ALKALI RELEASE OF AGGREGATES. EFFECTIVENESS OF DIFFERENT SOLUTIONS AND CONDITIONS OF TEST

E. Menéndez^{1*}, R. García-Rovés¹, B. Aldea¹, S. Ruíz²

¹Institute "Eduardo Torroja" of Construction Science (CSIC), Madrid, SPAIN

²Dragados, S.A. <u>SPAIN</u>

Abstract

The alkali release of aggregates can constitute a source of alkalis in concrete exposed to wet environment for long time. Feldspars are one of the minerals that can release alkalis to the concrete with the time.

With granite aggregates has been observed the formation of reaction products in the interface with the paste due to the alkali release from sodium and potassium feldspars. This is observed after more than 25 years of the exposition. It is necessary to evaluate the potential amount of alkalis releasable to define the formulation of concrete before the manufacturing of it.

To evaluate the alkali release of aggregates different solutions and test conditions are used. In the present work the potential alkali release of a granodiorite rock has been determined using different solutions and test conditions. The influence of the type of ions presents in the solution, the concentration of them and temperature have analyzed.

Keywords: Alkali release, aggregates, extraction, test method, effectiveness

1 INTRODUCTION

The appearance and the development of the aggregate-alkali reaction and especially the silicaalkali reaction is associated mainly with the presence of alkalis in the cement, however other components may also provide alkalis. The presence of these supplementary alkalis affects the development of the aggregate-alkali reaction. Different aggregates may give rise to the leaching of alkalis to the concrete. According to [1-6] the leaching of alkalis from feldspars has been confirmed. Likewise, [4,6,7] indicate that the leaching of alkalis takes place in micas. Even though, according to [4,6,8], there is only indirect evidence of the leaching of alkalis from the aggregates in the concrete to bring about an increase in the aggregate-alkali reaction in real concretes. However, according to [9,10] there is direct evidence of damage caused by AAR in concrete, due to the leaching of alkalis from feldspars, associated with the presence of dawosnite and nepheline. Furthermore, [6] indicates that the sodium and potassium feldspars present in the alaskite may give rise to expansion and the formation of aggregate-alkali reaction products, concluding that feldspars may give rise to an increase in expansion in the concrete, especially cements are used with a low content of alkalis, due to the incorporation of alkalis at the porous phase. For its part, [11] observes that the presence de aggregates with potassium feldspars contribute to the formation of aggregate-silicate reaction products.

According to [6,12] it is difficult to bring about the decomposition of the feldspars in solutions of saturated KOH, NaOH and $Ca(OH)_2$. In these cases, the increase in alkalis in the solution or in the porous phase would be related to the ionic exchange of Na and K with Ca. Furthermore, part of the leached alkalis is incorporated into the reaction products, even though the types of products formed depend on the composition of the solution and of the amount of Ca [13]. In accordance with the results, the Na of feldspars of the alaskite is stable in alkaline solutions of K (0.5N) and saturated Ca. For its part, the K feldspars in this same solution give rise to a reduction in Al and Si and generate the formation of reaction products.

However, different authors are critical as regards the relationship with the incidence of the alkalis leached from the aggregates in the development of the silica-alkali reaction. [6,14] pose the need to consider the efficacy of the alkalis liberated by the aggregates as regards those liberated by the cement. The alkalis liberated by the cement are produced under the conditions of an elevated presence of CaO, which is why the Na⁺ and the K⁺ are not fixed. While [14] indicate that in the case of potassium feldspar, K is liberated, but Al2O₃ and SiO₂ remain. These acid oxides need to be well

^{*} Correspondence to: emm@ietcc.csic.es

combined with CaO or even with K_2O and Na_2O to give rise to high-basicity products. As regards the variations that are brought about in the solution of the porous phase of the concrete, [15,16] indicate that the liberation of alkalis on the part of the aggregates contributes to the increase in OH- ions and the pH in it. However, the great contribution of alkalis to the porous phase is brought about by the contribution of the cement, even though this contribution of alkalis depends on the type of cement used.

