Alkali-Aggregate Reactions in concrete: Methodologies applied in the evaluation of Alkali Reactivity of Aggregates for concrete.

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Keywords: ASR; aggregates; alkali reactivity.

Abstract. The alkali-aggregate reaction (AAR) in concrete is a chemical reaction that occurs between several types of minerals present in aggregates and alkali ions and hydroxyl present in the interstitial solution of cement paste in concrete. These reactions, involving the dissolution of poorly crystallized or amorphous forms of silica in alkaline medium, resulting in the formation of an alkaline hygroscopic gel that absorbs water and expands increasing internal stresses in the concrete, which can result in them cracking [1].

The potential alkali reactivity of aggregates can be evaluated by several test methods. The petrography indicates forms of reactive silica present in aggregates, however, can be difficult to quantify, can and must be complemented by expansion tests for concrete, in mortar bars ASTM C 1260 [2] or in concrete prisms RILEM AAR-3 [3] or RILEM AAR-4 [4].

Several studies of evaluation the alkali reactivity of aggregates used in various concrete structures in Portugal, including bridges and dams, indicated that performance of some aggregates, in the engineering works, not correspond with the previously evaluation performed for characterization studies. The current methodology, is based on the specification E- 461-2007 [5], but has some limitations and isn't suitable for all types of rock, including granitoids ones.

This situation motivated the development of a research project, which involves, in particular expansion tests in different conditions, namely in medium and long term, under accelerated and natural exposure, as well as previous petrographic evaluation of each aggregate types studied.

This paper aims to present the first results of applying different methods of assessment of the alkali reactivity of aggregates for concrete, referring in particular its applicability to different lithologies.

Introduction

The alkali-aggregate reactions (AAR) are a chemical reactions that develop among the constituents of the reactive aggregate and alkali and hydroxyl ions present in the concrete interstitial solution. If these reactions can often be beneficial in ancient lime mortars, portland cement in concrete have very damaging consequences. In particular, the alkali-silica reaction (ASR), involving rocks and minerals containing reactive forms of silica, are currently considered as the cause of early deterioration of an increasing number of concrete structures. The ASR, which leads to expansion and cracking of concrete, significantly facilitates other processes of deterioration, particularly in the case of reinforced concrete, corrosion of the reinforcement. The ASR is essentially on attack of some kind of forms of reactive silica, possessing a more or less disordered and therefore unstable in an environment of high pH by alkali ions (Na^+ and K^+) and hydroxyl (OH^-) present in the interstitial solution of concrete. The speed of the attack depends on the concentration of alkalis in the interstitial solution and the structure of silica. Quartz "well crystallized" is generally considered non-reactive in alkaline solution. In fact, when quartz grains are placed in the concrete interstitial solution, the attack by alkalis occurs mainly on its surface. Speed penetration of alkalis in the structure of well crystallized quartz is low due to their small specific surface, while the cryptocrystalline quartz is already higher due to increased specific surface. The same behavior is observed in large grains of quartz that have defects or are deformed. This suggests that non silicon aggregate can be considered, of outset, as “inert” concerning ASR [6], [7].

Methodology

The methodology adopted in this study objective is to create a database, allowing to meet the present and future needs in relation to behavior of aggregates in work. The potential reactivity of the alkali aggregates can be evaluated by several test methods. The petrography indicates the potentially reactive forms of silica present in aggregates, however, can be difficult to quantify, must be complemented by tests expansion in mortar bars or concrete prisms, as had already been reported. The current methodology is based on the specification E 461-2007 and it is very similar to the recommendations of some countries particularly those where more investigated and has been invested in seeking of solutions to mitigate this way of degradation in concrete. However this approach presents some limitations, particularly because it is not suitable for all types of rock, like for example the granitoids ones.

For this paper has been selected two singular granites of different regions, one dolomite and two aggregates of reference, a reactive one and one nonreactive, presents the results obtained by different methods of analysis of reactivity, including petrographic analysis and testing expansion in mortar bars and concrete prisms.

