Development of research related to alkali-silica reaction in concrete with recycled aggregates

Miguel Barreto Santos
Instituto Politécnico de Leiria (IPL), Escola Superior de Tecnologia e Gestão, Leiria, Portugal

Jorge de Brito
Universidade Técnica de Lisboa, Instituto Superior Técnico (IST), Lisboa, Portugal

António Santos Silva
Laboratório Nacional de Engenharia Civil (LNEC), Lisboa, Portugal

ABSTRACT: Since there is a possibility of incorporating recycled aggregates (RA) as a complement to primary aggregates (PA) in concrete production, taking advantage of construction and demolition waste, there are some questions on the durability of concrete with recycled aggregates (CRA) that need to be answered.

The durability of concrete with primary aggregates only (CPA) is conditioned, among other factors, by its degradation due to alkali-silica reactions (ASR). Since the first cases of ASR in CPA were identified, this expansive reaction has been a research theme resulting in the development of prevention and mitigation methodologies and in the comprehension of the chemical reactions involved.

The present paper proposes to describe the current development of a research program on ASR in CRA based on an experimental campaign involving the production of CRA with different replacement ratios of coarse PA with coarse concrete RA, the use of different cement classes, and variations on the concrete curing conditions and on the reactivity of the mixes.

1 INTRODUCTION

Alkali-silica reaction (ASR) is one of the chemical degradation causes of concrete with mineral aggregates (CMA). These reactions are included among the internal expansive reactions and occur in the simultaneous presence of high amounts of alkalis, reactive aggregates and humidity. During the reaction a silica-alkaline gel is developed that expands in the presence of humidity leading to various phenomena within the concrete that condition and change its properties. Research in this area has tried mostly to understand the expansive mechanism and the methodologies for its prevention and mitigation.

The incorporation of recycled aggregates (RA) in concrete, namely those from crushed concrete, as a complement to mineral aggregates (MA) leads to some questions related to its durability. In order to know the CRA in the same areas as the CMA it is necessary to study the possible causes of their degradation.

The theme of the research work presented in this paper was triggered by the possible occurrence of ASR in CRA and its manifestation perhaps being a consequence of the potential reactivity of the RA from the original crushed concrete.

An experimental campaign on ASR in CRA is presently being developed in order to understand how the total or partial incorporation of RA in concrete changes this deleterious reaction development, and to what extent the incorporation of RA in concrete is effective without risk of ASR.

Various CRA will be produced containing different replacement ratios of coarse MA with concrete coarse RA, different cement classes, variations in the weathering conditions of the original concrete (OC) and in the reactivity of the mixes.

In the various situations under analysis there is always a reference concrete, exclusively with MA. The RA for replacement purposes comes from an OC whose origin and characteristics are controlled.

2 RESEARCH RELATED TO ASR IN CRA

CRA have various properties apart from those of CMA that may lead to a different performance concerning ASR. There are studies on the topic of ASR in CRA, some of which are included in the references at the end of this paper, which mention the occurrence of ASR in the accelerated mortar or concrete expansion tests. However, some other references state that the use of RA did not always lead to high expansion rates.

These studies do not allow fully understanding and relating the development of ASR in CRA and CMA, even though they highlight differences in the progress of expansive reactions in CRA probably due to the characteristics of the RA and CRA themselves.

In terms of experimental analysis of ASR in CRA the bibliography referred presents relevant aspects and some proposals to change the methodologies of ASR testing (e.g. remarks on the accelerated test in mortar bars for RA according to ASTM C 1260 test method).

Some researchers consider that, in terms of the accelerated test in mortar bars, crushing concrete to obtain RA for the samples or the use of fine RA from primary crushing of a CMA influences the aggregate's characteristics and influences the expansion results. Therefore proposals were made to test separately the aggregates and the adhering mortar in the RA or to use only those RA resulting from a secondary crushing, i.e. crushing coarse RA. The pre-saturation of RA to be used in the expansion tests is also recommended to avoid erroneous results of samples with shorter ages.

