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Research Paper

Alkali-Aggregate Reactivity –Determining Expansion Mitigation in Mortar Bars through the Accelarated Method

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ABSTRACT: *Previous studies have shown that replacing fine aggregate in mortar for porcelain electric isolators ground in similar granulometry improvesits physical and mechanical properties. However, this porcelain contains silica in its composition, which in certain conditions may contribute to the occurrence of alkali-aggregate reactivity. Thus, the studies performed show that porcelain is potentially reactive. Mitigation measures were defined for this, in order to decrease the effects of the alkali-aggregate reaction in mortars: it is indicated that substituting 20% of the cement for fly ash attenuates the effects, and the porcelain can be used to replace fine aggregate in mortars.*

Keywords: *alkali-aggregate reactivity, porcelain isolator, alternative materials, mortar.*

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I. INTRODUCTION

In recent years, environmental concernshave led to the reuse of the most varied materials – civil construction being a prominent sector for this. It is relevant to note the fact that innumerable residues such as demolition materials, tires, ash, and dross are incorporated in concretes and mortars, which reduces the volume of discarded material and the extraction of natural resources. This also adds value to the residue, which before was discarded.

The industrial ceramic sector has a largeindustrial park spread throughout Brazil, with each region producing specific products according to the market demand and available raw materials. However, this sector generates a large quantity of discarded material, which is slowly being incorporated into civil construction itself.

The city of Pedreira in the Metropolitan Region of Campinas in the state of São Paulo is an important production hub for porcelain, concentrating around 80% of the Brazilian production of porcelain electric isolators, which is estimated at around 35,000 tons/year. This ceramic sector discardsup to 7% of the total amount produced for quality control. In addition, ceramic producers may discard replaced pieces. With this, annual liabilities from this porcelain alone amount to around 25,000 tons per year [1].

Thus, previous studies considered this ceramic residue as an alternative to the common aggregates used in the production of concretes and mortars. The porcelain residue, after undergoing a process of grinding and granulometric classification, can be used to substitute a number of granulometries of fine aggregates and/or common gravel, sand, and crushed stone, respectively, and, depending on the mix of the concrete or mortar, may even improve the mechanical properties when compared to the conventional mix.

These studies were restricted to laboratory tests of mechanical properties, and until now there are no studies regarding chemical tests and those on the durability of the use of the porcelain electric isolators.

These porcelain isolators contain in their composition material originating from silica, which, over time, may triggeralkali-aggregate reactions, impairing their initial function. The objective of this study was to verify the potentiality of the reactivity of the porcelain electric isolator as an aggregate, and propose mitigation measures to decrease it, based on NBR 15577 [2].

The preliminary results showed that porcelain electric isolators are potentially reactive; however, with the incorporation of pozzolanic materials, the reactivity tends to decrease as the content rises, as shown by the results of this study, allowing them to be used in civil construction, even in locations that could trigger the alkali-aggregate reaction.

