Chapter 32

Mitigation of the alkali-aggregate reaction against the addition of sugarcane berry ash

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José Vitor da Silva Macedo
Master in Civil Engineering
Institution: Polytechnic School of Pernambuco - University of Pernambuco
Address: Rua Benfica, 455 - Madalena, Recife-PE. ZIP Code: 50720-001
Email: jose.vitor@hotmail.com

Bernardo Inojosa Lyra
Graduated in Civil Engineering
Institution: Polytechnic School of Pernambuco - University of Pernambuco
Address: Rua Benfica, 455 - Madalena, Recife-PE. ZIP Code: 50720-001
E-mail: bernardo.lyra17@gmail.com

Eliana Cristina Barreto Monteiro
PhD in Civil Engineering
Institution: Polytechnic School of Pernambuco - University of Pernambuco and Catholic University of Pernambuco
Address: Rua Benfica, 455 - Madalena, Recife-PE. ZIP Code: 50720-001;
E-mail: eliana@poli.br

Angelo Just da Costa e Silva
PhD in Civil Engineering
Institution: Polytechnic School of Pernambuco - University of Pernambuco and Catholic University of Pernambuco
Address: Rua do Principe, 526 - Boa Vista, Recife-PE. ZIP Code: 50050-900
E-mail: angelo@tecomat.com.br

Tibério Wanderley Correia de Oliveira Andrade
PhD student in Civil Engineering
Institution: Federal University of Pernambuco
Address: Avenida Professor Moraes Rego, 1235 - Cidade Universitária, Recife-PE. ZIP Code: 50670-901
E-mail: tiberio@tecomat.com.br

1 INTRODUCTION

The alkali-aggregate reaction (RAA) is a pathological manifestation caused by the chemical reaction between the reactive minerals of the aggregates and the alkaline oxides of sodium and/or potassium (Na_2O and K_2O, respectively), derived essentially from cement, forming a gel that in the presence of water expands inside the concrete or mortar. The expansion of this gel, which is deposited in the pores of the structure, can generate cracks, displacements, and may lead to the rupture of the structure if the tension reaches a level in which the concrete or mortar does not resist (Poole, 1992; Figuerôa and Andrade, 2007; Fernandes and Broekmas, 2013).

The emergence and magnitude of this phenomenon depend on several factors such as the presence of reactive aggregates, alkalis (usually coming from cement) in pore solution and moisture content. According to Haskapy (2005), there are some preventive measures for the mitigation of AAR such as (i) the limitation of alkali content in concrete, (ii) the use of non-reactive aggregates and (iii) the use of AAR inhibitormaterials (natural pozzolans, active silica, metakaline fly ash, etc.).

According to Thomas (2011), the use of additions to cement is the most used preventive measure for the inhibition of AAR. Some thermoelectric residues with biomass boilers can be considered pozolanic materials such as rice husk ash (Sandhu and Siddique, 2017). According to Katere and Madurwar (2017), there are also studies that evaluated the pozzollanicity of sugarcane bagasse ash (CBCA), but the literature of this inhibition regarding AAR is still reduced.

Cordeiro et al. (2009) determined that CBCA is basically made of silica (SiO_2), having a potential to be used as mineral addition, replacing part of the cement in mortars and concrete, and acting as pozolanic material. Santos et al. (2020) concluded that when used as a replacement in the Portland cement plot, CBCA presents satisfactory and similar results to the reference composites due to its pozolatic behavior, thus reducing the consumption of necessary cement and consequently the emission of harmful gases into the atmosphere from the manufacturing process.

Pozzolan is a natural or artificial material that contains silica in reactive form. According to standard C 125-03 (ASTM, 2003), pozzollans are silicous or silicoaluminous materials that, by themselves, have little or no binder activity, but which, when finely divided and in the presence of water, react with calcium hydroxide at room temperature to form compounds with binder properties. Thus, in Portland cement-based compounds, calcium hydroxide released by the hydration of silicates reacts with silicon dioxide (SiO_2) present in pozzolan, resulting in an extra production of hydrated calcium silicates, which are more stable products of hydrated cement responsible for hardening cement.