Petrographic analysis

Petrography consists in the study, by petrographic microscope, of the mineral composition and texture of aggregates/rocks. Through this study it is possible to collect information: the shape of the crystals, clasts and grains, the texture of the unit grain itself; degree of alteration, degree of cracking, forms of reactive silica minerals and suppliers of alkali. The petrographic analysis, is a technique that requires compulsory basic geological knowledge but is very dependent of the observer's experience. In order to remedy some of these difficulties there are some testing standards that seek to standardize concepts and methods ASTM C 295 [8]; LNEC E 415 [9], RILEM AAR-1 [10].

Expansion tests

The tests allow for the expansion of the potential reactivity to alkali aggregate to the extent that it assumes that if any expansion in specimens, this is also due to gel formation of ASR. These tests measure the variation in length of test specimens of mortar or concrete using a comparator which consists of a metal holder and deflections. These tests can be performed by three different methods: accelerated in mortar bar or in concrete prisms (slow and accelerates test), being all own to the determination of potential alkali reactivity of aggregates.

Accelerated test of the mortar bar. This essay does an assessment of the alkali reactivity of an aggregate for concrete and consists on evaluating of the behavior of an aggregate after being crushed to a grain size less than 4.75 mm, used for making mortar prismatic specimens of dimensions 2.5 cm x 2.5 cm x 28.5 cm. After demolding, the prisms are placed in water at 23 ° C and placed in an oven at 80 ° C. After 24 hours the initial measurement is made (zero) of each specimen is then placed in a solution of sodium hydroxide 1 mol / L at 80 ° C where they stay 14 days, and during this period at least four measures of expansion are made. The aggregate is considered reactive if the expansion after 14 days of immersion in NaOH is higher than 0.20%. If the result at 14 days is between 0.10% and 0.20%, it is desirable that the test will last up to 28 days, and sort the alkali aggregate reactivity doubtful whether the expansion at 28 days not to exceed 0.20%, such as RILEM AAR-2 [11] or ASTM C1260 [2].

Method for aggregate combinations using concrete prisms (Slow Test). The concrete prism test, consists in behavior evaluate of a coarse or fine aggregate, or a mixture of aggregates in concrete prismatic specimens of dimensions 7.5 cm x 7.5 cm x 25 cm ± 5. The samples are prepared with a cement with high alkali content, usually above 0.9% Na_2Oeq., after adjusting the alkali content by adding sodium hydroxide to the mixing water to achieve a level of 1.25% Na_2Oeq. in relation to the mass of cement. The samples, after demolding are kept for 12 months in a chamber at 38°C and relative humidity (RH) above 95%, making up measures to expand the ages defined, being the aggregate considered reactive if the value of expanding the 12 months is greater than 0.05%, such as RILEM AAR-3 [3] or ASTM C 1293 [12].

Method for aggregate combinations using concrete prisms (Accelerated Test). This test is similar to the test RILEM AAR-3 (or ASTM C 1293) with the exception of the test temperature, that passes of the 38ºC to 60ºC, and the duration, which is reduced from one year to three months, making up measures expansion of the ages defined, being the aggregate considered reactive if the value of expansion to three months is greater than 0.02%, such as RILEM AAR 4 [4] or NF P18-454 [13].

Results

The results for all aggregates, in each of the tests, are presented in (Table 1). For the test of RILEM AAR-3 are presented only the results obtained at 6 months of testing because the tests are not yet finished. In this table is still a possible classification of potential reactivity based on the results obtained in each of the tests, including petrographic analysis.

Table 1: Compilation of results obtained in expansion tests and petrographic analysis.