With the intention of obtaining more data on the development of ASR in concrete with total or partial incorporation of RA and of investigating whether the expansive reaction is more damaging in CRA than it is in CMA, the following points present the results so far of the study under way of the authors of the present paper.

2.1 *Research methodology*

The experimental work is partly based on the recommendations of the Portuguese specification LNEC E 461 from the Portuguese National Laboratory of Civil Engineering that presents a methodology to evaluate the reactivity of a single aggregate or of an aggregate mixture. This specification is based on the alkali reactivity obtained by petrographic analysis which is complemented by accelerated expansion tests in mortar bars or concrete prisms.

CRA are produced and evaluated according to the mix compositions and test recommendations referred to in the specification for CMA. The evaluation of RA and CRA will take into account the specification and the observations of different authors on expansion tests in specimens with this type of aggregate. Changes in CRA properties will be studied through current tests of physic-mechanical evaluation, porous structure and microstructure.

RA from crushing controlled OC (made with MA with identical characteristics to those used to produce the CRA) will be used. Various situations that can influence ASR development were simulated in the study. Three CRA families will be produced with different MA-RA replacement ratios, reactivity levels, RA ages and cement types. Table 1 presents the different situations and the methodology employed.

Table 1. Scenarios created to study the development of ASR in CRA.

Scenarios concerning the CRA	Methodology used in the production of the CRA
- Influence of the RA	- Replacement ratios of 0, 20, 50 e 100%
- Different reactivity levels	- Use of reactive and non-reactive MA and RA
- Influence of the RA's age	- Use of weathered and non-weathered RA
- Physical changes and in the porous structure	- Use of 2 types of cement

2.2 *Experimental work done so far*

The experimental work is still in a preliminary stage, corresponding to the MA characterization and the production of two types of OC. Type A was made with non-reactive fine and coarse MA and type B with reactive fine and coarse MA. The same mix composition and cement type (CEM I 42.5R) was used for both OCs.

The OC's weathering is done in outdoor natural environment and in accelerated conditions (climatic chamber with 38º C and HR > 95%). This methodology allows the production of RA, reactive and non-reactive, coming from recent concrete (outdoor environment) and old concrete (accelerated weathering conditions).

After weathering, the OC's are crushed and the corresponding RA will be characterized and their properties confronted with those of the original MA. After these first steps, various families of CRA will be designed and produced. The next phase is the analysis of CRA's performance under the influence of ASR. Current tests will be performed in hardened concrete, as well as the evaluation of the its porous structure and reactivity, and the microstructure observation according to the evolution of the ASR in the CRA.

In points 2.2.1 and 2.2.2 some of the options are explained and some results from the first stage of the experimental campaign are presented.

2.2.1 *MA characterization*

The MA to be used in the concrete mixes was selected for their reactive potential and the possibility of keeping the aggregate's characteristics identical, both for the OC and the RCA. Table 2 groups the MA used in the experimental campaign and identifies the OC type in which they were used.

Table 2. MA used in the experimental campaign

Denomination	Potential reactivity	Type of aggregate	OC type
AGP-NR1	Non-reactive	Limestone gravel	A
AGP-NR2	Non-reactive	Limestone gravel	A
AFP-NR	Non-reactive	Siliceous sand	A
AGP-R1	Reactive	Siliceous pebble	B
AGP-R2	Reactive	Siliceous pebble	B
AFP-R	Reactive	Siliceous sand	B

The types of MA described were submitted to petrographic analysis and also to mortar bars expansion tests. The latter, based on ASTM C 1260 and similar to RILEM's test AAR-2, allows checking the MA potential reactivity to alkali through the measurement of the average expansion of 3 mortar bars during at least 14 days. The bars (25 x 25 x 285 mm) are produced with the MA under analysis, crushed to a given size distribution, and immersed in a solution of sodium hydroxide 1M at a temperature of 80 ± 1ºC - Figure 1.

