

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

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Abstract. The alkali-aggregate reaction (AAR) in concrete is a group of chemical reactions that involves the reaction of certain minerals present in the aggregates with alkali and hydroxyl ions in the interstitial solution of cement paste in concrete. These reactions form an alkaline hygroscopic gel that absorbs water and expands causing internal stresses with cracking [1].

The AAR mitigation measures oblige the correct evaluation of the alkali reactivity of the aggregates. This is normally assessed by petrographic, chemical or expansion test methods.

Several studies regarding alkali reactivity of aggregates for concrete structures in Portugal, including bridges and dams, indicated that their field performance does not correspond to the previously performed evaluation.

Presently, Portuguese methodology is based on the LNEC Specification E461-2007, which shows some limitations regarding rock types such as granitoids [2]. This situation motivated the development of a research project, involving medium and long term expansion tests in different conditions, under accelerated and natural exposure conditions, as well as petrographic evaluation of the main Portuguese aggregates used/to be used in concrete. This paper presents the preliminary results of this research.

Introduction

The alkali-aggregate reactions (AAR) are a group of chemical reactions that occur between the constituents of the reactive aggregate and alkali and hydroxyl ions present in the concrete interstitial solution. In particular, the alkali-silica reaction (ASR), involves minerals present in rocks that contain reactive forms of silica. Currently, it is considered as the cause of early deterioration of an increasing number of concrete structures in Portugal. The ASR, which leads to expansion and cracking of concrete, may lead to other processes of deterioration, particularly in the case of reinforced concrete, the reinforcement corrosion. The reaction speed depends on the concentration of alkalis in the interstitial solution and on the structure of silica. Well crystallized quartz 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. The rate of alkalis ingress in the well crystallized quartz structure is lower due to the small specific surface area. Instead the alkali ingress in cryptocrystalline quartz is higher due to its increased specific surface area. The same behavior is observed for large grains of quartz that have defects or are deformed. This suggests that no siliceous aggregate must be considered as “innocuous” concerning ASR [3, 4]. The potential alkali reactivity of the aggregates can be evaluated by several test methods. Petrography is the first method normally applied in this characterization, indicating potentially reactive forms of silica present in the aggregates. However, this can be difficult to quantify, and must be complemented by expansion tests in mortar or concrete.

The Portuguese methodology is based on the LNEC Specification E 461-2007, being very similar to the European and North American standard recommendations, particularly in those countries where the research about AAR is more developed. Nevertheless, this approach presents some limitations, particularly because it is not suitable for all rock types, for example the granitoids.

This paper presents the results obtained in the alkali-reactivity characterization of two granites, one dolomite and two other, used as reference (a reactive and nonreactive alkali aggregate). The correlation obtained in the different test-methods is presented and discussed.

Experimental methodology

Petrographic test

Petrography consists in the study by petrographic techniques, namely the optical microscope, of the mineral composition and texture of aggregates. Through this technique is possible to collect information on the reactive forms of silica, the potential alkali suppliers and the minerals alteration degree. The petrographic analysis was followed according to LNEC E 415, ASTM C 295-03 and RILEM AAR-1 [5, 6, 7].

Expansion tests

Expansion tests measure the variation in length of prismatic specimens of mortar or concrete in accelerated AAR conditions.

Accelerated mortar-bar test. This test consists on evaluating the behavior of an aggregate after being crushed to a grain size less than 4.75 mm, used for making mortar prismatic specimens with dimensions 2.5 cm x 2.5 cm x 28.5 cm. The mortar prisms are immersed in a solution of 1M NaOH at 80 ° C at least during 14 days. Through this period several length measurements are made. The aggregate is considered reactive if the expansion after 14 days of test is higher than 0.20%. If the result at 14 days is between 0.10% and 0.20%, it is recommended to extend the test up to 28 days, being the aggregate considered reactively doubtful if the expansion does not exceed 0.20% [8, 9].