Kazmi et al. (2017) identified that CBCA helps to agglutinate alkalis as a result of the pozolanic reaction, and due to the decrease in alkali concentration, its addition to concrete consequently led to a reduction in the expansion of aAR. Saraiva (2017) also concluded that the addition of CBCA minimized the expansions of cementitious composites compared to the reference specimens, which had reactive aggregates. According to Cordeiro et al. (2016) for the effective application of CBCA in mortar and concrete, it is necessary, first, that it be processed, which allows it to achieve the fineness and homogeneity that are necessary to meet industry standards, and it is observed that the pozolanic activity of ash is directly related to its fineness.

Among the benefits obtained by the use of pozolanic additions in concrete, the following stand out: the improvement in resistance to thermal cracking due to lower hydration heat, increased resistance and impermeability due to pore refinement, strengthening of the transition zone, improving durability to chemical attacks, such as sulfated waters and alkali-aggregate expansion.

It is also known that sugarcane production in Brazil has been increasing since 2003, motivated by the growth of sugar demand in the international market, with the reform of European product policy, and by the increasing use of ethanol, from the development of vehicles with Flex Fuel engines in the country (Federation of industries of the state of São Paulo - FIESP, 2013). Cordeiro (2006), in his experimental study, realized that 0.7% of the bagasse burned in mass becomes the form of residual ash. In the 2017/2018 harvest alone, it is estimated that approximately 4.5 million tons of CBCA were produced in Brazil, evidencing the need for its own destination.

In addition to the mechanical advantages conferred on concrete, according to Teodoro et al. (2013), the use of pozzolans as a replacement adds economic value to this waste and also generates environmental benefits, eliminating a large amount of material that would otherwise be discarded as garbage and reducing the use of cement clinker, thus reducing $CO_{emission\ 2}$ which is released during its manufacture. It is important to highlight that the burning of bagasse during the process of cogeneration of energy produces substantial release of CO_2, however, according to Cordeiro et al. (2009), the balance in CO_2 **emissions is practically zero** , because, through photosynthesis, the biomass burned is replaced in the next cycle of sugarcane crop.

In this context, the present work aims to evaluate the inhibition of the occurrence of alkali-aggregate reaction by the addition of sugarcane bagasse ash from the expansion of mortars with a reactive aggregate, with replacement of Portland cement by CBCA in percentages of 0, 10, 20 and 25%.

2 METHODOLOGY

It was used as the basis for the construction of this methodology, several works of Brazilian and international literature (Ganesan et al., 2007; Cordeiro et al., 2009; Chusilp et al., 2009; Ribeiro and Morelli., 2014; Bahurudeen et al., 2015; Goes, 2016; Cordeiro et al., 2016; Hail, 2017; Kazmi et al., 2017; Berenguer et al., 2018; Ojeda-Farias et al., 2018).

2.1 MATERIALS

2.1.1 Additive, water and sodium hydroxide

In order to adjust the mortar spread for molding, the third generation accelerated handle superplasticizer additive for high performance concrete (SP - II A) according to NBR 11768 (ABNT, 2011) whose properties are set in Table 1 were used.

Table 1 - Properties and features of Sika ViscoCrete 20 HE Additive.

Properties and features	Findings
Chemical Base	Polycarboxylatosolution in aqueous medium
Density	1.07 ±0.02 kg/litre
ph	5.5±1.0

Source: Author.

To perform tests of mortar bars they were immersed in a saturated solution of sodium hydroxide. Sodium hydroxide available on the market and distilled water was used to manufacture the solution.

2.1.2 Cement

In this research, the cement used in all tests was CP V ARI cement, standardized by NBR 16697 (ABNT, 2018). Tables 2 and 3 show the results of the chemical and physical characterization, respectively, of CP V - ARI.

Table 2. Chemical characterization of the cement used.

Tests	Methodology	Unit	Result	Regulatory requirements
Insoluble waste - IR	NBR NM 15 (ABNT, 2012)	%	0,88	≤ 1.00
Fire loss - PF	NBR NM 18 (ABNT 2012)	%	2,44	≤ 4.50
Magnesium Oxide - MgO	NBR NM 14 (ABNT, 2012)	%	1,71	≤ 6.50
Sulphur Trioxide - SO_3	NBR NM 16 (ABNT, 2012)	%	3,35	≤ 4.50
Carbon dioxide - CO_2	NBR NM 20 (ABNT, 2012)	%	2,01	≤ 3.00

Source: Author.

