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ORIGINAL ARTICLE

Influence of granitic rock fines addition in the alkali-aggregate reaction (AAR) in cementitious materials

Influência dos finos de rocha granítica (FRG) nas propriedades físico-mecânicas e na reação álcali-agregado (RAA) de argamassas

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Abstract: According to previous studies, fine materials originated from reactive aggregates can act as a Alkali-Aggregate Reaction mitigator, having its effectiveness dependent on their reactivity, fineness and added content. Thus, the present work aims to study if reactive granitic rock fines can mitigate or reduce the AAR and how the fineness of the material influences its mitigation capacity. For this purpose, granitic rock fines (GRF) from 2 different deposits and Pyrex glass fines (PGF) were tested as concrete addition. Each one of these fines were used in two different finesses and added to the concrete in the contents of 20% by mass of cement. It was observed that the addition of GRF did not affect the physical-mechanical properties of concrete and allowed the reduction in the AAR, being more accentuated with the increase of its specific surface.

Keywords: alkali-aggregate reaction, granitic rock fines, durability, performance.

Resumo: Segundo estudos anteriores, materiais finos provenientes de um agregado reativo podem agir como mitigadores da reação álcali-agregado (RAA), contudo, a efetividade da ação desses finos depende do seu grau de reatividade, finura e teor adicionado. Assim, o presente trabalho visa estudar se finos de rochas graníticas reativas (FRG), passante na peneira #200, podem mitigar ou reduzir a RAA e como a finura do material influencia na sua capacidade de mitigação. Para isso, foram utilizados FRG provenientes de 2 diferentes jazidas, obtidos após moagem. Cada adição foi utilizada em três finuras diferentes e adicionadas à argamassa nos teores de 10% e 20%, em relação à massa de cimento. Observou-se que a presença dos FRG não prejudicou as propriedades fisico-mecânicas da argamassa, e ainda possibilitou redução da RAA, sendo mais acentuada à medida que se aumentou a superfície específica do material.

Palavras-chave: reação álcali-agregado, fino de rocha granítica, durabilidade, desempenho.

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1 INTRODUCTION

According to the Brazilian Mining Institute [1], in 2017, Brazil produced about 420 million tons of aggregates for civil construction. In the crushing process of the rocks, fine particulate materials are released, with particles smaller than 75 µm. This material is often improperly discarded, generating negative environmental impacts, besides being harmful to human health.

As an alternative to add value to this material, studies about its incorporation on concrete and mortars have been made. However, such alternative should be performed with caution, because some aggregates can cause a deleterious reaction to the concrete, known as the alkali-aggregate reaction [2].

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The alkali-silica reaction (ASR), which will be studied in this article, is defined as a deleterious reaction of the concrete and occurs when the unstable silica, contained in some aggregates, reacts with the alkaline hydroxides present in the interstitial solution of the concrete, forming an expansive gel in the presence of water [2]. Priskulnik [3] presents the chemical reaction that represents ASR from sodium hydroxide (NaOH), being analogous for KOH potassium hydroxide, according to Equations 1 and 2.

$$SiO_2 \cdot nH_2O + 2NaOH \rightarrow SiO_3Na_2 + (n+1)H_2O \quad (1)$$

$$xSiO_2 \cdot nH_2O + 2NaO \rightarrow Na_2O \cdot xSiO_2 + (n+1)H_2O \quad (2)$$

In calcium-free systems, silica is dissolved and remains in solution. However, in the presence of calcium, the silica precipitates in the solution as an alkali-silicate gel (CaO-Na_2O/K_2O-SiO_2-H_2O) [4] and causes internal pressure that, by exceeding the tensile strength of the cement matrix, causes its differential expansion, leading to mechanical failures [5].

Dunant and Scrivener [6] describe the progress of expansion in three stages. Initially, the expansion is caused by the aggregate cracking and elastic deformation of the paste. In the transition period, the cracking propagates to the paste, presenting much larger expansions. Finally, the expansion generates a matrix cracking with subsequent depletion of the reactive materials.

For AAR to occur, three factors must occur simultaneously: sufficient amount of alkali in the interstitial solution of the concrete, high humidity level and existence of potentially reactive aggregate [2]. In the absence of at least one of these factors, the reaction does not occur. However, once the reaction has started, it cannot be interrupted. Therefore, the best way to prevent its action is to prevent the AAR from occurring. For this, it is necessary to be cautious when selecting the materials used in concrete production.

Priskulnik [3] indicates several factors that can contribute to the reduction and/or mitigation of the AAR, among them: decrease of concrete permeability due to the low water/cement ratio, dosage of an adequate cement consumption and use of active mineral additions, such as silica fume and blast furnace slag, because they fix cement alkalis in the initial phase of cement hydration and decrease the pH of the interstitial concrete solution.

Some materials, such as ground glass, when incorporated into the cement matrix may be favorable to the occurrence of the AAR or act as a mitigator, depending on the particle size of the material. When the glass is used in concrete with particle sizes greater than 0.5 mm, the development of the AAR is observed. However, when ground in dimensions smaller than 100 µm, it can present a pozzolanic behavior and reduce the expansion potential of the ASR [7].

Rajabipour et al. [8] explain that larger particles (in the small aggregate particle size range) of glass have micro cracks wide enough to allow the diffusion of hydroxyles, which will result in a high concentration of dissolved silica and sodium, since these will have greater difficulty in being released to the solution outside the crack. This high concentration will result in the ASR gel.

On the other hand, at the cement-glass interface, the gel formed is not expansive, since silica and sodium are not confined. Unlike what occurs in larger particles, in smaller particles (such as powders), the intraparticle AAR is minimal, prevailing the interfacial pozzolanic reaction.