Different test methods are posed to evaluate the potential contribution of the alkalis of the aggregates to the concrete, with the aim of extracting and quantifying the alkalis of the aggregates. Van Aardt [17] analyses different test methods proposed by [18-21]. These test methods use different types of extraction solutions based on the use of saturated solutions in calcium [18-20] and calcium hydroxide solutions with an excess of it [21]. Furthermore [19] uses distilled water for the evaluation of the aggregates. For its part, [17] proposes a test method based on the use of solutions with both alkalis and calcium; using different methods for the test, such as distilled water, solution saturated with calcium hydroxide with an excess of it, 0.7N of NaOH and 0.7N of KOH. For its part, [6] uses an accelerated method, testing the aggregates at 150°C for 24 hours with saturated extraction solutions in calcium with excess, 0.7N of NaOH saturated in calcium and 0.7N de KOH saturated in calcium. For its part, [22] uses solutions to simulate the pH of the porous phase of the concrete, with different proportions of sodium, potassium and calcium, testing granite aggregates for 28 days at 20°C and 40°C. According to [23] the extraction of potassium and sodium with only NaOH or KOH is mainly due to ionic exchange processes and there is no change in the balance of ions in relation to the initial state. However, according to [24], when there is a total absence of calcium in the solution, the OHions are consumed and the pH descends and the anions of the aggregates are extracted, provided that there is no saturation of ions. However, in the concretes the portlandite may contribute OH ions with the aim of re-establishing the balance with the cations in the porous solution. To avoid the drop in the pH and the consumption of OH- ions it is necessary to use an excess of calcium hydroxide in the extraction solutions to supply these OH- ions [17, 25]. For its part, [6] indicates that the maximum extraction of alkalis is brought about by saturated solutions and with an excess of calcium. Menéndez [22] proves that the saturated solutions in $Ca(OH)_2$ and those that simulate the porous phase are the most efficient at bringing about the extraction of alkalis in granite-type aggregates.

However, as well as the extraction of alkalis in the aggregates, it may give rise to the formation of aggregate-alkali reaction products in the aggregates subject to testing, especially in tests of a relatively long duration [15,22]. Furthermore, [6] indicates that the formation of reaction products may come about in the tests carried out with a low liquid:solid relationship, as there are not enough ions available in solution and a precipitation of the reaction products comes about.

The extraction of alkalis in granite aggregates when subject to the action of different solutions which simulate the pH of the porous phase of the concrete is analyzed in this work. This granite aggregate has proven to be reactive in hydraulic structures, observing the formation of alkali-silicate reaction products.

The main characteristics of the aggregate, related to its reactive behaviour against the alkalis, likewise the test methods for the extraction of the alkalis, which allows the potential leaching of the alkalis from the aggregates to concrete to be evaluated is set out below.

2 MATERIALS AND METHODS

In the present work the extraction of alkalis has been analyzed in a granitic rock. The granodiorite has been tested using different test methods to evaluate the potential extraction with these methods and the relationship with the behavior of the aggregate in the field concrete.

2.1 Materials

A granite aggregate has been selected for this study. This aggregate was used in the concrete of a dam, which over time has demonstrated damage from the aggregate-alkali reaction.

The origin and petrographic classification according to the ASTM C294 regulation [22] is detailed in Table 1.

2.2 Methods for assessment and analysis

General

The test methodology is established at two levels: Characterization of the aggregate and the extraction of the alkalis, which allows the potential leaching of the alkalis from the aggregates to the concrete to be evaluated. The test methods are detailed below.