Table 3. Physical characterization of the cement used.

Tests	Methodology	Unit	Result	Regulatory requirements
Specific Area (Blaine)	NBR 16372 (ABNT, 2015)	^{2cm}/g	4.309	≥ 3,000
Specific Mass	NBR NM 23 (ABNT 2001)	g/cm^3	3,10	Does not apply
Fineness index - #75 µm (#200)	NBR 11579 (ABNT, 2013)	%	0,08	≤ 6.00
Water of normal consistency	NBR 16606 (ABNT, 2017)	%	31,40	Does not apply
Start of handle	NBR 16607 (ABNT, 2017)	minutes	157	≥ 60
End of catch	NBR 16607 (ABNT, 2017)	minutes	218	≤ 600
Hot expandability	NBR 11582 (ABNT, 2016)	Mm	0,01	≤ 5.00

Source: Author.

2.1.3 Aggregate

The kid aggregate used in the expansion tests in mortar bars by the accelerated method was an artificial aggregate acquired after the crushing process of a quarry. This quarry was selected, because some works affected by the manifestation of the alkali-aggregate reaction of the Metropolitan Region of Recife used the gravel of this place.

The artificial aggregate was characterized, before crushing, through the petrography test according to NBR 7389-2 (ABNT, 2009).

To perform the petrography assay of the artificial aggregate, general, macroscopic characteristics of the aggregate (Table 4) and the petrographic description itself made using a transmitted light optical microscope, presented in Table 5, were analyzed.

Table 4. General Characteristics of the Household.

Features		
Kind		Crushed stone
Colour		Grey
Form		Equidimensional to lamelar
Degree of rounding		Angled
Physical-mechanical characterization	Coldness	Not friable
	Compactness	Compact
	Tenacity	High

Source: Author.

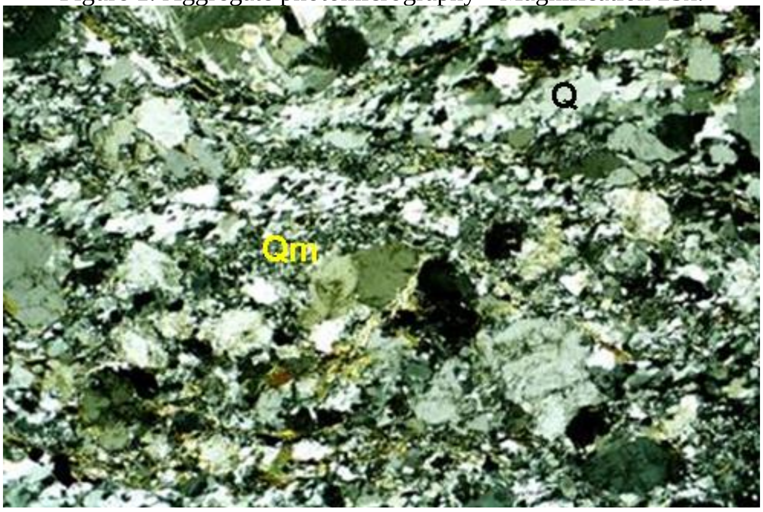
Table 5. Synthesis of the petrographic characteristics of the aggregate.

Microscopic features		
Structure		Foliate oriented
Texture		Milonitic
Grain		Average
Alteration		Little altered to are
Aggregate deformation		Warped
Rock Type		Metamorphic
Petrographic classification		Milonito
Minerology	Primary	Quartz, feldspar and mica
	Subordinate	Titanite and opaque
	Reactive/Deleteria	Deformed quartz with undulating extinction, thin quartz and recrystallized quartz
Potential Reactivity		Reactive aggregate

Source: Author.

From the mineralogical point of view, the deformation observed in the aggregates favors the triggering of expansive reactions of the alkali-silicate type. The presence of quartz with undulating extinction, masses of fine quartz and recrystallized quartz are features that give the aggregate the reactive character. The aggregate has textural characteristics that allow us to characterize it as potentially reactive to the alkalis. Figure 1 shows the photomicrography of the aggregate in which deformed quartz crystals (Q) and fine quartz mass (Qm) are observed.

