chemical composition of cement is shown in Table 1.

The rock used to produce the aggregate was extracted from the quarry originated from the construction of the Hydroelectric Plant of Furnas, in the state of Minas Gerais, Brazil. The reactive aggregate used came from rock of metamorphic nature, classified as quartzite. The investigation into the reactivity of quartz was realized through petrographic analysis and AMBT - accelerated mortar bar test method (ASTM C1260 [13]). On hand of the petrographic analysis one could observe that the aggregate had a fine granulation and consisted mainly of quartz (>98%), although in restricted form it presented also mica sericite and opaque mica (<2%). Important characteristics were verified about to reactive potentiality with frequent (~100%) undulatory extinction angle of quartz grains (~20º). Tests were performed considering two types of cement, the standard and the CP V ARI. The expansions presented similar behaviors, reaching values close to 0.80% at 30 days. At 16 days, the expansions were high and equal to 0.51% for the two cements. This behavior resulted in the indicative of harmful potential expansion, or rather, presented expansions higher than 0.20% at 16 days, conforming to the prescription contained in the specification for aggregate (ASTM C33) [17]. The specific mass of small aggregate produced with quartz is of 2.64g/cm^3 and its granulometric distribution is confirming to ASTM – C1260 [13].

The residual SCBA was collected from an industrial unit of a sugar/alcohol producer located in the state of Rio de Janeiro, Brazil. The ash utilized for addition was obtained by grinding the residual ash of sugarcane bagasse in an impact mill, operating dry in a closed circuited aeroclassificator. The pulverized ash has a specific mass of 2.68 g/cm^3, a specific surface B.E.T. of 5230 cm^2/g, an average particle diameter of 13.93 μm, and presents an index of pozzolanic activity with cement of 91% [18]. The test, used to determine the pozzolanic activity, indicates potential for this SCBA to be applied as pozzolanic admixture, although the diffractogram of the ash, shown in Figure 1, suggests a low reactivity of material due to its absence of the amorphous band and the presence of various crystalline phases. The content of amorphous silica verified by means of refinement of Rietveld is 7.8%. The main phases of the crystalline composite detected through analysis by X-ray diffraction were the quartz and the cristobalite. The chemical composition of bagasse ash is presented in Table 1. Cordeiro et al. [6] showed that SCBA may have moderate pozzolanic activity even with predominance of crystalline phases in its mineralogical composition.

The silica fume admixture has a specific mass of 2.04 g/cm^3, a specific surface B.E.T. of 200844 cm^2/g and D_{50} of 0.4μm. Its chemical composition is shown in Table 1 and the crystallography in the diffractogram in Figure 2. The analysis by X-ray diffraction shows that the sample is essentially composed of amorphous material.

2.2 Mix designs

Four mixtures were produced: mortars with substitution of 0, 8 and 12% of cement mass with SCBA and with substitution of 8% of cement mass by silica fume, designated successively as REFN, CB8N, CB12N and SI8N. These percentage were chosen because, as verified by Cordeiro [19] more than 20% replacement of cement mass per SCBA decreases the strength of the concrete. Otherwise, within the framework of the present research it was decided that superplaticizer should not be used in the mixtures.

All mixtures were produced in proportion of cementitious material and sand of 1:2.25 with water-cementitious material ratio equal to 0.47 by mass, in conformance with ASTM C 1260 [13].

The curing of the mortars was realized in a moist chamber, with relative air humidity of 100% and temperature of 21 ± 2°C. The test samples remained in the humid chamber for 28 days. Afterwards samples were stored in polyethylene recipients, immersed in a sodium hydroxide solution (NaOH) at 1 N inside a chamber with temperature of 40 ± 2ºC.

2.3 Experimental methods

Free expansion tests were performed in mortars affected by alkali aggregates in 3 cylindrical test samples of 147 mm diameter by 298mm length for each of the following mixtures: reference (REFN), SCBA of 8% (CBN8%), SCBA of 12% (CBN12%) and silica fume of 8% (SI8N). The measurement of diametric variation, length, and therefore volumetric were obtained in the cylindrical test samples based on a stainless steel gauge, during approximately 425 days counting from day 28. For measuring the volumetric deformation of the produced mixtures an equipment called robot was used. The equipment was developed in partnership with the energy generating company FURNAS and COPPE-UFRJ (Institute of Post-Graduation and Research in Engineering of the Federal University of Rio de Janeiro), in a R&D program.

Figure 3 shows the robot in the processes of centralization and acquisition of readings of the samples. This robot consists of 7 inductive transducers which realize the readings diametrically opposite to the cylinder, 6 being utilized in pairs, to measure the variation of the sample's diameter and the seventh is responsible for measuring the height variation. The longitudinal deformations are realized in 15 generators of the cylinder, through a sensor LVDT with a pneumatic drive. The chosen LVDTs possess retractable pistons, which are activated from the interior of the sensor at the moment of each reading. For this, they need an internal pressure provided by a compressor fitted to the equipment.