Chemical composition

Representative samples of the aggregate were analyzed, for the determination of its chemical composition, by means of X-ray fluorescence (FRX), using Bruker S8 Tiger equipment. The loss through calcination is determined through the difference in weight both before and after the calcination at 1,000°C and the Na₂O, K₂O, MgO, CaO, MnO, Al₂O₃, Fe₂O₃, TiO₂, SiO₂, P₂O₅, SO₃, Rb₂O, Cr₂O₃ and MnO is determined through FRX. The average chemical composition of the aggregate is shown in Table 2. The average alkalis present in the samples is 4.33 and 4.53% in K₂O and 2.91 and 2.55% in Na₂O, which corresponds to 3.2% of Na₂O_e.

Petrography by means of optical microscopy

The petrography of a representative sample of aggregate is analyzed by means of a thin wafer, using Olympus BX51 equipment. The mineralogy and composition is deduced.

The petrographic classification is carried out according to the ASTM C294 regulation, which presents a more detailed classification than that found in the UNE-EN 932-3 regulation [23].

The petrographic composition of the aggregate, according to the epigraph of plutonic rocks of the ASTM C 294 regulation [26] is that of a granite oriented, predominating the plagioclases on the potassium feldspars (granodiorite), its modal composition is detailed in Table 3.

Due to their idiomorphic texture, with phenocrystals of plagioclases are greater than 3 mm, they may be considered as reactive aggregates, favouring the reactivity of the alkaline phases which are altered to sericitice and illitice phases [27,28] (the large grains are more susceptible to developing fissures and deformations). Petrologically, it is a calcoalkaline hercyniane granodiorite oriented at two micas [29,30]. The texture of the sodium and potassium feldspars, as well as that of quartz can be observed in Figure 1.

The reactivity index of the quartz, associated with its deformation, and estimate the percentage of reactive quartz is calculated through image processing.

It could be argued that this index gives a spatial relationship for the support capacity of siloxane groups to the interstitial solution, since it is accepted that the phases are reactive from the contact areas (structures like porous or fissures, capable of connecting different points between constituents) establishing the relationship between edge contacts (percentage of phases which share common borders). The following mathematical equation is applied to determine the reactivity index (Menéndez et al, 2014) [13,14,15,16]:

$$I_{Qr} = \frac{P_{ext}}{P_{ext} + P_{int}}$$

Where;

$$\begin{split} I_{Qr} &= \text{The reactivity index of the quartz (non-dimensional)} \\ P_{ext} &= \text{Perimeter of the exterior edge of the grain} \\ P_{int} &= \text{Internal perimeters with individualised phases of undulose extinction} \end{split}$$

If the reactivity index tends towards 1, it is a more stable and ordered crystallographic network, though $1 \le I_{Qr} \le 0.7$ indicate stable structures and without defects, and $0.7 \le I_{Qr} \le 0.4$ indicate structures with some defects, but stable). If this index approximates to 0, it is a consequence of a high deformation and reticular asymmetry ($0.4 \le I_{Qr} \le 0$ indicate deformed and fractured structures, developing phases with undulose extinction. A value very close to zero is mathematically impossible to obtain due to a purely geometrical problem and limits in reticular deformation.

The experimental data correlated with quantitative values, fixes a threshold to define the potential reactivity of $I_{Qr}=0.38$ (Grattan-Bellew, 1993) [12] or $I_{Qr}=0.25$ (Poole, 1992) [24]. Below these values it is considered that the quartz it potentially reactive.

The quartz susceptible to reacting with alkalis is 82.5% of the total percentage of quartz of the sample is obtained from Table 4. The reactivity threshold I_{Qr} is fixed at $I_{Qr}=0.26$, being less than 0.4, and therefore, indicating a high reticular deformation of the quartz.

As a complementary petrographic analysis, the classification of the aggregate is also carried out according to the test method recommended in RILEM AAR-1 [25]. This method consists of a general procedure for the petrographic examination in concretes, useful for identifying the types of rocks and minerals that may react with the hydroxyl ions of the interstitial solution of the concrete.

The main objective of the method consists of classifying an aggregate in terms of alkaline reactivity, by the presence of potentially reactive mineralogical phases that favors reactivity.