Aggregate	Petrographic analysis		ASTM			AAR				
	Reactivity	Forms of reactive silica	C 1260 (80º C) Expansion (%)		Reactivity	AAR-3 (38º C) Expansion (%)		AAR-4 (60º C) Expansion (%)		Reactivity
			14 days (> 0,10%)	28 days (> 0,20%)		3 and 6 months (> 0,05%)		3 and 5 months (> 0,02%)		
Reactive coarse aggregate	R	qz. crypt	0,30	0,51	R	Ongoing test		Ongoing test		-
Nonreactive coarse aggregate	NR	-	0,00	0,00	NR	-	-	-	-	-
Granite A	PR	lower granularity of quartz	0,03	0,05	NR	0,00	0,01	-0,01	0,01	NR
Granite B	R	qz. crypt	0,02	0,03	NR	0,00	0,00	0,05	0,07	R
Dolomite	PR	qz def.	0,02	0,03	NR	0,01	0,02	0,02	0,02	R

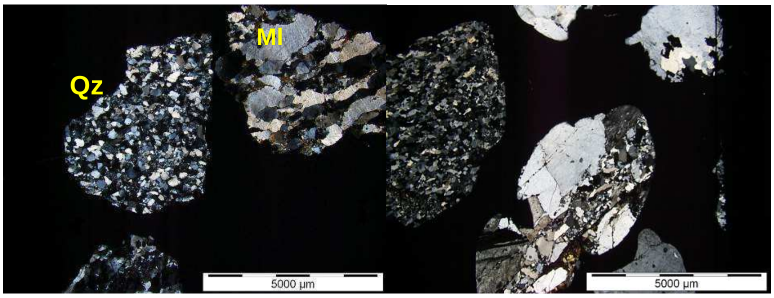
(qz crypt. – quartz cryptocrystalline; qz def – quartz deformed)
(R – Reactive; PR – Potentially reactive; NR – Nonreactive)

Petrographic Analysis

According to recent international criteria [9] the occurrence of undulatory extinction in quartz crystals only suggests the presence of quartz microcrystalline or cryptocrystalline but is not recommended for quantification of potential reactivity. It is noted that in the granite rocks is a common the occurrence of extinction undulating in quartz crystals, which is due to the growth process of the crystals itself and not necessarily as a result of some kind of deformation. In this context, the attention was given to the quartz crystals of small size, since it they can engage most easily in chemical reactions of alkali-silica type.

Reactive coarse aggregate (siliceous)

This aggregate was classified as reactive by petrographic analysis, because it consists of quartzite (crystalline quartz), mylonites (stretched quartz) and chert (cryptocrystalline quartz) grains, which are reactive forms of silica. (Fig. 1).

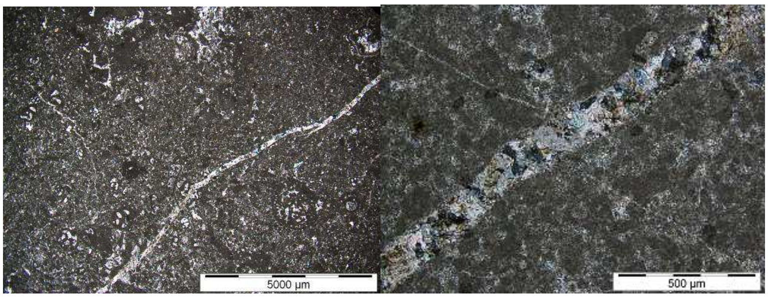


(a) (b)

Figure 1. General images of the siliceous coarse aggregate where it is possible observe the existence of reactive silica forms namely quartzite (Qz) and mylonite (Ml), image obtained in Xs nicols mode.

Nonreactive coarse aggregate (limestone)

This aggregate was classified as nonreactive by petrographic analysis due to the absence of potentially reactive forms of silica; a carbonate rock (limestone) with no deformation. (Fig. 2).

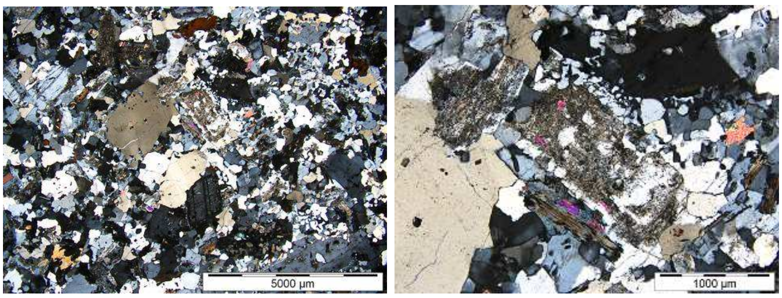


(a) (b)

Figure 2. Images of the limestone coarse aggregate there is an absence of reactive silica forms, image obtained in Xs nicols mode.