Figure 1. Aggregate photomicrography - Magnification 25x.



Source: Author.

2.1.4 Ashes

The ashes used in the research were collected in a power plant, located in the municipality of Igarassu, Metropolitan Region of Recife, in the State of Pernambuco about 48 km from the center of Recife. These samples were dried in a greenhouse, ground for 30 minutes at 60 rpm rotation because this process increases the pozolanic action of CBCA (Cordeiro et al., 2016), and sifted in an opening sieve 0.075 mm so that its granulometry resembled that of Portland Cement.

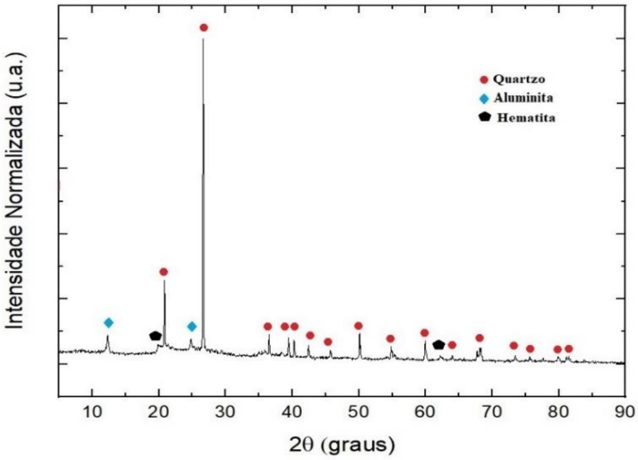
CBCA was characterized physical-chemically in order to analyze its pozzolanicity by x-ray diffraction spectrometry (XRD), X-ray fluorescence spectrometry (FRX), laser granulometry, analysis of the specific surface area by the Brunauer-Emmet-Teller (BET) technique, cbca thermogravimetric analysis and apparent specific mass.

2.1.4.1 X-ray diffraction spectrometry (XRD) assay

For the XRD assay, the following parameters were used: variation of 2ɵ incidence angle from 5° to 90° with speed of 1°/min, voltage of 40 kV and current of 40 mA with Nickel filter, under radiation by all copper. The results of the diffrotometer tests were first analyzed in the X'Pert HighScore Plus program in order to find the peaks of the diffatogram and to compare the diffatograms of the samples with the PDF-2 database of the International Centre for Diffraction Data.

Figure 2 shows the difratogram of ash, which presents peaks of silicon dioxide in the form of quartz. These results are similar to the studies of Ribeiro and Morelli (2014) and Saraiva (2017). The presence of amorphous silica confers pozolanic activity to ash (Cordeiro, 2009).

Figure 2. CBCA difratogram.



Source: Author.

2.1.4.2 X-ray fluorescence spectrometry (FRX) assay

In the FRX assay, a sample aliquot was dried in an oven at 110 ºC. Then a dry sample sample was pressed into aluminum capsules with 30 tons of force. The pressed tablet was analyzed in x-ray fluorescence spectrometer.

The chemical compositions of CBCA oxides by FRX are presented in Table 6. This chemical composition is similar to that of the study by Ganesan et. al (2007), Cordeiro (2009), Berenguer et al. (2018) and Ojeda-farias et al. (2018). ATSM C 618 (2017) establishes the chemical requirement for pozzolanic materials in relation to oxides: the sum of SiO_2 + Al_2O_3 + Fe_2O_3 should be greater than 70% for class N pozzolan (81.54% was observed in the CBCA of this study).

Table 6. CBCA chemical composition by FRX.