Before each course of measuring, the stainless steel gauge with 147mm diameter and 318 mm length is utilized to calibrate the readings. After the acquisition of the reading realized in the gauge, readings are taken of the samples. These readings are always in relation to the obtained values for the reference sample. A computational control code and acquisition of data generate all measuring procedures. This acquisition system, after taking a sample of the measurement value, deduces the average diameter, the average height of the sample and respective changing pattern and informs if the measurements are within the limits of pre-established values.

To confirm the reliability of the measurements and contemplate the investigation of heterogeneity and of deformation anisotropic of the mixture the system provides the measurements of each test sample, estimated based on the 45 diametrical and 15 longitudinal measurements. Each of these measurements is obtained from the average of 14 readings taken by each of the sensors based on the automatic successive turns of 24^0 in the specimen. For a statistical inference of the deformation measurements a variance analysis (ANOVA) and a post-test TUKEY was carried out, with a significance level of 5%.

3 RESULTS

The temporary graphs of the average volumetric, longitudinal and diametric deformations of the mortar and the respective diversions are presented in Figures 4a, 4b and 4c.

Table 2 gives the average values obtained for volumetric, longitudinal and diametric measurements in three specimens of each type of mortar at 360 and 425 days of the test.

There was no significant difference between the obtained values for volumetric expansions of mixtures CB8N and CB12N in relation to the REFN at 360 and 425 days of test. There was significant difference between the deformations of SI8N and of the others mixtures, as well as between the expansions of mixtures CB12N and CB8N, in the 360 days and 425 days of test.

The graphs of evolution of the volumetric deformations show that a substitution of 12% of cement mass by SCBA does not cause a significant mitigation of expansions under the experimental conditions adopted. The substitution of 8% of cement mass with silica fume has mitigated the expansions of alkali-silica reaction.

The shrinkage observed for SI8N seems paradoxical and until now the authors do not have an explanation for such phenomenon. More tests would be suitable to verify the repeatability of these measures.

The mixtures REFN and CB12N presented a similar performance. It was observed, however, that the initiating of the expansions of mixtures CB12N and CB8N occurred at an earlier stage than REFN, possibly due to the higher quantity of alkali originating from the SCBA. The dispersion between the obtained results in the three specimens of each mixture emphasized an existing intrinsic heterogeneity in the alkali-silica reaction.

Larive [20] explains the anisotropy in laboratory samples. She relates the anisotropy observed in concrete affected by AAR to the predominant direction of cracking and it can be altered by factors that interfere with porosity. The relation between the longitudinal expansion and the diametric measurements, denominated the anisotropic factor by Larive [20], varies between the produced mortars and the time function as presented in Table 3. The anisotropic behavior of the expansions is verified in this research based on the expansions greater than 0.03%. The anisotropic factors for the CB8N and CB12N mixtures indicate a reduction from the tests of 360 days to 425 days.

4 DISCUSSION

In the extensive experimental program developed by Larive [20], which include measurements in transversal and longitudinal directions of various concrete specimens subjected to alkali-aggregate reaction, a value of approximately 2 was obtained as the average relation between longitudinal (in the direction of molding) and transversal expansions. The determined relations varied between 1.3 and 2.8. They were obtained in free expansion tests and with samples stored in moist chambers at temperatures of 23^o and 38^o C. Larive [20] alerts about the distinction between error and heterogeneity, as this emerges based on the distribution differences of reactive silica in the aggregate.

The expansions presented by CB8N mortar show occurrence of signs of "pessimum effect" in this study, but to any conclusion would be necessary to test mixtures with various levels of sugarcane bagasse ash and also analyze the variability of the results, as pointed out by MAAS et al. [21]. The "pessimum effect" caused by a low pozzolan replacement content can be due to a faster growth of concentration of alkali and the pH of the solution of the pores caused by the addtion, associated with a delayed start of the pozzolanic reaction [22] . A similar trend was checked by HASPARYK [23], who found similar effect for the 4% level with the addition of silica fume.

5 CONCLUSIONS

Based on the procedures and equipment adopted in this research to measure the expansions of the alkali-silica reaction, it was verified that the substitution of a content of 8% and 12% of cement mass by SCBA did not lead to a reduction of expansions. Furthermore, 8% of SCBA had performed as a pessimum content in this study for all determinations (volumetric, longitudinal and diametric expansions), increasing ASR expansions when compared to reference sample. Thus, sugarcane bagasse ash could no mitigate ASR with tested quartzite aggregate. On the other hand, the mixture with 8% of silica fume was efficient and did not present expansions in magnitudes that are considered harmful.