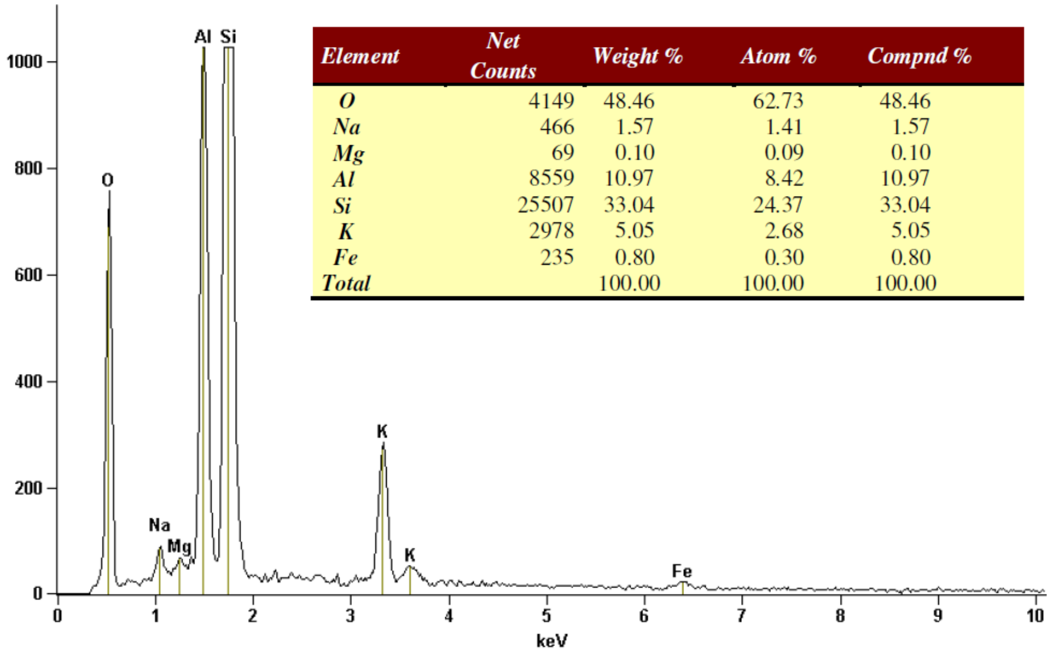
Mitigation Measures for the Alkali-Aggregate Reaction. The alkali-aggregate reaction (AAR) is characterized by the expansion and cracking of the concrete, which leads to the loss of resistance and modulus of elasticity. It can also result from chemical reactions involving the alkalis and hydroxyl ions in the Portland cement paste and of certain reactive siliceous minerals that are frequently found in the aggregate. Popping andexudation of a viscous silico-alkaline fluid are other manifestations of AAR. It can be concluded that the most important factors that influence the AAR phenomenon are:
I –alkali content in the cement and the cement consumption of the concrete;
II – contribution of the alkaline ion from other sources, such as additives, additions, aggregates contaminated with salt, and penetration of sea water or a solution of thawing salts in the concrete (this last case is not frequently observed in Brazil);
III – quantity, dimension, and reactivity of the reactive components in the aggregate – which must be considered in the concretes and mortars with aggregates of porcelain electric isolators;
IV – availability of humidity for the concrete structure;
V – room temperature.
The main solution for decreasing alkali content is using cements with low alkalinity, alkalis expressed in Na2O eq. < 0.6%. However, when this criterion cannot be met, NBR 15577 [2]recommends partial substitution of the high-alkalinity cement for cementitious or pozzolanic additions, such as silica fume and metakaolincombined with any type of Portland cement [3].
Fly ash is a material in fine particles that originates from burning pulverized charcoal in thermoelectric power plants in order to generate energy. It is most commonly used to make cements, as the NBR 5736 [4]norm specifies cement that allows bulk substitution of clinker for pozzolanic material with content varying from 15 to 50%, for the PC IV (pozzolanic Portland Cement). NBR 11578 [5]defines PC II Z (Portland Cement composed with pozzolan) with a pozzolan content of 6 to 14%. Fly ash is also used as an additive or to partially replace cement in concretes (the latter use must be monitored rigorously, since the mixture is made in the concrete mixer, where dosage errors can be made).
Metakaolin is a material that originates from the calcination of some types of clay, such as kaolinitic and kaolin clays, and is specifically produced for use in construction. Its additive content is lower than the other pozzolans. Currently, there is no cement produced in Brazil with the addition of metakaolin, but there is a technical regulatory norm, NBR 15894 [6],that regulates its use in concretes, mortars, and paste as a pozzolanic addition [7].
However, the use of these pozzolanic materials does not guarantee mitigation of AAR, since it depends on the additive content, the aggregate's degree of reactivity, and the total alkali content in the concrete. The contents that are most efficient for reducing AAR are: fly ash of up to 35%, metakaolin around 10%, of substitution of the cement [8].