Figure 1. Casting of the mortar bars (left) and expansion measurement (right)

According to LNEC E 461 specification if after 14 days the average expansion of the mortar bar is higher than 0.20% the aggregate is considered highly potentially reactive; however, if the expansion value is within the interval 0.10-0.20% at that age it is recommended that the test proceeds until 28 days. The aggregate's reactivity is considered doubtful if the expansion at 28 days is lower than 0.20%.

To study the evolution of expansion the test took 28 days for all MA. Figure 2 shows graphically the results of the reactive and non-reactive MA tested.

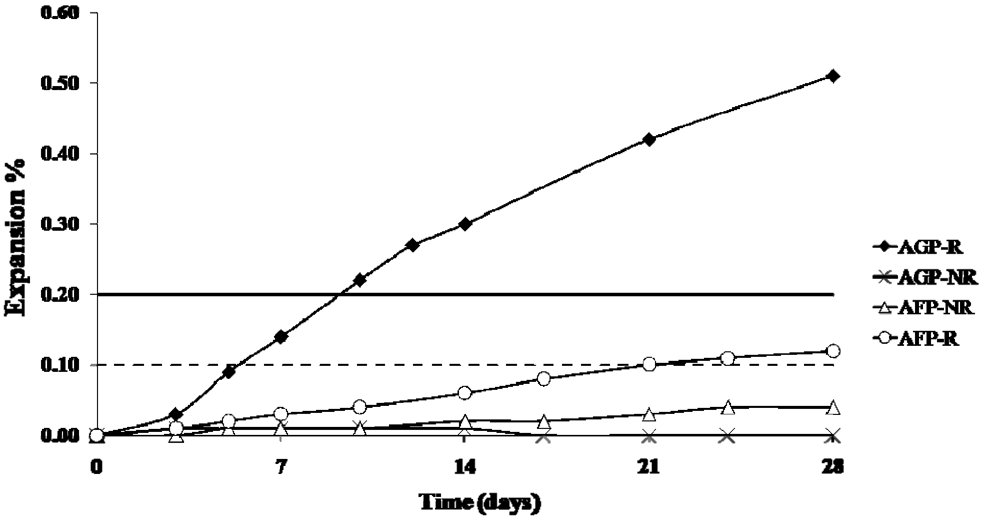

Figure 2. Expansion of the mortar bars during 28 days, according to ASTM C1260

The results demonstrate the reactive potential of the AGP-R with an average expansion at 28 days of 0.51%, with the limit achieved after only 10 days. Gels were observed in the specimens with AFP-R. Given also the results of the petrographic analysis their reactivity to alkali was proved, even though it is slow to develop and therefore it is not detected at 14 days with the ASTM C 1260 test. In these cases it is recommended to perform the concrete prisms test according to the RILEM AAR-3 or RILEM AAR-4 test methods.

According to the limits established, the aggregates AGP-NR and AFP-NR are considered non- alkali reactive. This creates two sets of aggregate for the production of OC types A and B. Aggregate with similar characteristics will be used to produce the various CRA.

The size distribution was determined to physically characterize the aggregate, based on NP EN 933-1, which classifies by average size the aggregate of a given sample. Other physical and chemical tests of the MA will be performed at this stage of the experimental campaign.

Succinctly the test starts by sampling the MA and creating two specimens using the adequate procedure. The material is dried in an oven at 110 ± 5 ºC and then weighted. The specimens are then washed to eliminate most of the fines under 0.063 mm and dried, and their dry weight is determined. The resulting material is then passed through a column of calibrated sieves. The quantity retained in each sieve provides the MA size distribution. The dimensions of the sieve meshes used in this work are those from the basic series plus those of series 2, both from NP EN 12620, which regulates the characteristics of aggregate for concrete. Figures 3 and 4 show the size distribution of the fine and coarse MA used in the production of OC types A and B.