The chemical composition of silica associated with its large surface specific and high degree of amorphousness could explain this behavior.

The anisotropy factor, ratio between longitudinal and diametrical deformations, in mortar with no admixture varies from 1.3 to 2.2 respectively to the 275 days and 425 days after immersion in the alkaline solution. The anisotropy factors of mortars with cement substitution of 8% and 12% per sugarcane bagasse ash show different values to the same periods, with variations between 0.7 and 1.1.

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TABLE 1: Main chemical characteristics (% by mass) of the cement, SCBA and silica fume.

Compound	Cement	SCBA	Silica Fume
SiO_2	19.96	80.99	96.77
Al_2O_3	4.81	3.76	–
Fe_2O_3	2.23	2.44	0.25
CaO	63.9	2.51	0.41
K_2O	0.76	3.99	0.67
Na_2O	0.15	0.29	0.25
TiO_2	–	–	–
MgO	–	2.74	0.42
SO_3	2.69	–	–
Free lime	2.29	–	–
Loss on ignition	4.33	0.84	2.21
Insoluble Residue	1.02	–	–
Na_2Oeq	0.65	2.92	0.69
	Soluble Alkalis	Available Alkalis	
K_2O	0.59	2.58	0.11
Na_2O	0.10	0.001	0.10
Na_2Oeq	0.49	1.7	0.17
$Na_2Oeq = 0.658\ K_2O + Na_2O$			

TABLE 2: ASR average deformations (%) of mortars immersed in NaOH during 360 days and 425 days.

	Deformations (%) –28+360 days in NaOH				Deformations (%) - 28+ 425 days in NaOH			
	REFN	SI8N	CB8N	CB12N	REFN	SI8N	CB8N	CB12N
Volumetric	0.199	-0.076	0.345	0.192	0.253	-0.097	0.415	0.197
Diametric	0.055	-0.013	0.110	0.063	0.060	-0.029	0.138	0.067
Longitudinal	0.089	-0.050	0.125	0.066	0.133	-0.039	0.139	0.063

TABLE 3: Anisotropy of the expansions (longitudinal/diametric) at 360 days and 425 days in NaOH.

Mixture	28±275 days	28±360 days	28±425 days
REFN	1,34	1.62	2.22
CB8N	0,92	1.14	1.00
CB12N	0,67	1.05	0.94

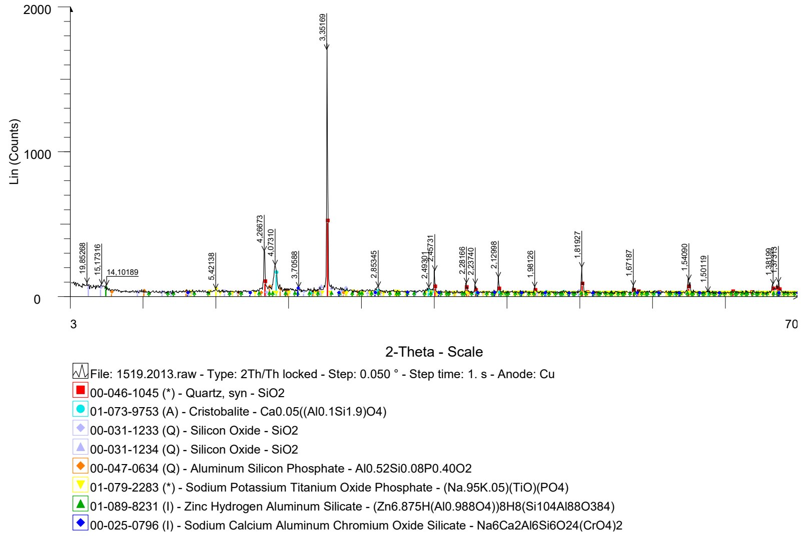


FIGURE 1: X-ray diffraction patterns of SCBA.