Granite A

It is a siliceous rock composed by quartz, feldspar, plagioclase, biotite, muscovite and chlorite. Accessory minerals include zircon, sericite and clay minerals. This aggregate doesn’t present forms of amorphous silica or deformed quartz, however it has a very low granularity which can give this rock a potential reactive behavior. (Fig. 3).

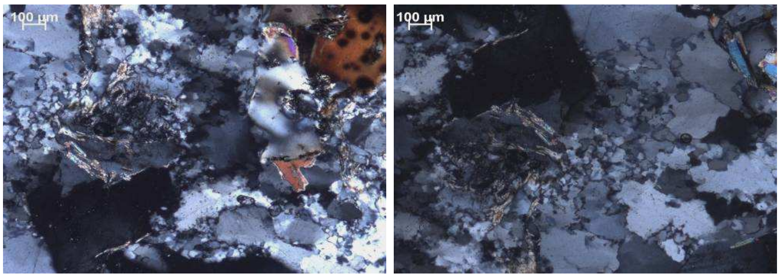


(a) (b)

Figure 3. Images of granite A sample, a) lower granularity of quartz; b) presence of sericite, both image obtained in Xs nicols mode.

Granite B

Rock composed by feldspar, plagioclase, quartz, muscovite, biotite, chlorite, tourmaline, apatite and rare opaque minerals. Quartz crystals demonstrate strong deformation, showing ondulatory extinction, deformation lamellar and an intense subgranulation which gives the rock an alkali reactive behavior (Fig. 4).



(a) (b)

Figure 4. Images of granite B sample, a) quartz with undulating extinction; b) quartz with intense subgranulation, both image obtained in Xs nicols mode.

Dolomite

Carbonate rock with siliceous veins, which can be classified due to its deformation features as marble. This rock is intensely deformed and presents potential reactive forms of silica, namely stretched quartz. Such form of silica, gives to this aggregate a potential reactive behavior, (Fig. 5).

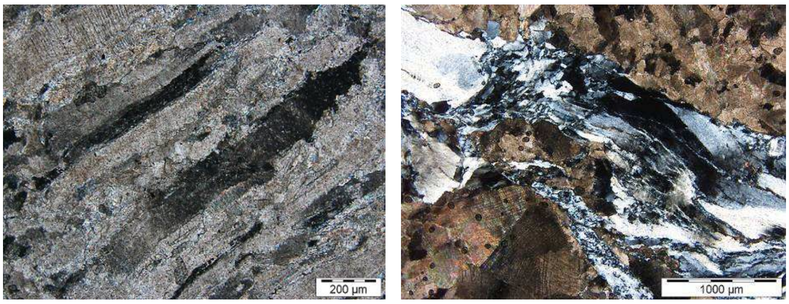


Figure 6. : Images of dolomite sample, a) carbonate deformed; b) reactive forms of silica, namely stretched quartz, both image obtained in Xs nicols mode.

Expansion measurements

The Figure 7, shows expansion curves of ASTM C1260 test, for all aggregates studied at different ages of testing. There is high value of expansion to the "reactive coarse aggregate" and total lack of expansion in “nonreactive coarse aggregate”. With regard to granites, in this study, the "Granite 1" was the one that increased most, although the difference in values for the other granite aggregates is very low. It appears that these results are not consistent with the petrography because, though there have been classified as potentially reactive, the all granitic rocks studied this was the one that present the lowest potential alkali.

In Figure 8 it appears that none of the aggregates in the study had expansion values above the limit given by the AAR-3 trial is therefore classified as non-responsive. Regarding the test AAR-4, only the aggregate "Granite A" was below the limit of expansion, and all other were classified by reactive aggregates. According to these results, it is possible to verify that there is low correlation between the applied test methods, including petrography, mortar and concrete expansion tests.