As a result of subjecting an aggregate to a RILEM petrographic examination, it will be classified qualitatively in one of the following types:

- Type I Improbable reactivity with alkalis
- Type II Inconstant reactivity with alkalis. The aggregate cannot be classified definitively in classes I and III
- Type III Very probable reactivity with alkalis

This method demands previous geological, petrographic and tensional knowledge of the aggregate together with its behaviour in similar uses. In this study, the points counter is substituted by digital image processing techniques, assigning it the corresponding identifier Table 2 which is perfectly correlated with the classification of the ASTM C-294.

Thus the recommended method of RILEM AAR-1, classifies the aggregate analyses in type III-S, since it contains quartz with a high reticular deformation, sarcoid quartz, altered feldspars, altered micas and occasional opaque materials, as potentially reactive mineralogical phases.

Backscattering electronic microscopy combined with X-ray dispersed energies microanalysis

The aggregate is characterized by means of Backscattering electronic microscopy combined with X-ray dispersed energies microanalysis, using Jeol 5400 equipment and an Oxford Link microanalysis. The aspect, the distribution and the composition of the feldspars in the interior of the aggregates is observed, clearly identifying the sodium feldspars (plagioclases) and the potassium feldspars, as well as the micas and other accessory minerals. The aspect of the sodium and potassium feldspars and the map of the associated elemental composition can be seen in Figure 2. The distribution of the associated elements with each one of the feldspars and other minerals in the granite are also seen.

In the microstructural analysis of the concretes, manufactured with this granite aggregate, the formation of reaction products, associated with the development of the silicate-alkali reaction is observed. These observations confirm the reactivity of these granite aggregates, including the feldspar phases, however, it does not value the potential migration of alkalis from the feldspars to the concrete, which would contribute to the development of the aggregate-alkali reaction. The aspect of the concrete with granite aggregate and reaction products in the interface with the cement paste, type of vitreous gel (rich in silicon, potassium, sodium and calcium), with sodium and potassium feldspars is observed in Figure 3.

Expansion according to the ASTM C1260 and ASTM C227 Regulation

The potential expansion of the granite aggregates, analysing the fine grading fraction (the smallest size being 5 mm) by means of accelerated and semi-accelerated tests is determined. The potential expansion of the aggregate by means of the test method set out in the ASTM C1260 Regulation [31], which is similar to the method described in the UNE 146.508EX Regulation [32] is analysed. The linear expansion of the samples subject to a 1M of NaOH solution at 80°C, for 14 or 28 days is determined in this method, considering it as potentially expansive when it exceeds 0.2% of expansion. Likewise, the potential reactivity is determined by means of the test method described in the ASTM C227 Regulation [33], in which the linear expansion of the mortar samples manufactured with the aggregate to be evaluated under conditions of 38°C and 100% of H.R. for six months to a year is analysed. It is considered that the aggregate is potentially expansive when it exceeds 0.05% after three months or 0.1% after six months of testing.

The aggregate is potentially reactive, both in the accelerated and the semi-accelerated test, even though it is at the limit of reactivity, especially in the accelerated test, in which it can be observed that both at 14 days and at 28 days the expansion is located at the limit of the expansivity to be considered as reactive (Figure 4a). For its part, in the semi-accelerated method (ASTM C227), it is observed that the aggregate does not exceed the limit of the expansivity at 90 days, even though after 180 days the aggregate would be qualified as potentially reactive (Figure 4b). These results indicate that, even though the aggregate is potentially reactive against the alkalis, it is a slow reaction; therefore, the concretes manufactured with the same will take quite a time to manifest the expansion, even though it will be conditioned to a large extent on the ambient exposure of the element or the structure.

Extraction of alkalis

As has been indicated, there are different test methods that use different types of extraction solutions and test conditions to analyze the potential leaching of alkalis from the feldspars to the concrete. This would influence the development of the silicate-alkali reaction which comes about on occasions with granite-type aggregates.