As a theoretical basis for the present research, several authors have studied the influence of rock fines in the AAR and proposed theories to explain the reduction of AAR caused by the fines generated from reactive aggregates. In a direct way, due to the reduction of cement consumption, there is the reduction of alkaline ions, making it difficult to occur the AAR [9].

The reactive silica, when finely ground, contributes to the gel forming in a distributed manner in the cement paste. However, when it is present in the aggregates, it causes the accumulation of the alkali-silica gel in specific places, making them potential expansion points [10].

Wang et al. [11] concluded that fine materials can act in two ways on cement paste. Due to their fineness, they can act as nucleation points for the paste hydration and thus accelerate the production of portlandite.

On the other hand, due to the reactivity of the fine, it can react with the portlandite, resulting in a higher content of formed C-S-H, which has the capacity to agglutinate the alkalis present, thus reducing the AAR. However, the authors warn that, although the sand fines used could contribute to a greater retention of alkalis, the binding capacity is low due to their low reactivity.

He et al. [9] argue that the substitution of cement by reactive aggregate fines causes a reduction in ASR due to several factors. The reduction of cement consumption from the substitution of cement by fine causes a reduction in the alkali content available for the reaction. In addition, the presence of amorphous silica and high specific surface causes an increase in calcium hydroxide consumption due to pozzolanic activity, contributing to the reduction of the thickness of the ASR gel around the aggregate and reducing the effects of ASR. Despite reducing the expansion caused by ASR, the substitution of 50% of cement by fine reactive reduced the compressive strength by 35%, in mortars with water/(cement + GRF) ratio equal to 0.47%.

Carles-Gibergues et al. [12] used four types of reactive aggregate powders to investigate whether these materials are efficient in compensating the expansion of ASR caused by the large aggregate. The authors replaced 10 and 20% of the aggregate mass (0.08 to 4mm) with fine (less than 0.08mm) of different finesses, with specific Blaine surfaces varying between 100 and 650 m^2/kg. As a result, it was observed that the use of the reactive fines reduced the expansion of mortars and that the efficiency of the material depended on the origin, fineness and content used.

The larger surface area of the fine contributes to the higher dissolution rate of silica, resulting in a decrease in the Ca/Si ratio in the C-S-H formed during the hydration of the cement and increasing its capacity to fix the alkalis. The depletion of free alkalis decreases the pH of the pore solution, reducing the attack on the reactive aggregates [12]. Cyr et al. [2] studied the AAR in mortars with replacement of 10 and 20% of the sand by reactive aggregate fine (<80 µm) from 11 different types of aggregates. The authors observed a reduction of the expansion that varied from 19% to 78%, depending on the type of aggregate and highlighted some parameters that affect the efficiency of the fines, namely: silica content, fineness of the fine, available alkaline content and specific surface area.

The substitution of cement for the fines causes a reduction in the mechanical resistance of concrete and mortars, therefore, in the present work we have chosen to introduce the fines as an addition to the cement mass. Thus, it was studied how this addition of rock fines influences the physical-mechanical properties of mortars and the alkali-aggregate reaction. Additionally, it was studied if this accelerated reaction harms the physical-mechanical properties of the mortars tested.

2 MATERIALS AND EXPERIMENTAL PROGRAM

2.1 Materials

For the reactivity evaluation of the aggregates and evaluation of the efficiency granitic rock fines in the mitigation of ASR (item 2.3), a special cement with high content of alkalis produced by the Brazilian Association of Portland Cement (ABCP) was used, according to NBR 15577 [13]. For the physical-mechanical tests (item 2.4), Portland Cement CPII-F 32 was used, as it does not present pozzolanic additions and is a cement that does not mitigate the alkali-aggregate reaction. Table 1 shows the chemical composition of the cements used, determined by X-ray fluorescence spectrometry (XRF), using the Bruker S2 Ranger equipment.

Table 1. Chemical composition, in oxides, of the cements used.

Materials	**Compound (wt %)**										
	SiO_2	**Al_2O_3**	**Fe_2O_3**	**CaO**	**MgO**	**SO_3**	**K_2O**	**Na_2O**	**Others**	**Na_2O_{eq}***	**LOI**
CP II-F 32	16.13	3.67	3.04	60.73	3.90	5.30	1.78	0.00	0.49	1.17	4.97
CP ABCP	16.13	4.46	2.69	56.69	3.54	5.74	1.15	1.95	0.72	2.71	6.92

*LOI = Loss on ignition at 1000°C

Distilled deionized water was used in the molding of the mortars and in the preparation of the solution. The small aggregate used came from the crushing of granitic rock and has a specific mass of 2.77 g/cm^3. It was sifted, washed and, later, each granulometric fraction was weighed in order to obtain the granulometric composition determined by NBR 15577 [13].

The fines, passing fraction in sieve #200 (75 µm), used were the granitic rock fines (GRF), from two different quarries, defined as A and B, all of them being ground in order to obtain three distinct specific surface of each material. Table 2 presents the physical characterization of GRF obtained. The specific surface area was determined by BET (Gemini VII equipment from Micromeritics) and Blaine (Acmel automatic permeability, model BSA1) methods, and the specific mass by helium pycnometry (AccuPyc II 1340 Micromeritics).