Concrete Slow-Test (38°C). This concrete prism test consists in evaluating the behavior of a coarse or fine aggregate, or a mixture of aggregates in concrete prismatic specimens with dimensions 7.5 cm x 7.5 cm x 25 cm, in closed environment at 38°C and relative humidity (RH) above 95%. The specimens are prepared with a cement with high alkali content, usually above 0.9% Na₂O_{eq.}, adjusting the alkali content by adding NaOH to the mixing water to achieve 1.25% Na₂O_{eq.} in relation to the cement mass. The aggregate is considered reactive if the expansion value at 12 months is greater than 0.05% [10, 11].

Concrete Accelerated-Test (60°C). This method is similar to the 38° C prism-test, with exception of temperature (60° C) and duration of the test (five months). The aggregate is considered reactive only if the expansion value at five months is greater than 0.02% [12, 13].

Results

The results obtained are presented in Table 1. In the case of 38° C concrete test the results are presented up to 6 months of testing. A potential classification of the alkali-reactivity based on the results obtained is given in Table 1.

Petrographic Analysis

According to recent international criteria [5] the occurrence of undulatory extinction in quartz crystals only suggests the presence of microcrystalline or cryptocrystalline quartz. It is noted that in granite rocks the occurrence of undulatory extinction is common 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, attention was given to the small size of quartz crystals, since they can be responsible for ASR.

Table 1: Results of petrographic and expansion alkali-reactivity tests on Portuguese aggregates.

| Aggregate | Petrographic analysis | | Mortar | | | Concrete | | | | |
|----------------------------|-----------------------|--------------------------|---------------------|--------|------------|-------------------|----------|--------------------------|----------|------------|
| | Reactivity | Forms of reactive silica | ASTM C 1260 (80° C) | | Reactivity | Slow-test (38° C) | | Accelerated-test (60° C) | | Reactivity |
| | | | Expansion (%) | | | Expansion (%) | | Expansion (%) | | |
| | | | 14 days | 28 day | | 3 months | 6 months | 3 months | 5 months | |
| Reactive aggregate (RA) | R | crypt. qz | 0,30 | 0,51 | R | Ongoing test | | Ongoing test | | - |
| Nonreactive aggregate (NR) | NR | - | 0,00 | 0,00 | NR | Ongoing test | | Ongoing test | | - |
| Granite A | PR | microcryst. qz | 0,03 | 0,05 | NR | 0,00 | 0,01 | -0,01 | 0,01 | NR |
| Granite B | R | crypt. qz | 0,02 | 0,03 | NR | 0,00 | 0,00 | 0,05 | 0,07 | R |
| Dolomite | PR | str qz | 0,02 | 0,03 | NR | 0,01 | 0,02 | 0,02 | 0,02 | R |

Notation: crypt. qz– cryptocrystalline quartz; str qz– strained quartz; R – Reactive; PR – Potentially reactive; NR – Nonreactive

The reactivity of the RA reference aggregate was confirmed by petrographic analysis, due to strong presence of quartzite (crystalline quartz), mylonites (stretched quartz) and chert (cryptocrystalline quartz) grains, well known alkali-reactive forms of silica (Fig. 1).

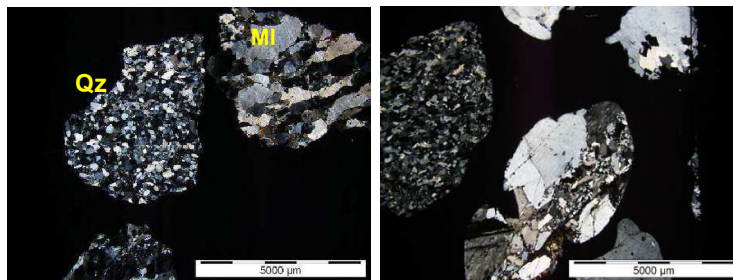


Figure 1. Microphotographs (Xs nicols mode) of the RA aggregate where the existence of reactive forms of silica namely quartzite (Qz) and mylonite (Ml) is observed.

Petrographic analysis confirms that the non-reactivity of NR reference aggregate (Fig. 2), does not present any features related with potentially reactive forms of silica. This aggregate is a carbonated rock (limestone) with no silica.