Compounds	(%)	Compounds	(%)	Compounds	(%)
SiO_2	60,24	TiO_2	1,53	Cr_2The_3	0,04
Al_2O_3	14,38	SO_3	1,32	Sro	0,03
Fe_2The_3	6,92	In_2O	0,29	V_2O_5	0,02
K_2O	5,29	ZrO_2	0,29	Cuo	0,02
Cao	4,17	MnO	0,16	Nio	0,01
P_2The_5	3,56	Bao	0,11	Rb_2O	0,01
MgO	1,53	ZnO	0,05	Nb_2The_5	0,01

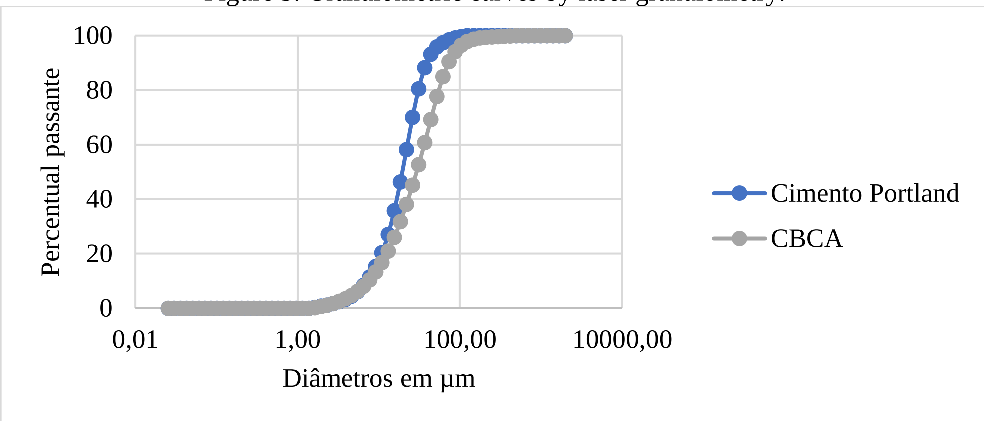
Source: Author.

2.1.4.3 Laser Granulometry

Laser particle size, or Particle Size Distribution Analysis by Dynamic Light Scattering, was performed as a liquid medium, with distilled water solvent with the use of ultrasound for 60 seconds and the obscurity achieved was 10%. Due to the lack of refraction index of the material, the Fraunhofer model was used for approximation.

The granulometric curves of CBCA and Portland Cement obtained according to the laser particle size method are shown in Figure 3. It is noticed that the granulometric distribution of Portland Cement is more similar to the distribution of BCC.

Figure 3. Granulometric curves by laser granulometry.



Source: Author.

2.1.4.4 Analysis of the specific surface area of the ashes by bet technique

In the analysis of the specific surface area of the ashes by the BET technique, the material was treated in a vacuum station and then promoted to adsorption of the gas (nitrogen). The adsorption was made by the insertion of nitrogen under controlled pressure to the analysis station, at low temperature. The surface area was determined from the ratio of the amount of adsorbed/desorbed gas and gas pressure (isotherm). This technique was chosen to the detriment of the Blaine method, because this method has a limitation when particles have a specific area greater than 8000 cm2/g as CBCA, according to NBR 16372 (ABNT, 2015).

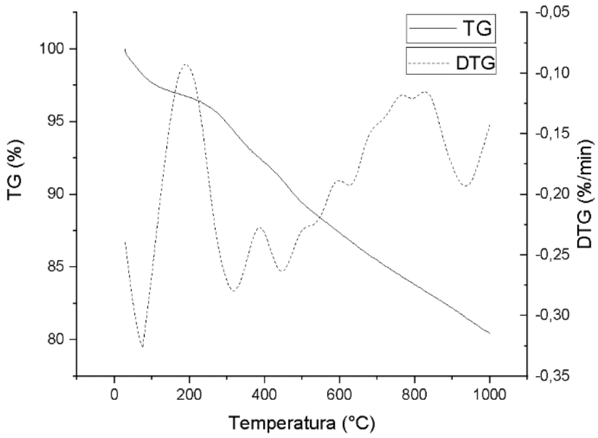
The result of the specific surface area BET was 1.3269 m2/g for Portalnd Cement and 24.3469 m2/g for CBCA. It is verified that the surface area of the ash is much larger than that of cement, being about 18 times larger than that of cement. A larger surface area means a loss of workability and a possible improvement in the durability of cementitious composites. In the work of Costa (2017), the result of the surface area (BET) was 84.62 m2/g for passing CBCA in the sieve no. 400. This difference is quite expressive, but it can be explained by the difference in sieving processes, since the present work used the passing ashes of sieve no. 200.