Table 2. Physical characterization of the fines used

	Blaine surface area (cm^2/g)	**BET surface area (m^2/kg)**	**Specific gravity (g/cm^3)**	**Average particle diameter (µm)**
FA1	2042 ± 1	11500	2.86 ± 0.01	55.13
FA2	5936 ± 37	35200		8.39
FA3	6665 ± 30	46174		4.43
FB1	3521 ± 12	25700	2.83 ± 0.01	17.61
FB2	5233 ± 4	39500		7.71
FB3	6599 ± 13	52127		3.24

2.2 Characterization of materials

After obtaining the fines, they were characterized as to their granulometric distribution. For this, the Mastersizer 3000 Hydro 3000 laser granulometer was used.

The chemical compositions of the fines were determined by X-ray fluorescence spectrometry (XRF), using the Bruker S2 Ranger equipment and the pozzolanic activity was determined by chemical titration test, according to the European standard EN 196-5 [14], replacing 25% of the cement with fine.

The mineralogical characterization of cements and fines was performed by the X-ray diffraction (XRD), using a D2 Phaser, Bruker diffractometer, with 10mA and 30Kv copper target tube, wavelength (λ) equal to 0.15406nm, without filtering system with secondary monochromator. The diffraction spectra were obtained in the range 2θ from 5° to 70°, continuous mode at 0.1/s and the phases were identified using the software DIFFRAC plus-EVA, with the Crystallography Open Database (COD) centered database.

2.3 Evaluation of the alkali-aggregate reaction

In the analysis of the evaluation of the occurrence of the alkali-aggregate reaction and assessment of the efficiency of granitic rock fines in the mitigation of ASR, the accelerated method was used in mortar bars, according to NBR 15577 [13] in parts 4 and 5.

For these tests, mortars were molded with the formulation, in mass, of 1: 2,25: 0,47x (cement: aggregate: GRF: water), being x the GRF content, equal to 0 for the reference mortar (without GRF) and 0,10 and 0,20 for mortars containing 10% and 20% of GRF, respectively.

The introduction of granitic rock fines was performed in addition to cement so that it remained constant in all specimens studied, also keeping constant the cement/aggregate ratio. Moreover, a previous study showed that the substitution of cement by GRF, despite being efficient to reduce the AAR, caused a high loss of mechanical resistance [8].

Table 3 presents the nomenclature, the formulations, the water/(cement+GRF) ratio and cement consumption of the mortars studied. It is worth mentioning that in this stage all the formulations were molded using the cement supplied by ABCP.

Table 3. Design parameters of the of the mortars mixes

Nomenclature	**Mix proportion by weight**	**Water/ (cement + GRF) ratio**	**Cement consumption (kg/m^3)**
REF	1: 2.25: 0.47	0.47	600.10
A10FA1/A10FA2/A10FA3	1: 0.10: 2.25: 0.47	0.43	587.77
A20FA1/A20FA2/A20FA3	1: 0.20: 2.25: 0.47	0.39	575.93
A10FB1/A10FB2/A10FB3	1: 0.10: 2.25: 0.47	0.43	587.64
A20FB1/A20FB2/A20FB3	1: 0.20: 2.25: 0.47	0.39	575.69

For each formulation, three CPs (2.5 x 2.5 x 28.5 cm^3) were molded, according to NBR 15577-4 [13]. About 24 hours after molding, the CPs were immersed for 24 hours in distilled water at 80°C and then immersed in 1N Na(OH) solution at 80°C for 28 days. The specimen expansion was measured every two days.

2.4 Evaluation of the physical-mechanical characteristics of mortars

To evaluate the physical-mechanical characteristics of the mortars, the same formulations were used in the AAR tests (item 2.3), however, in this stage CP II-F 32 cement was used. Reference mortars (without GRF) and with the addition of GRF of Blaine surface area between 5000 and 6000 cm^2/g (index 2 fines) were molded, in 20% of the cement mass. For each formulation, 22 specimens (CPs) of 4 x 4 x 16 cm^3 dimensions were molded for physical-mechanical characterization of the mortars.

For mechanical strength performance analysis, axial compression and flexural tensile strength tests were performed at 3, 7 and 28 days of cure in water at 24°C, and after 28 days immersed in Na(OH) saturated solution, following NBR 13279 [15]. Four samples were tested in flexure and five samples in axial compression, using half of the CPs ruptured in flexure. In addition, the capillary water absorption, according to NBR 9779 [16] and apparent density and porosity, following NBR 9778 [17], were determined at 28 days of cure in water saturated with lime and at 28 days in Na(OH) solution.

The data obtained were statistically analyzed using single factor variance analysis (ANOVA) and when it indicated that at least one of the GRF significantly influenced the property, Tukey's test was used to verify which fine(s) caused such change.

3 RESULTS AND DISCUSSIONS

3.1 Characterization of materials

Table 4 shows the chemical composition, in oxides, of the GRF used. It can be observed that these have higher levels of silicon (SiO_2) and aluminum (Al_2O_3) oxides than the other oxides present in the material. It is noted that the aggregate used in this research has the same origin of FA and consequently the same chemical composition.

Table 4. Chemical composition, in oxides, of the granitic rock fines studied

Materials	**Constituents (%)**									
	SiO_2	**Al_2O_3**	**Fe_2O_3**	**CaO**	**MgO**	**SO_3**	**K_2O**	**Na_2O**	**Outros**	**LOI***
FA	54.21	15.77	9.31	5.81	4.93	0.33	2.70	3.75	1.80	1.40
FB	59.66	15.63	8.93	5.26	4.33	0.86	2.36	0.00	1.29	1.69

*LOI = Loss on ignition at 1000°C

Figure 1 shows the granulometric distribution of cements and GRF used. Fines FA1 and FB1 have D50 larger than cements, while fines FA2, FB2 have D50 smaller than cements. Fines FA3 and FB3 have D50 smaller than index 2 fines due to the longer grinding time of the fines represented by index 3.