Different test methods have been used to evaluate the behavior of the aggregates as regards the potential extraction of alkalis. In the main, these tests are based on subjecting the aggregates to the action of the solutions with an elevated pH, like that which is found in the porous phase of the concrete. Furthermore, the extraction of the ultrapure water is analyzed, as a reference for neutral pH.

The test methods to evaluate the granite aggregate have been selected in accordance with the type of extraction solution and the pH, different authors propose different evaluation methods for the leaching of the alkalis, with different conditions and exposure time. Six test methods have been used with the aim of analyzing the behavior of the aggregates under different test conditions and evaluating which of them are the most efficient. Method 1 is carried out with distilled water in ultrapure water for 48 hours, which means a moderate test time, even though the average test has a pH different from that of the porous phase of the concrete [22, 34]. For its part, Method 2 is based on the use of solutions with an elevated pH, similar to the values of the liquid phase of the concrete, with a different combination of ions but with an exposure time of 28 days [22, 34]. Method 3 also used solutions with an elevated pH, but it has some conditions very far from the conditions of the concrete [36]. Method 5 is an alternative method to determine the soluble alkali content of concrete [36]. Method 5 is an alternative method to determine the leaching of alkali aggregate in concrete [37]. The test conditions for the different test methods used are detailed in Table 5.

3 RESULTS

The elements leached at the end of each test are analysed, determining the concentration by means of inductive plasma spectroscopy (ICP), using Varian 725-ES equipment. Likewise, the pH value in each of the test solutions, at the beginning and the end is determined.

The concentration of alkaline oxides present in the solution is calculated as a certain percentage in the mass of the aggregate. Likewise, the equivalent sodium oxide is determined, corresponding to the sum of the alkaline oxides expressed as sodium oxides in accordance with the following equation: $Na_2O_e = Na_2O + 0.658 \cdot K_2O$.

The percentages of Na₂O and K₂O leached from the aggregates, in accordance with the mass of the aggregate tested are detailed in Figure 5a. It is seen that, in general, a moderate extraction of alkalis from the aggregates takes place, which varies in accordance with the type of extraction solution used; the saturated solutions in calcium hydroxide being the most efficient (D3 and R1) and the D6 solution which simulates the concentration of alkalis present in the aqueous phase of the concrete [35]. In the case of the solutions with only calcium the extraction can be attributed to a Na-Ca or K-Ca ionic exchange; however, the behaviour observed in the solution with the three ions (D6) indicates that the potential migration of alkalis to the concrete is feasible. On the other hand, in some cases a decrease in the sodium ion or the potassium ion of the solution is observed. The combination of the sodium ion in the aggregates takes place in the D1 solution in which there is an elevated concentration of sodium (1N of NaOH), therefore this behaviour is associated with the Na-K ionic exchange, giving rise to the substitution of potassium in the aggregates for sodium. For its part, a similar behaviour is observed in the solutions with an elevated content of potassium (D2 and D6), which contain respectively one 1N of KOH and 0.5N of KOH; in this case the ionic exchange would be K-Na, which would give rise to a potassium ion defect in the solution. As regards the ultrapure water and the R1 to R5, it is observed that the extraction of alkalis is more moderate than in the D1 to D6 test solutions, which indicates that the most determinant factor for the extraction of the alkalis is time, much more than temperature, since in alkali solutions at 150°C (R1 to R5) the extraction is less than for solutions with similar pH tested at 20°C and 40°C. The time factor is also corroborated as the determinant for the results obtained in the solutions D1 to D6, exposed at 20°C and 40°C, observing that the extraction is of the same order or in some cases superior, in the tests carried out at 20°C. Figure 5a shows the results of the extraction of Na₂O and K₂O in the same tests.