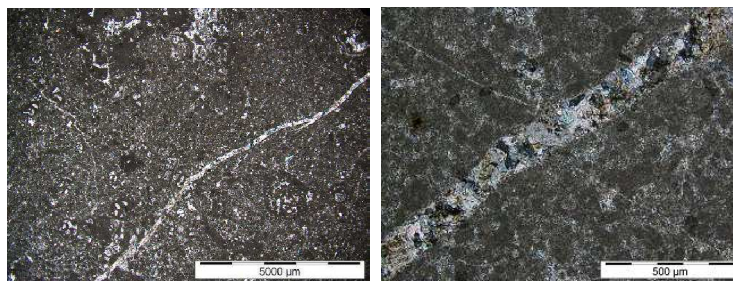


Figure 2. Microphotographs (Xs nicols mode) of the NR aggregate showing the absence of reactive forms of silica.

Granite A is a siliceous rock composed mainly by quartz, K-feldspar, plagioclase, biotite, muscovite and chlorite minerals. Accessory minerals include zircon, sericite and clay minerals. This aggregate does not present forms of amorphous or deformed silica, however it has a very low granularity (microcrystalline quartz) which can give this rock a potential reactive behavior (Fig. 3).

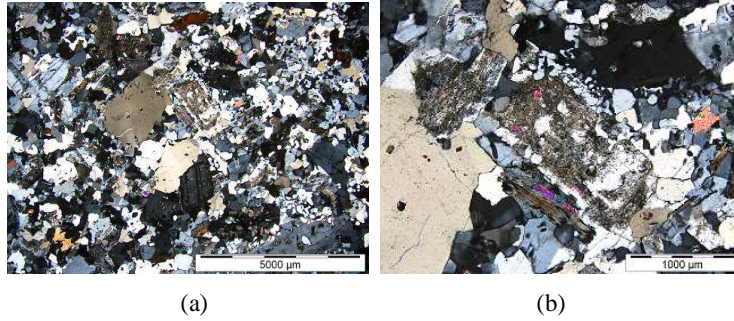


Figure 3. Microphotographs (Xs nicols mode) of granite A: a) quartz with low granularity; b) Presence of sericite.

Granite B is a rock composed by K-feldspar, plagioclase, quartz, muscovite, biotite, chlorite, tourmaline, apatite and rare opaque minerals. In this granite the quartz crystals show strong deformation with ondulatory extinction, strain lamellae and an intense subgranulation. These features (Fig. 4) give this rock an alkali reactive behavior.

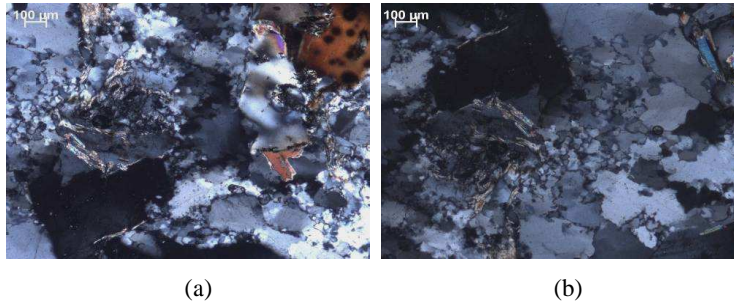


Figure 4. Microphotographs (Xs nicols mode) of granite B: a) quartz with ondulatory extinction; b) quartz with intense subgranulation.

The dolomite aggregate is a crystalline carbonated rock with siliceous veins which should be classified as marble, due to its deformation features. This rock is intensely deformed and presents potential reactive forms of silica, namely stretched quartz (Fig. 5). Such forms of silica give this aggregate a potential reactive behavior.

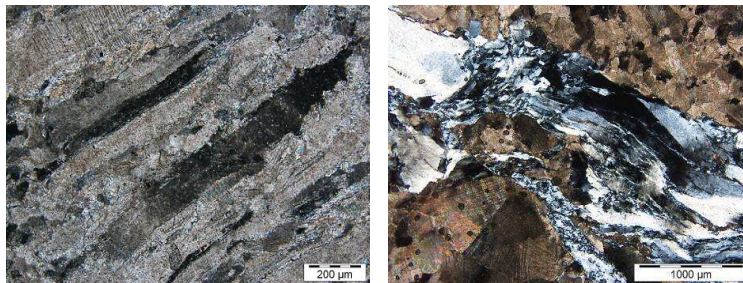


Figure 5. Microphotographs (Xs nicols mode) of dolomite aggregate: a) deformed carbonate; b) stretched quartz.