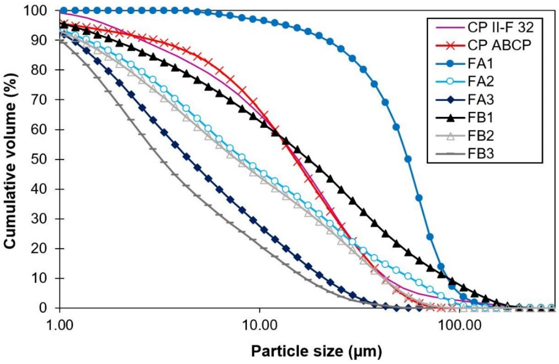
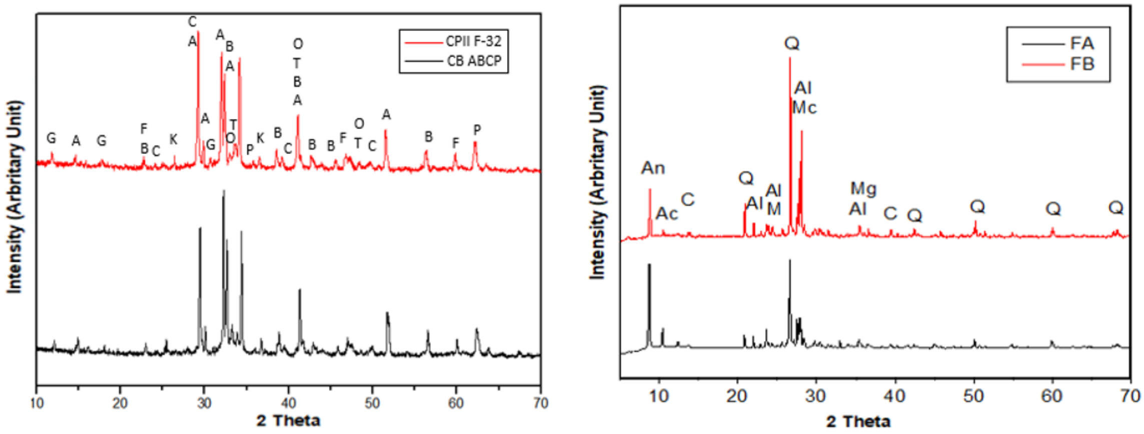


Figure 1. Particle size distribution of cements and GRF used.

Figure 2 shows the cements diffractogram (Figure 2a) and GRF (Figure 2b) used. The cements (Figure 2a) present the same crystalline phases, being identified as the phases alite ($C_3S–3CaO.SiO_2$), belite ($C_2S–2CaO.SiO_2$), C_4AF ($4CaO.Al_2O_3.Fe_2O_3$), cubic C_3A ($3CaO.Al_2O_3$), orthorebic C_3A ($3CaO.Al_2O_3$), calcite ($CaCO_3$), gypsum ($CaSO_4.1/2H_2O$), arcanite (KSO_4), and periclase (MgO).

The granitic rock fines (A and B) have very similar mineralogical compositions, with the presence of the minerals albite ($NaAlSi_3O_8$), quartz (SiO_2), annite [KFe_3^{2+} $AlSi_3O_{10}(OH)_{1,5}F_{0,5}$], microcline ($KAlSi_3O_8$), actinolite [$Ca_2(Mg,Fe^{2+})_5Si_8O_{22}(OH)_2$], magnetite ($FeO.Fe_2O_3$), dolomite [$CaMg(CO_3)_2$] and kaolinite [$Al_2Si_2O_5(OH)_4$].



(a)

(b)

Figure 2. Identification of the crystalline phases of the (a) cements and (b) GRF studied. A-Alite; B-Belite; F-C_4AF; T-cubic C_3A, O-orthorambic C_3A, C-Calcite, G-Gypsum, K-Arcanite, P-Periclase; Al-Albite; Q-Quartz; An- Annite; M-Microcline; Ac-Actinolite; Mg-Magnetite; C-Caulinite.

As the GRF were used as mineral addition to the cement, the pozolanicity analysis was performed by the modified Fratini method, which evaluates the consumption of hydroxyl (OH^-) and calcium oxide (CaO) from pastes containing cement and the GRF. The results obtained are presented in Figure 3.

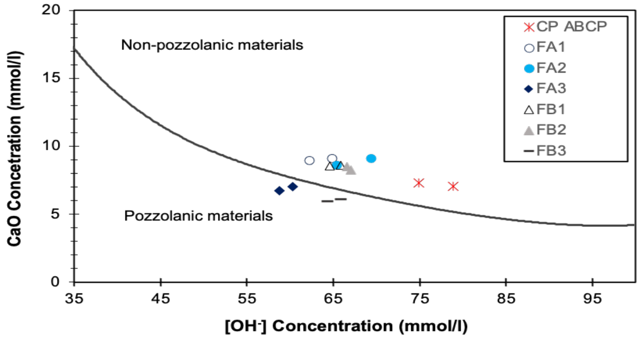


Figure 3. Result of the chemical titration test, according to standard NP EN 196-5.

The presence of alkaline ions in the solution causes the portlandite [$Ca(OH)_2$], formed during cement hydration reactions, to release hydroxyl (OH^-) in order to balance alkaline sodium (Na^+) and potassium (K^+) cations [10].

By the test performed, only FA3 and FB3 fines were characterized as pozzolanic materials. However, although FA1, FA2, FB1 and FB2 fines were characterized as non-pozzolanic materials, their presence in the mixture caused a reduction of hydroxyl ions, due to a lower amount of cement in the mixture or due to ion retention by the GRF.