II. MATERIAL AND METHODS

Characterization of the Materials. This study illustrates the results of tests determining alkali-aggregate reactivity through the method recommended by NBR 15577-4 [9].The method is indicated to evaluate the reactivity of aggregates in a sodium hydroxide alkaline solution, through monitoring the dimensional expansions of the mortar bars, using in the test a standard cement proven to be non-inhibitive of the alkali-aggregate reaction.

Also presented are the results of the tests determining mitigation for expansion in bars of mortar by the accelerated method prescribed by NBR 15577-5 [10], for which the procedure has the same principle, but which is indicated to evaluate the efficiency of cements with added pozzolans, high-furnace dross, silica fume, and metakaolin in inhibiting the expansion of aggregates classified as potentially reactive by the methodology recommended in NBR 15577-4 [9].

The EDS spectrum of the sample of the porcelain electric isolator aggregate (Fig. 1) presents a considerable percentage of silica in its composition, for which reason its analysis was proposed to evaluate its degree of reactivity. Having identified this reactive potentiality (Fig. 1), it was analyzed with standard cement to evaluate the aggregate's degree of reactivity (NBR 15577-4 [10]), and with the standard cement with added fly ash in percentages of 15 and 20% and of liquid metakaolin in percentages of 10 and 20% as a substitute for standard cement, which were the technically and economically viable options for mitigating the AAR shown in Fig. 2. The tests were performed with the goal of evaluating if these combinations have characteristics that favor use in civil construction sites with low risk of pathologies from the alkali-aggregate reaction.



Element	Net Counts	Weight %	Atom %	Compnd %
O	4149	48.46	62.73	48.46
Na	466	1.57	1.41	1.57
Mg	69	0.10	0.09	0.10
Al	8559	10.97	8.42	10.97
Si	25507	33.04	24.37	33.04
K	2978	5.05	2.68	5.05
Fe	235	0.80	0.30	0.80
Total		100.00	100.00	100.00

Fig. 1 – EDS Spectrum of the Porcelain Aggregate

Mortar Dosage. Table 1 presents the composition of the materials used to prepare three bars of mortar. The porcelain aggregate sample was previously crushed and pulverized using a Renard jaw crusherof theBMA 125.80 model, until the indicated granulometry was obtained.

Table1 – Composition of the Materials

Composition of the Materials	Sieve Opening (mm)[1]					Total Mass (g)
	4.8 - 2.4	2.4 - 1.2	1.2 - 0.6	0.6 - 0.3	0.3 - 0.15	
Aggregates	99	247.5	247.5	247.5	148.5	990
Cement			440			440
Distilled Water (a/c = 0.47) [2]			206.8			206.8

[1]Only for the fine aggregate
[2]For the mixesusingmetakaolin, the water content of this product was discounted

To evaluate mitigation of the alkali-aggregate reaction by the accelerated method from NBR 15577-5 [10], tests were performed using standard cement with added fly ash in contents of 15 and 20%, and liquid metakaolin in percentages of 10 and 20% replacing the standard cement. These percentages are effective for mitigating AAR according to the bibliography, in addition to being economically viable, as mentioned in Table 2.

Table2 – Composition of the Cements.

Percentagesin Bulk (%)	Test 1	Test 2	Test 3	Test 4	Test 5
Standard Cement[1]	100	85	80	90 (95)[2]	80 (90)[2]
Fly Ash[3]	-	15	20	-	-
Liquid Metakaolin	-	-	-	10 (5)[2]	20 (10)[2]

[1] Standard cement provided by the Brazilian Association for Portland Cement (ABCP).
[2]Refers to the solid part added, as the liquid metakaolin is 50% solid and 50% water. The water content in the liquid metakaolin was discounted from the distilled water.
[3]Fly ash provided by Pozo Fly.
[4] Liquid metakaolinprovided by Rheoset (product METATEC HP BRANCO).