Analysis of expansion tests

Figure 6 shows the expansion curves obtained in the ASTM C1260 test. As expected, the RA and NR aggregate show the highest and lowest expansion respectively, confirming the petrographic and field information of their alkali-reactivity behaviour.

Regarding granites, none was classified as reactive according with this test method. Granite A presented the highest expansion value, however these results are not consistent with the petrographic analyses.

Figure 7 presents the comparison between the expansion results according to the 38°C slow and accelerated (60°C) concrete tests. The results of the 38° C concrete test do not confirm the reactivity potential given by petrography for such aggregates. With exception of granite A the concrete accelerated test (60°C) results show that the other aggregates are classified as reactive.

These results points out the low correlation between the applied test methods regarding the alkali-reactivity evaluation of the selected aggregates.

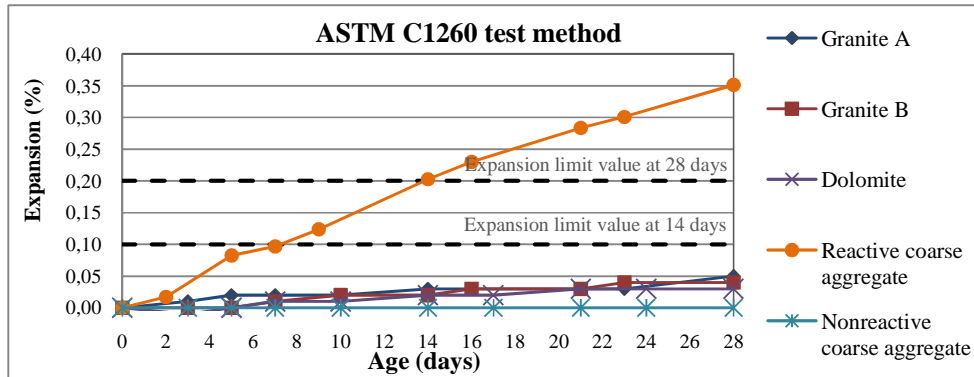


Figure 6. Expansion results of ASTM C 1260 mortar-bar method.

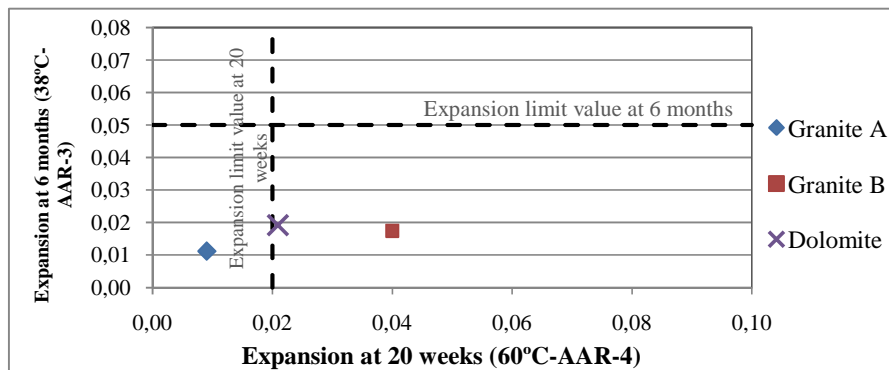


Figure 7. Expansion results of concrete slow-test (38°C) vs concrete accelerated -test (60°C).

Conclusions

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

The results obtained reveal low correlation between the recommended test methods for the evaluation of the alkali-reactivity of aggregates for concrete. This implies the urgent need for improving the methodologies for the assessment of potential alkali-reactivity of aggregates for concrete.

The mortar-bar test method is not applied to granitoid aggregates, as already had been pointed out in LNEC Specification E461-2007.

This study requires further development of the characterization of other rock lithologies, including aggregates that were already used in concrete structures (e.g. bridges, dams) with and without ASR features, in order to validate the characterization methodology.

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