The authors warn that complementary tests are necessary so that the GRF studied can be used as pozzolanic materials.

Ichikawa [18] describes that initially the aggregate is attacked by alkaline hydroxides, converting the superficial layer of the aggregate into alkaline silicate. The OH^- consumption causes the dissolution of Ca^{2+} ions of $Ca(OH)_2$, which, by reacting with the alkaline silicate layer, makes the layer more resistant, penetrates the aggregate and generates an expansive pressure.

Bektas and Wang [19] warn that the phenomena associated to AAR are complex and that, although there are no definitive conclusions about the chemistry of AAR gel, the alkali and calcium contents seem to be the key parameters for the understanding of the reaction. Ichikawa [18] complements that the high concentration of both $Ca(OH)_2$ and OH^- are necessary for the expansion due to AAR, however, their performance in the reaction is not yet fully understood.

3.2 AAR accelerated mortar bar test

For the accelerated mortar bar test, the GRF studied were added to the mixture at levels of 10% and 20% in relation to the cement mass and the results are presented in Figure 4 and Figure 5, for mortars containing FA and FB, respectively. It can be observed that, at the end of the test, only the mortars containing FA1 and FB2 fines presented expansions lower than 0.19%, being these fines characterized as reaction mitigators.

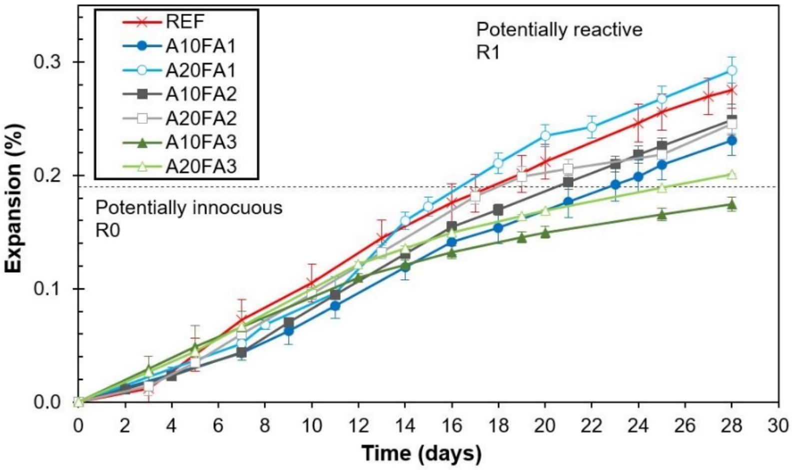


Figure 4. Expansion of the mortars, containing the fine of origin A, during the accelerated test for evaluation of the alkali-aggregate reaction (AAR) and the classification ranges.

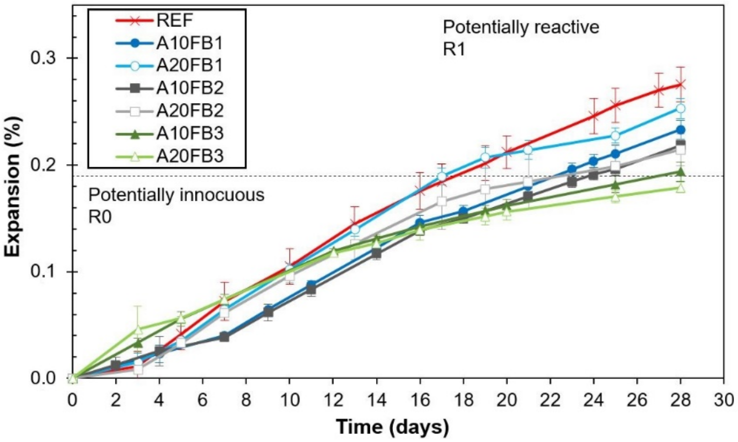


Figure 5. Expansion of the mortars, containing the fine of origin B, during the accelerated test for evaluation of the alkali-aggregate reaction (AAR) and the classification ranges

For a better view of the results, the expansions of the mortars containing the granitic rock fines A (Figure 6) and granitic rock fines B (Figure 7) at 28 days in solution of NaOH 1N at 80°C are presented.

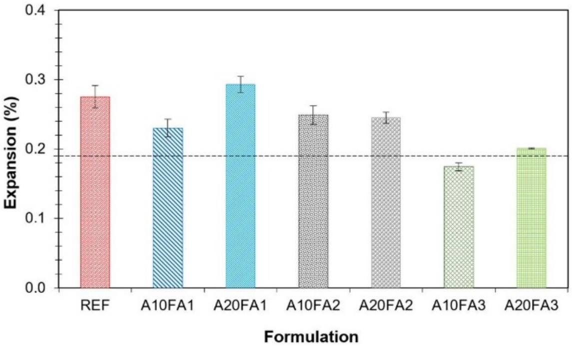


Figure 6. Expansion of mortars containing 10% and 20% of the origin A fines, after 28 days, in NaOH 1N solution

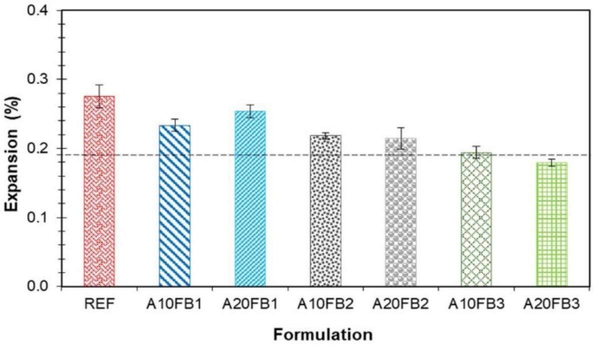


Figure 7. Expansion of mortars containing 10% and 20% of the origin B fines, after 28 days, in NaOH 1N solution.