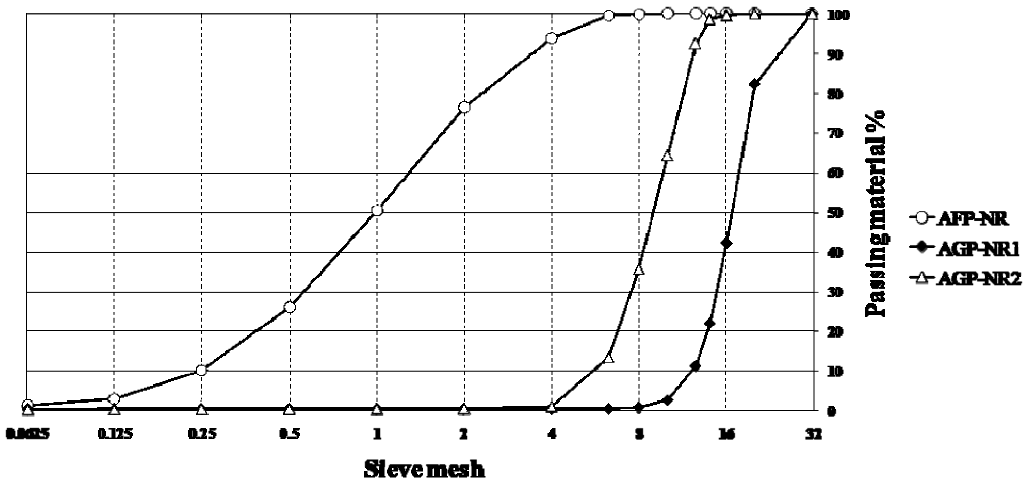

Figure 3. Size distribution of the MA used in OC type A

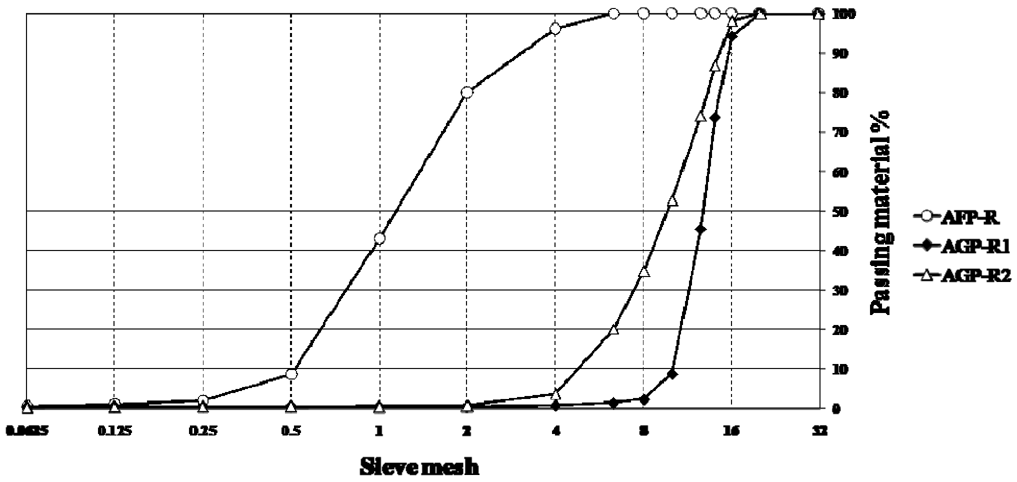

Figure 4. Size distribution of the MA used in OC type B

In both cases the final results validation feel within the limits set by standard NP EN 933-1. The sum of the material retained and of the residue differed less than 1% in mass from the dry mass of material over 0.063 mm.

2.2.2 *OC characterization*

The two types of OC, exclusively made of MA either reactive or non-reactive, were produced with the same composition. This is explained by the need to differentiate the OCs fundamentally by the type of MA used. The cement was in both cases CEM I 42.5R.

To characterize the OC the compressive strength (Figure 5) and splitting tensile strength were measured according to NP EN 12390-3 and NP EN 12390-6, respectively. Cubic and cylindrical specimens were prepared and were kept under the conditions stated in NP EN 12390-2. The test was performed in the Construction Laboratory of Instituto Superior Técnico (IST) using a 4 column hydraulic press with a controlled loading rate.