2.1.4.5 Thermogravimetric Analysis

In the thermogravimétry analysis, CBCA was inserted into the equipment that heats it and commutatively a scale provides mass data and the apparent specific mass assay was performed according to NM 23 (ABNT, 2001).

The thermogravimetric analysis of CBCA is presented in Figure 4, in which it presents a drop of 2.45% around the temperature of 100 °C (probably due to the loss of humidity of the sample). Between temperatures of 200 °C and 600 °C, there was again a drop of 12.63% by mass, this is due to the detachment of volatile carbons. At 1000 °C, there was a residual mass of 80.45%.

Figure 4. Thermogravimetric analysis.



Source: Author.

Taylor (1997) proves that calcium hydroxide decomposition occurs between 425 °C and 550 °C. Therefore, if there is a decrease in the peak in this interval, a pozolanic activity may have occurred. Figure 4 shows that there was a decrease in mass in this temperature range, which should be the result of the decomposition of portlandite in CaO and water. This result is similar to that of Góes (2016) for ash calcined at 400°C and passed in sieve #200.

2.1.4.6 Apparent specific mass

The apparent specific mass of ash obtained by means of the volumetric bottle of Le Chatelier had a value of 2.20 g/cm3. It is noticed that this result is lower than that of cement observed in Table 3. However, it is similar to that used in silva's study (2018), similar to the specific mass of active silica (about 2.20 g/cm3) and slightly smaller than that of metcaulin (about 2.60 g/cm3).

2.2 METHODS

2.2.1 Mortar bar expandability test

The molding of mortars and the evaluation of their behavior were made by NBR 15577 (ABNT, 2008) and ASTM C1567 - 13 (2013). According to these standards, an a/c ratio of 0.47 in bulk and a proportion of one part of cement should be used for every 2.25 in separate aggregate mass. Table 7 presents the quantity of materials used for the production of each family.

Table 7. Quantitative materials for mortar production.

Family	**Cement (g)**	**Aggregate (g)**	**Water (kg)**	**CBCA (g)**	**Additive(g)**
0% (reference)	440	990	206,8	-	-
10%	396	990	206,8	44	1,33
20%	352	990	206,8	88	2,33
25%	330	990	206,8	132	2,75

Source: Author.

According to NBR 15577 (ABNT, 2018) it is necessary to perform expandability readings at the ages of 16 and 30 days and others at least 3 intermediate ages before age 16 days plus 3 intermediate readings between the ages of 16 and 30 days. However, in order to have a better sampling in this study, 5 intermediate readings were performed before and after 16 days.

3 RESULTS AND DISCUSSIONS

3.1 EXPANDABILITY TEST OF MORTAR BARS

Table 8 shows the expandability of molded specimenbodies with 10% (CP10), 20% (CP20) and 25% (CP25) in CBCA in replacement of cement, as well as the reference specimen (CP0) without addition.

Figure 5 graphically shows the expandability of the specimens analyzed in relation to their ages, as well as the limits established so that cementitious composites are not considered subject to alkali-aggregate reaction.

Table 8. CBCA chemical composition by FRX.

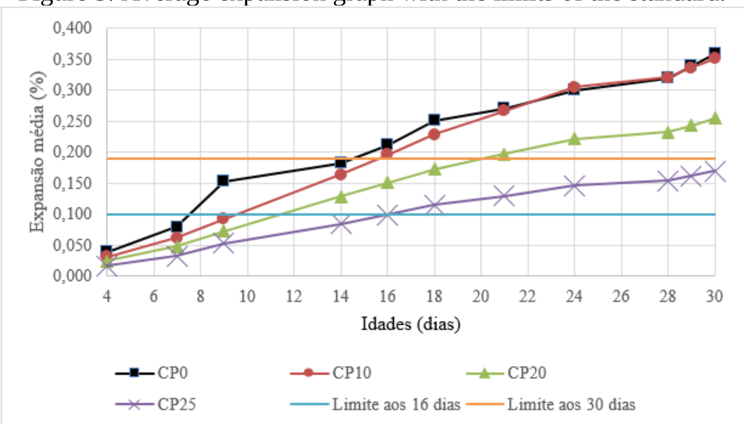
Age in days	Average expansion (%)			
	CP0	CP10	CP20	CP25
4	0,039	0,031	0,024	0,016
7	0,079	0,061	0,048	0,032
9	0,152	0,092	0,072	0,053
14	0,182	0,164	0,128	0,083
16	**0,212**	**0,196**	**0,150**	**0,098**
18	0,251	0,228	0,172	0,115
21	0,271	0,267	0,197	0,129
24	0,300	0,305	0,221	0,146
28	0,319	0,320	0,232	0,154
29	0,338	0,336	0,243	0,161
30	**0,358**	**0,351**	**0,255**	**0,170**

Source: Author.