The FA1 fine addition (Figure 6) obtained a greater expansion reduction when added at the content of 10% than for the 20% fine addition content, because the mortar A20FA1 obtained the same expansion as the reference mortar, this same effect was seen for the mortars with FB1 addition (Figure 7).

This effect suggests that the specific area of the fine is not sufficient to significantly reduce the expansion of mortars. Since, as shown in the particle size distribution, the GRF have some particles larger than 75 μm and the higher content added, the greater the amount of particles large enough to contribute to the alkali-silica reaction.

Regarding the FA2 and FB2 fines (Figure 6 and Figure 7), the addition of these materials caused a reduction in the mortar expansion. However, the addition of 10% and 20% of each fine obtained the same efficiency. These results suggest that it is necessary to add even higher amount of fines in order to mitigate the reaction in order to obtain expansions smaller than 0.19% at 28 days.

When analyzing the expansion results of mortars containing FA3 (Figure 7), it was found that 10% addition of this fine was sufficient for the expansion of the mortar to be in the expansion zone degree 0. However, by adding 20% of this same fine, there was a small increase in expansion compared to the addition of 10%. These results suggest that the optimal incorporation content for the mitigation of the expansion by FA3 fine is around 10%.

For the FB3 fine (Figure 7), the results show that 10% of addition of this fine contributed to reduce the expansion of the mortar studied, but the limit defined in standard is reached only for the 20% of fine addition. Considering the standard deviation, the expansion of mortar A10FB3 is very close to 0.19%, so it is likely that an addition around 15% of the fine FB3 is sufficient for ASR mitigation.

Such findings corroborate to the results obtained in the pozzolanic evaluation of the GRF (Figure 3), where only the fines characterized as pozzolanic (FA3 and FB3) were efficient in reducing the expansion of mortars to values below 0.19%.

A significant increase in the expansion of mortars could have occurred due to a higher content of reactive silica present (due to the sum of reactive silica contained in the aggregate and contained in the fine added). However, it is observed that the increase in the surface area of the GRF added has contributed to a significant reduction in the expansion of mortars, for all types of GRF.

The fine presence can make it difficult to expand the AAR because, due it has a higher fineness, being more reactive than the aggregate, making the hydroxyls react first with the fine and reduce the attack on the aggregate [20], this interaction of the hydroxyls with the silica present in the GRF can result in an expansive gel or the C-S-H gel, not expansive.

If the gel is expansive, the gel formed around smaller particles has a smaller thickness than the gel formed around the aggregate, causing less expansion of the mortar [9]. Therefore, the preferential attack of the hydroxyl ions to the GRF causes a smaller mortar expansion.

Due to the nature of the test, where the mortars are inserted in a solution rich in NaOH at 80ºC, it is not possible to assess whether the consumption of OH^- by the GRF causes a reduction in the AAR, since alkaline hydroxides are supplied continuously to the mortar [18].

Thus, although the accelerated test has shown that the addition of the GRF did not cause an increase in the expansion of the mortars, it is necessary that the test be performed on concrete bars or mortar bars without the insertion of the specimens in the alkaline solution. Such tests are recommended by NBR 15577 [13].

3.3 Physical-mechanical characteristics of the mortars

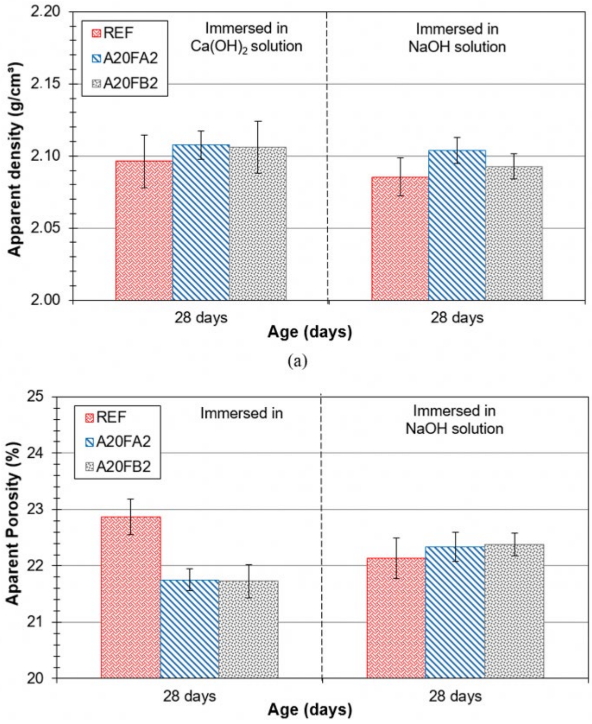
3.3.1 Density and apparent porosity

The apparent density and porosity values of the mortars used are shown in Figure 8a and Figure 8b, respectively.

According to ANOVA statistical analysis, the addition of the GRF did not cause a significant modification in the apparent density and porosity of the mortars studied. Likewise, the insertion of the mortars in NaOH solution did not cause a decrease in the pore structure of the mortars, when compared to the mortars submitted to the immersed cure.

The opposite behavior was observed by Ribeiro and Rey [21], who verified that thinner materials than cement fill the pores and promote a better densification of the paste and reduction of porosity.

This better packaging of the particles may not have been achieved, because the reduction in the workability of the mortars, caused by the introduction of the GRF, makes it difficult to densify them, since thinner materials require a greater amount of water to lubricate the particles and ensure workability.