The results of the equivalent calculated sodium oxide show results similar to those observed in the extraction of each of the ions. It is observed that the most effective solutions in the extraction of alkalis from the feldspars are those saturated in calcium and that whish not only simulates the pH but also the chemical composition of the liquid phase present in the porous phase of the concrete. Likewise, it is observed that the time in contact with the extraction solution is more important than the exposure temperature, even when solutions are used at 150°C. On the other hand, the solutions with only sodium or potassium ions, without calcium, are not efficient in the extraction of the alkalis of the feldspars in spite of having a pH similar to that of the liquid phase, which indicates the significant role of the calcium in this process. The action of the calcium will be related to the Na-Ca or K-Ca ionic exchange, even though this situation will come about in the same way in the concrete, since the portlandite is dissolved to maintain the elevated pH of the liquid phase and makes enough calcium available for this exchange. Figure 5a shows the results of the equivalent sodium oxides extracted in each test solution.

As regards the variation in the pH between the beginning and the end of the test, it is observed that, except in the D1 solution in which there is a slight increase in pH, in all of the alkaline solutions, the pH declines, as a consequence of the increase in ions in solution and the attack of the OH⁻ ions on the aggregates. While in the ultrapure water, there is an increase in pH, as a consequence of the extraction of alkalis and other ions from the aggregates, which gives rise to an increase in OH⁻ ions to maintain the equilibrium of charges (Figure 5b).

The potential supply of alkalis to the concrete can be calculated from the results obtained from the extraction tests. If we assume a standard proportion of concrete with 1.800 kg/m³ of aggregates, we have a potential maximum extraction of alkalis from the aggregates (expressed as Na₂O_e) of 2.53 kg/m³ (Ca(OH)₂ sat.–20°C–28d), 1.98 kg/m³ (Ca(OH)₂ sat.–40°C–28d) and 0.77 kg/m³ (Ca(OH)₂ sat.–150°C–24h) in the different tests. But when quantify separately K⁺ and Na⁺ with 0,7M NaOH+Ca(OH)₂sat. and 0,7M KOH+Ca(OH)₂sat. respectively, we obtained values of 5.09kg/m³ and 6.12 kg/m³ of Na₂Oe at 38°C or 60°C. In accordance with these values, the increase in alkalis in the concrete, as a consequence of the leaching from the granites, may have a significant influence on the development of the silicate-alkali reaction, if we bar in mind that 400kg/m³ of cement supplies between 2.4 and 3.2kg/m³ of alkalis, for a Na₂O_e content of 0.6% (cements with a low content of alkalis) or 0.8%. However, the efficiency of the extraction of alkalis in the concrete must be taken into account, since not all of the surface of the aggregate is in contact with the liquid phase and has the potentiality of leaching alkalis.

4 CONCLUSIONS

It has been proven that the granite aggregates with alkaline feldspars may leach alkalis in contact with solutions with an elevated pH factor, as happens in concrete. This leaching of alkalis increases the risk of a silicate-alkali reaction taking place, observing the formation of reaction products in the interfaces of the feldspars with the cement paste.

Different test conditions are analyzed for the extraction of alkalis, with different extraction solution compositions, test temperature and contact time. It is concluded that the determinant parameter for the extraction of alkalis is the duration of the test, thus the tests at 28 days at 20°C or 40°C extract more alkalis than those carried out at 150°C for 24 hours. For its part, the most efficient extraction solutions are those saturated in calcium hydroxide and that which simulates the composition of the liquid phase of the concrete (with sodium, potassium and saturated calcium), which corroborates the potentiality of the extraction of alkalis of the feldspars in the concrete. The role of the calcium would be related to the ionic exchange with the sodium and potassium, which could be brought about in the concrete, given the elevated content of calcium in its liquid phase.

In accordance with the different extraction test methods used, the granite aggregates could contribute 0.77 and 6.12kg/m³ of alkalis to the concrete, which would notably increase the risk of a silicate-alkali reaction. Even though the efficiency of the extraction has to be taken into account, not all of the surface of the aggregates is in contactor with the aqueous phase of the concrete.