In for an aggregate to be considered inert as to its expansive character for the alkali-aggregate reaction in this accelerated method of expansion in bars, the mortar must expand less than 0.10% at 16 days and 0.19% at 30 days of molding to the test body without additions.

Analyzing Table 8, it is notorious that the aggregate used in this research has an expansive character since the reference test body had an average expansion of 0.212% at 16 days and 0.358% at 30 days.

Figure 5. Average expansion graph with the limits of the standard.



Source: Author.

The CP10 had as average expansion 0.196% at 16 days and 0.351% at 30 days. These results are above the predicted limit for inhibition of the reaction. However, with the replacement of 10% CP-V ARI cement by CBCA, there was a 7.42% decrease in expansion at 16 days and 2.08% at 30 days in relation to the average expansion of CP0.

In addition, the CP20 family had as average expansion 0.150% at 16 days and 0.255% at 30 days. These average expansions are also above the limit predicted for inhibition, but as in the 10% series, the replacement of cement by CBCA resulted in a decrease in the average expansion in relation to CP0, being a reduction of 28.91% at 16 days and 28.98% at 30 days.

Finally, the CP25 family obtained as a result average expansions lower than the limit for inhibition of AAR, 0.098% at 16 days and 0.170% at 30 days, which attests that for the aggregate used in the research, a replacement of 25% of Portland Cement by CBCA, would inhibit the possibility of the manifestation of the alkali-aggregate reaction.

The results for the CP25 family confirm what was found by Saraiva (2017) and Kazmi et al. (2017), where the addition of CBCA minimized the expansions of cementitious composites compared to the reference specimens, which had reactive aggregates.

Saraiva (2017), when analyzing basalt aggregate, noticed a reduction of 11.84% for the replacement of 10% of BCC and 35.53% for the replacement of 20% at 32 days. When the author analyzed the quartizito aggregate, the reduction was 0.85% for the replacement of 10% of CBCA and 12.07% for the replacement of 20% at 32 days. In both aggregates, the author did not reach satisfactory expansion for the replacements of 10 and 20% of cement by CBCA. The average satisfactory expansion was only achieved for the family of 30%.

Kazmi et al. (2017) obtained a lower than the limit for the replacement of 20% in a aggregate of dolomitic limestone from Pakistan, but this result was only satisfactory due to the lower reactivity of this aggregate.

4 CONCLUSION

With the completion of the work, it can be concluded that the general purpose of the research was achieved with a reduction of the expandability regarding the alkali-aggregate reaction of the mortar bars with the partial replacement of cement by CBCA, thus showing the feasibility of using CBCA in the mitigation of AAR.

As for the inhibitory potential of CBCA in the alkali-aggregate reaction, it can be concluded that the expandability of the mortars produced (with 0, 10, 20% replacement) did not reach the reference limit for total inhibition of AAR. Despite this, the incorporation of ash mitigated the RAA, reducing the expansion of mortars by 7.42% at 16 days and 2.08% at 30 days for CP10, and in 28.91% at 16 days and 28.98% at 30 days for CP20, both in relation to CP0. On the other hand, the substitution of the ash in the percentage of 25% totally inhibited the possibility of the manifestation of the alkali-aggregate reaction.

It is also concluded that, in addition to the inhibition of AAR, the use of CBCA brings environmental and sustainable advantages. According to Savastano (2003), the use by civil construction of waste generated in other sectors of the economy is advantageous not only due to increased industrial activity and, consequently, by-products, but mainly due to the reduction of the availability of non-renewable raw materials, so necessary for conventional construction activities. It also states that much of the waste generated can be recycled, reused, processed and incorporated in order to produce new building materials and meet the growing demand for more efficient, economical and sustainable alternative construction technology.

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