(a)

(b)

Figure 8. (a) Apparent density and (b) apparent porosity of the reference mortars and containing 20% of the GRF, at 28 days of curing and after 28 days immersed in saturated solution in lime and 28 days immersed in solution of NaOH 1N.

Regarding the type of cure, Rashidi et al. [22] identified that in reactive samples, those immersed in water have a lower total porosity than the samples immersed in NaOH solution, because they do not have enough alkali concentration for the occurrence of AAR and consequent micro cracking. However, in non-reactive samples the microstructural changes are more subtle.

3.3.2 Water capillary absorption

The capillary absorption coefficients (sortivity) of mortars are presented in Figure 9. According to statistical analysis, the addition of fine FA2 caused a significant reduction in capillary absorption. It was also observed that there were no significant changes in the results according to the curing method (wet curing saturated in lime ($Ca(OH)_2$) or in NaOH solution).

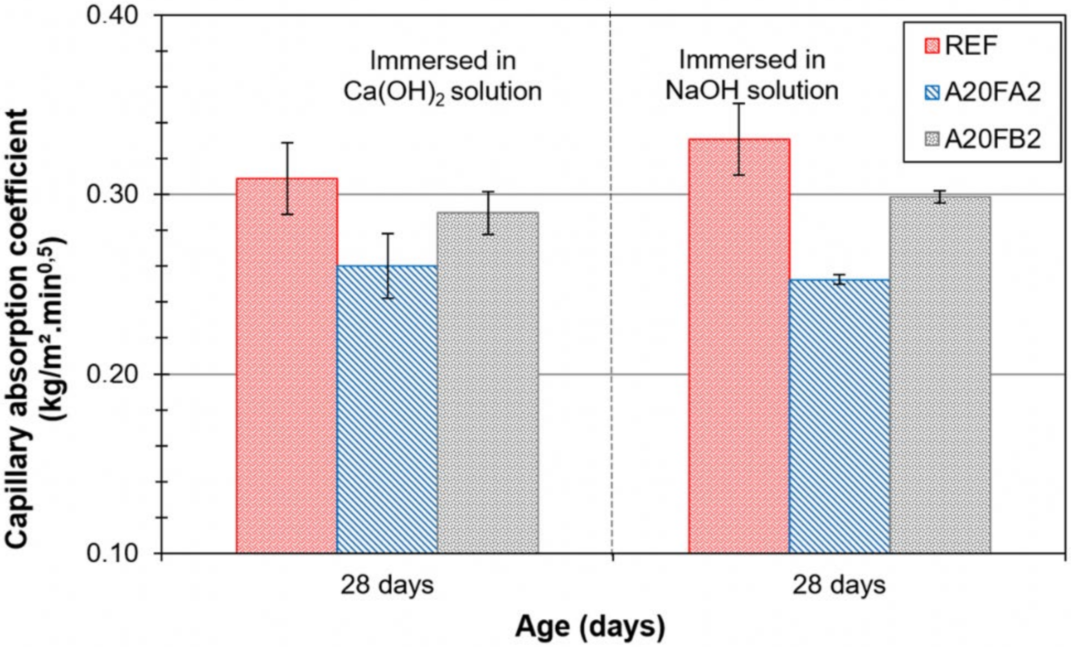


Figure 9. Capillary absorption coefficients of the reference mortars and those containing 20% of GRF at 28 days immersed in saturated solution in lime and at 28 days immersed in solution of NaOH 1N.

The presence of fine FA2 caused a decrease in capillary absorption, probably due to a reduction in the interconnectivity of the capillary pores. The mortar containing FB2 did not present any significant change in relation to the reference mortar, since these GRF and the cement present similar grain sizes.

3.3.3 Mechanical strength

Figure 10 presents the results of axial compressive strength of the mortars studied. Statistically, only the presence of the fine FB2 caused a significant increase in the resistance to axial compression, in relation to the reference mortar, at 3 days.

However, at 7 days and 28 days of curing immersed in $Ca(OH)_2$ solution at 24°C, the compressive strength of the samples was statistically the same. It is worth noting that cement consumption reduced with the increase in granitic rock fines, but the water to aggregate ratio was kept the same for all samples.

When comparing the curing methods used, it was found that the reference mortar was more significantly influenced when compared to the other formulations, having a greater reduction in compressive strength when inserted in NaOH solution at 80°C. For the mortars containing the FA2 and FB2 fines, the curing method did not significantly influence the axial compressive strength.

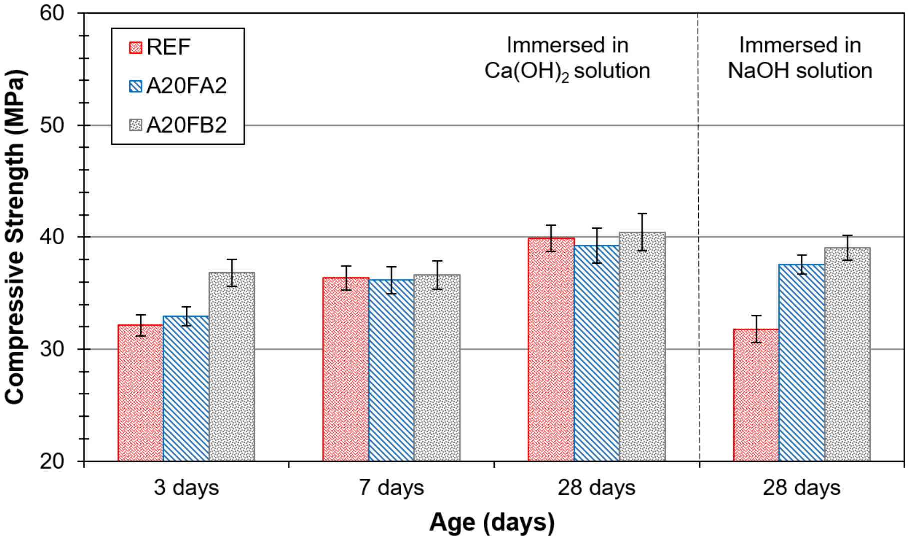


Figure 10. Compressive strength of reference mortars and containing 20% of the GRF, at 3, 7 and 28 days immersed in saturated solution in lime and at 28 days immersed in solution of NaOH 1N.