Standard Cement. The standard cement used to determine the reactivity of the aggregate is of the CP V-ARI type and wholly obeys the specifications in NBR 5733 [11], for which additional requirements from the NBR 15577-4 [9]norm registered in Table3.

Table3 – Characteristics of the Standard Cement.

Property	Sodium Oxide (Na_2O)	Potassium Oxide (K_2O)	Alkaline Equivalent in Na_2O*	Blaine Specific Area	Expandability inan Autoclave
Test Method	NBR NM 7[12]	NBR NM 17[12]	-	NBR 16.372[13]	ASTM C 151 [14]
Result	0.40%	0.68%	0.85%	4910 cm²/g	0.06%
NBR 15577-4[9]Specification	-	-	(0.90 ± 0.10) %	(4900 ± 200) cm²/g	< 0.20 %

* Alkaline equivalent in $Na_2O \rightarrow Na_2O_{eq} = 0{,}658\%\ K_2O + \%\ Na_2O$

III. RESULTS AND DISCUSSION

Table 4 presents the results of the tests performed according to NBR 15577-4 [9] (porcelain aggregate + standard cement), highlighting the values at 14 and 28 days of curing in an alkaline solution and by NBR 15577-5 [10] (porcelain aggregate + standard cement with added fly ash and liquid metakaolin), highlighting the values at 14 days and 28 days.

According to the parameters in NBR 15577-4 [9], it can be concluded that the porcelain electric isolators used in this study are potentially reactive, since the average dimensional variation was 0.66% at 28 days, which is higher than the norm limit, which is 0.19% at 28 days.

Table 4 – Dimensional Variation of the Mortar Bars in the Alkaline Solution.

Average Dimensional Variations	Aggressive Curing Age (days)											
(%)	2	5	7	9	12	**14**	16	19	21	23	26	**28**
Part 4 - Standard Cement	0.00	0.03	0.06	0.13	0.26	**0.34**	0.40	0.49	0.54	0.58	0.62	**0.66**
Part 5 - Standard Cement+ 15% Fly Ash	0.01	0.01	0.02	0.03	0.04	**0.05**	0.06	0.09	0.10	0.13	0.15	**0.18**
Part 5 - Standard Cement + 20% Fly Ash	0.01	0.01	0.02	0.02	0.03	**0.04**	0.04	0.04	0.04	0.06	0.08	**0.09**
Part 5 - Standard Cement + 10% Liquid Metakaolin	0.01	0.04	0.10	0.16	0.26	**0.34**	0.37	0.45	0.49	0.54	0.60	**0.64**
Part 5 - Standard Cement + 20% Liquid Metakaolin	0.01	0.03	0.04	0.06	0.11	**0.15**	0.17	0.22	0.25	0.28	0.34	**0.37**