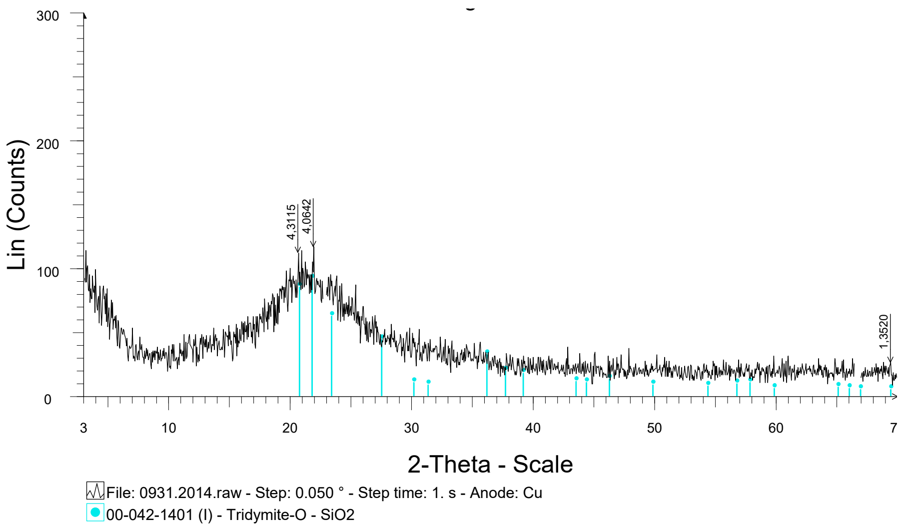
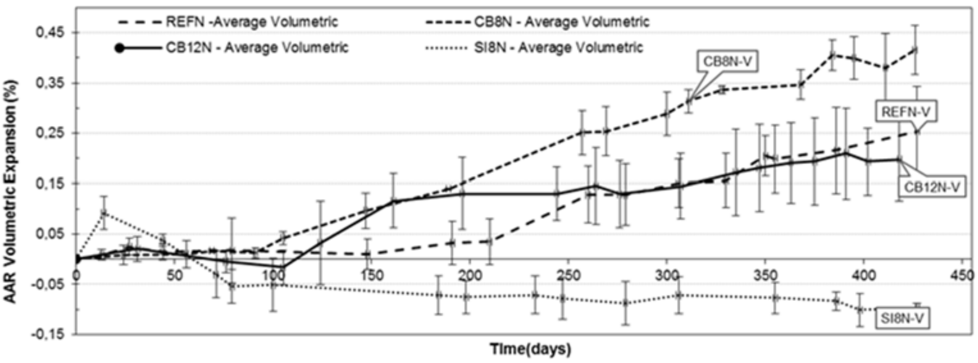
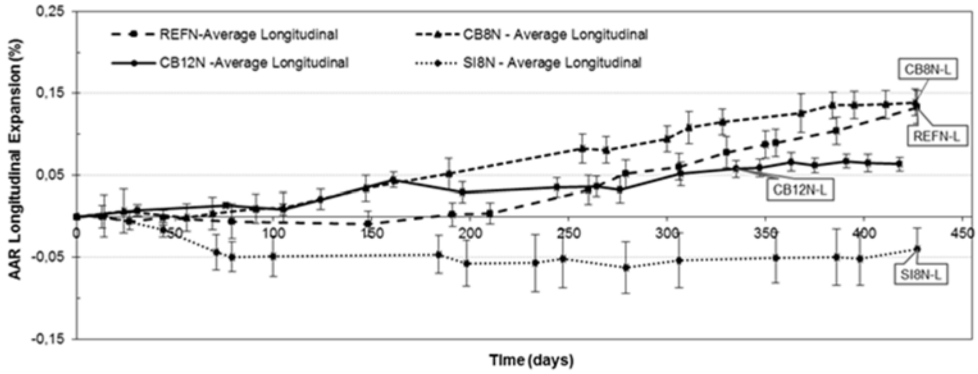


FIGURE 2: X-ray diffraction patterns of silica fume.

FIGURE 3: Photo equipment developed for readings of volumetric expansion (robot).



(a)



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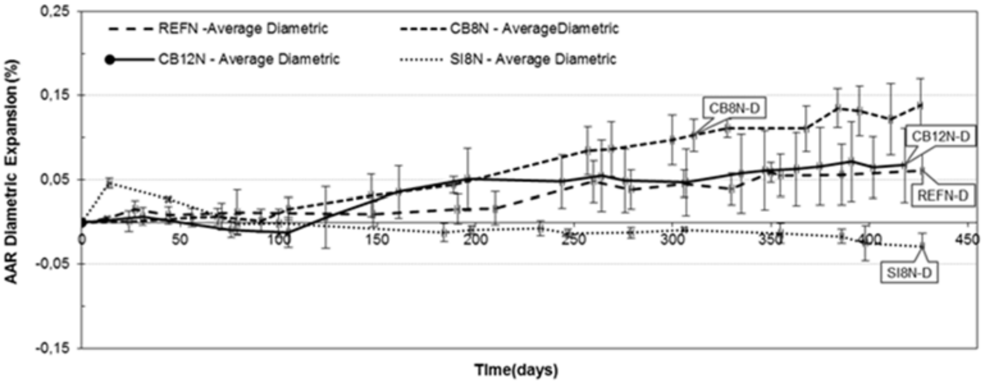

(c)

FIGURE 4: ASR average (a) volumetric, (b) longitudinal, (c) diametric expansions of different mortars.