Figure 11 shows the resistance to flexural tensile strength of the mortars, which was not significantly altered due to the introduction of the GRF studied after 3 and 7 days of cure. It was also observed that the immersion of the reference mortar in NaOH solution caused a reduction in the tensile strength in bending, however the strengths of mortars containing FA2 and FB2 were not influenced by the curing method.

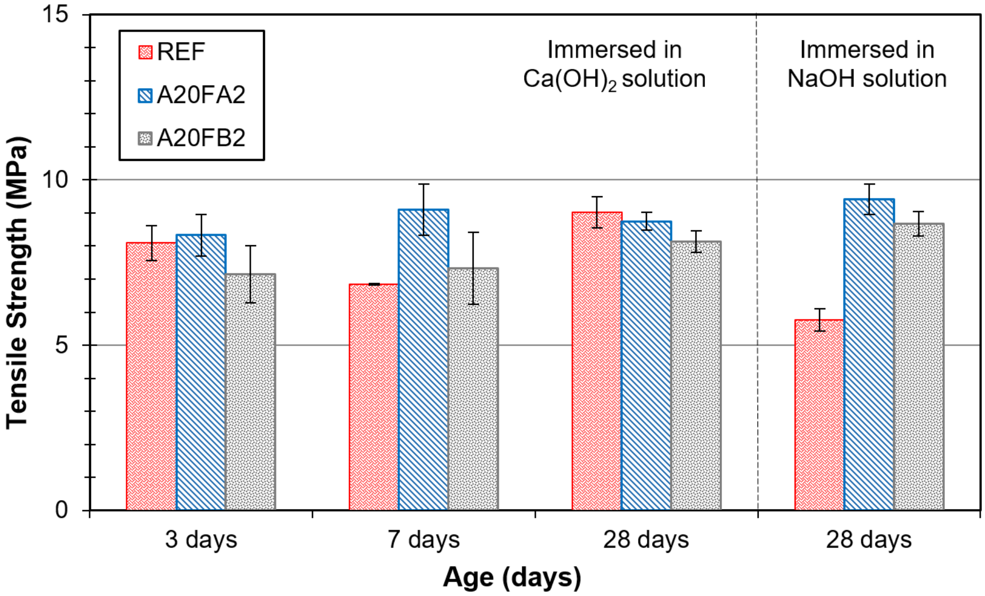


Figure 11. Tensile strength in the bending of reference mortars and containing 20% of the GRF, at 3, 7 and 28 days immersed in saturated solution of lime and at 28 days immersed in solution of NaOH 1N.

As for the curing method, it should be noted that both the curing immersed in water (saturated in $Ca(OH)_2$) and in NaOH solution at 80°C, provide an environment with basic pH, and the exchange of calcium hydroxide for sodium hydroxide favors the occurrence of the alkali aggregate reaction. Thus, the hydration reactions of the mortars are not significantly altered, which explains the maintenance of strength values to mortars containing GRF.

For the reference mortar, the expansion due to AAR may have caused a weakening in the matrix, thus reducing its mechanical resistance.

However, the tensile strength and modulus of elasticity are more sensitive to AAR cracking than to axial compression [18], [23]. This factor may be related to the microscopic damage caused by the AAR in the aggregates that impair the bond between these and the cement paste due to changes in its characteristics, such as texture, resistance, hardness, among others [24].

Souza et al. [23] describe that significant reductions in compressive strength occur when the expansion levels are high, with expansions close to 0.30%, due to the large amount of cracks in the cement paste, forming a network of cracks [25].

The small influence of the occurrence of AAR on the tensile and compression resistances of mortars in the presence of fine reactive can be explained by the reduction of the expansion pressure caused by the penetration of the expansive gel in the aggregate [18]. Thomas [10] explains that the size of amorphous silica influences the formation of the expansive gel, because finely divided materials cause the gel to form in a manner distributed throughout the cement paste, while larger particles lead to the accumulation of the alkali-silica gel in specific locations, making them points of expansion. The formation of the gel in a distributed manner causes that, if there is a breakage of the particles due to the expansion of the gel, it will interfere less in the matrix the smaller its size is.

4 CONCLUSIONS

From the results obtained, one can conclude:

- The addition of granitic rock fines reduced cement consumption without significantly altering the physical-mechanical properties of mortars;
- The addition of granitic rock fines presented a reducing effect of the ASR, which was intensified as the fineness of these fines increased, indicating that the probable increase in the amount of reactive silica dissolved in the solution did not contribute to the formation of the expansive gel, consuming the alkalis in the first ages;
- The granitic rock fines with surface area above 600 cm^2/g acted as a mitigator of the alkali-aggregate reaction, evaluated by accelerated testing on mortar bars;
- It should be noted that there is a need for complementary tests and with greater execution time, such as concrete prism tests, to prove the mitigating effect of fine;
- The immersion of mortars containing granitic rock fines in Na(OH) solution did not cause changes in their physical-mechanical properties, unlike what occurred for reference mortars.

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