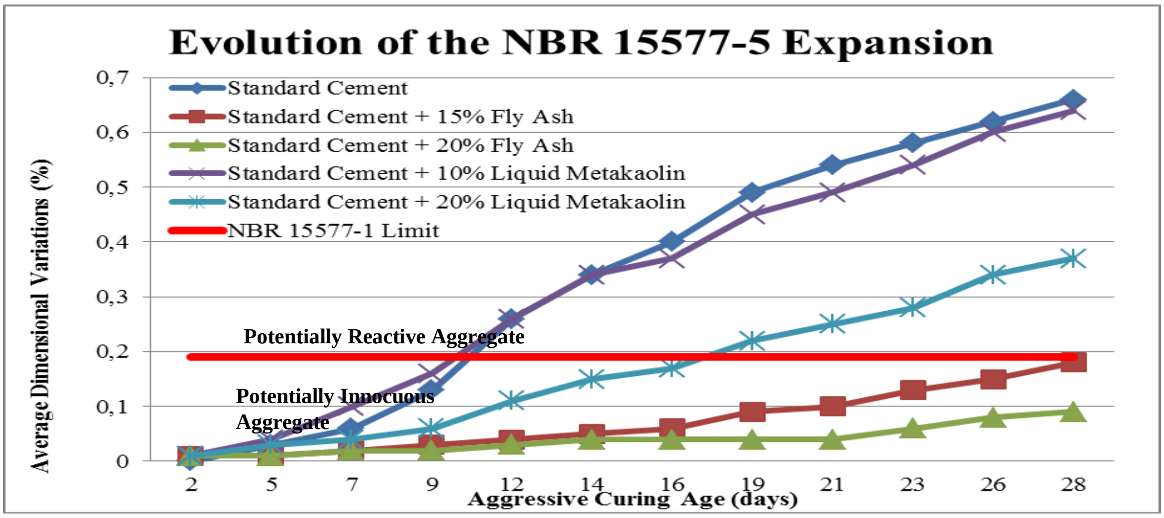


Fig. 2 – Chart of the Expansion's Evolution with Curing Time in an Alkaline Solution (Porcelain Aggregate + Standard Cement with Added Fly Ash and Liquid Metakaolin)

Fig. 2 shows a graphic representation of the average dimensional variation of mortar bars in an alkaline solution, where we highlight the measurement of the porcelain with the standard cement, which reached 0.66% at 28 days, and the mitigation measures. The incorporation of the liquid metakaolin was not an effective measure for mitigating AAR, as the values of the dimensional variation were 0.64% and 0.37% for the percentages of 10% and 20%, respectively.

The addition of fly ash was the most effective measure for mitigating the effects of AAR, as they were kept below the limits established by NBR 15577[2]with a use content of 15% having a dimensional variation of 0.18% at 28 days, so that for the percentage of 20% of incorporation, the average dimensional variation at 28 days was 0.09%.

IV. CONCLUSION

According to the NBR 15577-1 [2] norm, when the results of the test indicate expansion lower than 0.19% at 30 days (28 days of curing in an alkaline solution), the aggregate is considered potentially innocuous for use in concrete. Expansion greater than or equal to 0.19% indicates that the aggregate is potentially reactive.

With the results presented, it can be observed that the average expansion value of the mortar bars at 28 days of curing in an alkaline solution of the porcelain aggregate sample was 66%, indicating that the aggregate is potentially reactive according to the criteria established.

As for the evaluation of the mitigation of the alkali-aggregate reaction through the accelerated method in NBR 15577-5 [10], Part 1 of the norm establishes that proof of mitigation of the reaction is obtained when the expansion is less than 0.10% at 16 days (14 days of curing in an alkaline solution). For expansion values equal to or greater than 0.10%, new tests are necessary so as to meet the established limit, where one can opt to trade the cement used or incorporate or increase the contents of silica fume or metakaolin or even substitute the aggregate.

The results obtained indicate that the combinations made with the porcelain aggregate + standard cement with the addition of fly ash at contents of 15 and 20% presented expansion values lower than the maximum expansion limit of 0.10% at 14 days of curing in an alkaline solution specified by the norm, indicating that the fly ash was effective in mitigating the alkali-aggregate reaction in the contents tested.

Regarding the combination of the porcelain aggregate + standard cement with the addition of liquid metakaolin at percentages of 10 and 20%, it can be observed that the expansions were higher than 0.10%, indicating that the content of metakaolin added was insufficient for mitigating the alkali-aggregate reaction. Effectively, the metakaolin percentages added were 5 and 10%, since liquid metakaolin contains 50% solid material and 50% water.

In short, the porcelain aggregate sample is potentially reactive in relation to the alkali-aggregate sample and the addition of fly ash content higher than 15% will be enough to mitigate the alkali-aggregate reaction. As for liquid metakaolin, new tests must be performed to determine the percentage adequate for mitigating the alkali-aggregate reaction.

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