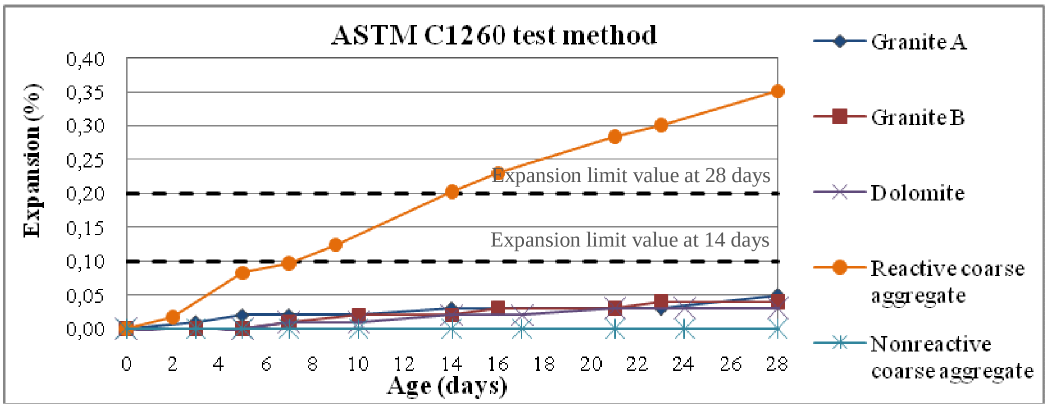


Figure 7. Expansion results of ASTM C 1260 mortar bar method.

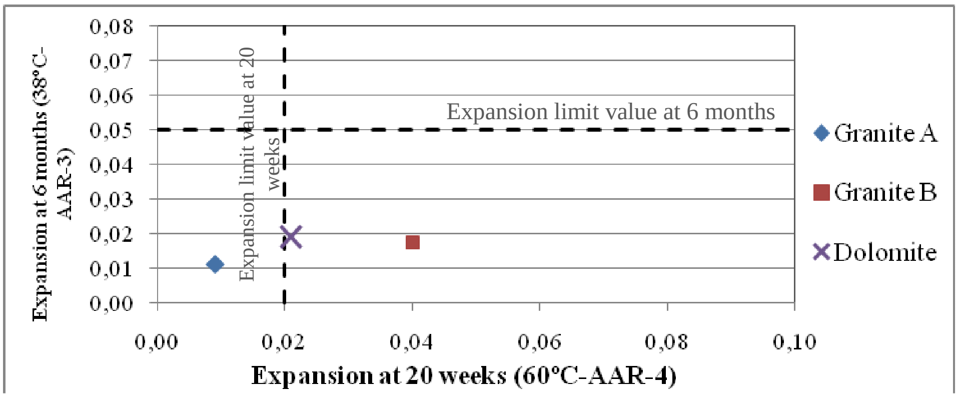


Figure 8. Expansion results of AAR-3 method vs. AAR-4 method.

Conclusions

It is known that petrography can provide good indicators of the potential reactivity of aggregates for concrete, however should not be used alone, being necessary to proceed to further testing.

The results obtained in different test methods reveal low correlation, therefore it is necessary to improve and refine the present methodology for the assessment of potential alkali-reactivity of aggregates for concrete.

The ultra-accelerated ASTM C 1260 mortar bar test method does not apply to granitoid aggregates, as already had been pointed out by LNEC Specification E461-2007.

It is extremely necessary to further extend the study to lithologic families of rocks, with similar origins of aggregates that were already used in several concrete structures (e.g. bridges, dams) with and without ASR features, in order to validate the characterization methodology.

Acknowledgement: This work is financed by National Funds through FCT - Fundação para a Ciência e Tecnologia under the project EXREACT (Mitigation of deleterious internal expansive reactions in concrete structures, PTDC/CTM/65243/2006), IMPROVE (Improving the performance of aggregates for the inhibition of alkali-aggregate reactions in concrete, PTDC/ECM/115486/2009), DURATINET (Durable Tranport Infrastructures in the Atlantic Area Network) for Transnational Programme of Atlantic Area 2007-2013, co-financed by FEDER and to Projecto Plurianual Project GeoREMAT of the Geology Centre of Oporto University.

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