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TABLE 1: Sample for test.									
Typology	Petrographic classification	Origin							
Granite aggregate	Granite	NW Iberian Peninsula							

TABLE 2: Average chemical composition of the granite aggregate.															
Comp.	LOI	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	P_2O_5	SO3	TiO ₂	Rb ₂ O	Cr_2O_3	MnO	K ₂ O	Na2O	Na ₂ O _{eq}
(%)	0.78	58.85	12.36	1.12	0.66	0.27	0.43	0.08	0.18	0.04	0.02	0.01	4.45	2.84	5.77

Minerals	Phases	Range (%)	Characteristics of the phases
Essentials	Feldspar Na	34.5 %	Partially altered rings
	Feldspar K	23.2 %	Altered clays (Chlorites, etc.)
	Quartz	19.5%	Undulose extinction ($\geq 26\%$)
	Micas (Biotite)	15.3%	Pleochroism with wafer texture
	Muscovite	4%	Foiled structure. Green, partially altered
Accessories	Chlorites	2.7%	High interference colours
	Opaques	0.8%	Sulphite phases

TABLE 3: Petrographic characterization of the granite aggregate.

TABLE 4: Analysis of the reactivity of the quartz.

Q total	Q React	Q_{reactive} of the Q_{total}	I _{Qr} (adimensional)	Reticular state of the Q		
19.5 %	16.1 %	82.5	~0.26	Microgranular crystals, fissured and sarcoid sandstone		

TABLE 5: Test conditions of the different test methods for the extraction of alkalis.

Method	Size of the aggregate	Liquid: solid ratio	T^{a}	Time	Extraction solutions
Method 1 [22,34]	<500µm	2:1	20°C	48 hours	Ultrapure water
Method 2 [22,34]	315μm<árido>160μm	3:1	20°C y 40°C	28 days	D1 \rightarrow 1N NaOH D2 \rightarrow 1N KOH D3 \rightarrow Ca(OH) ₂ Sat. D4 \rightarrow 0,2N NaOH + Ca(OH) ₂ Sat. D5 \rightarrow 0,5N KOH + Ca(OH) ₂ Sat. D6 \rightarrow 0,1N NaOH + 0,6N KOH + Ca(OH) ₂ Sat.
Method 3 [21]	315μm<árido>160μm	1:1	150°C	24 hours	R1 \rightarrow Sat Ca(OH) ₂ R2 \rightarrow 0,7N NaOH R3 \rightarrow 0,7N KOH R4 \rightarrow 0,7N NaOH + Ca(OH) ₂ R5 \rightarrow 0,7N KOH + Ca(OH) ₂
Method 4 [36]	<80µm	10:1	100°C (10 min)	24 hours	Deionized water

Method 5	<160µm	2:1	100°C	1/2 hour	Ultrapure water
Method 6 [37]	<125µm (10%) 125µm -250µm (15%) 250µm -500µm (25%) 500µm -1mm (20%) 1mm -2mm (20%) 2mm -4mm (20%)	4:1	38°C y 60°C	13 weeks	Z: (1) 0,7M NaOH + Ca(OH) ₂ sat. (2) 0,7M KOH + Ca(OH) ₂ sat.



FIGURE 1: Aspect of the different granite phases, (a) sarcoid quartz with undulose extinction, (b) plagioclase, (c) potassium feldspar and (e) micas (muscovite and biotite).



FIGURE 2: Microstructure of the sodium feldspars (the right-hand side of the image) and potassium (the left-hand side of the image), as well as the quartz and other associated minerals.



FIGURE 3: Concrete manufactured with granite aggregate with sodium and potassium feldspars and aggregate-alkali reaction products (rich in silicon, potassium, calcium and sodium) in the interface with the cement paste.



FIGURE 4: Potential expansion of the granite aggregates by means of the accelerated method of mortar bars (a) and by means of the semi-accelerated method of expansion (b).



FIGURE 5: (a) Alkalis extracted from the different test solutions, expressed as Na₂O, K₂O y Na₂O_e.
(b) Variation in pH in the solutions at the beginning and the end of the test.