Figure 5. Hydraulic press used in the compressive strength test

Presently 6 concrete prisms are being weathered at 38 ± 2 ºC and at relative humidity over 95%, according to ASTM 1293 and similarly to the RILEM AAR-3 test method. The prisms allow following the OC expansion due to ASR for at least 12 months. No results of this text are ready to be presented.

Table 3 shows the results from the 28-day compressive and splitting tensile strength of the OC. A difference in the average compressive strength of the two mixes is visible due probably to the use of the same amount of material in the mixes notwithstanding the unequal characteristics of the MA. However the RA from these OC will not be mixed in any CRA mix, and therefore this problem is not relevant.

Table 3. Compressive and splitting tensile strength of OC

	Compressive strength						
Denomination	Force (kN)			f_c (MPa)			f_{cm} (MPa)
BO type A	1137	1326	1247	50.53	58.93	55.42	55.0
BO type B	1457	1478	1440	64.76	65.69	64.00	64.8
	Splitting tensile strength						
Denomination	Force (kN)			f_{ct} (MPa)			f_{ctm} (MPa)
BO type A	239.7	213.4	256.5	3.39	3.02	3.63	3.4
BO type B	226.6	231.4	232.8	3.21	3.27	3.29	3.3

2.2.3 *Natural and accelerated weathering of OC*

It was considered that the age of the RA may influence the development of ASR in CRA due to characteristics of the adhering mortar. Therefore an old concrete was simulated in part of the prepared OC by accelerated weathering in a climatic chamber and a recent concrete in the remaining part by outdoor natural weathering.

Accelerated weathering is proceeding at the Construction Laboratory of UBI (University of Beira Interior) in a walk-in climatic chamber. The concrete is cast in blocks that are subjected to 38 ± 2 ºC and a relative humidity higher than 95%, protect by plastics to minimize the calcium and alkalis lixiviation. These conditions are based on the recommendations of RILEM AAR-3 to study ASR using concrete prisms.

Figures 6 and 7 illustrate both weathering conditions. Through this methodology the aim is to create reactive weathered RA, non-reactive weathered RA, reactive non-weathered RA, and non-reactive non-weathered RA. These aggregate types will be used in the different CRA compositions.

Figure 6. Storage of the concrete blocks in a climatic chamber

Figure 7. Storage of the concrete blocks for open-air natural weathering

3 CONCLUSIONS

The research work presented in this paper is still in a preliminary stage of preparation and characterization of material for CRA production with the objective of analyzing ASR. The conditions are now ready to use RA, with various characteristics conditioned by the production and weathering of the different OCs, to simulate several CRA scenarios and study their performance when subjected to ASR.

4 ACKNOWLEDGEMENTS

The authors dully acknowledge the support of the National Laboratory of Civil Engineering (LNEC), the Polytechnic Institute of Leiria (IPL), Instituto Superior Técnico (IST), the University of Beira Interior (UBI), the ICIST Research Centre and the Foundation for Science and Technology (FCT).

5 REFERENCES

Calder, A. J. J.; McKenzie, M. (2005) *The susceptibility of recycled concrete aggregate to alkali silica reaction*, Published Project Report PPR037, Transport Research Laboratory, Wokingham, Berkshire, UK.

Desmyter, J.; Blockmans, S. (2000) *Evaluation of different measures to reduce the risk of alkali silica reaction in recycled aggregate concrete*, 11th International Conference on Alkali-Aggregate Reaction in Concrete, Quebec City, QC, Canada, June, pp. 603-612.

Dhir, R. K.; McCarthy, M. J.; Halliday, J.E.; Tang, M.C. (2005) *ASR guidance on recycled aggregates - Guidance on alkali limits and reactivity*, DTI/WRAP Aggregates Research Programme STBF 13/14C, The Waste and Resources Action Programme, UK.

Gottfredsen, F. R.; Thøgersen, F. (1993) *Recycling of concrete in aggressive environment*, Third International RILEM Symposium on Demolition and Reuse of Concrete and Masonry, Odense, Denmark, pp. 309-317.

Gress, D. L.; Kozikowski, R. L. (2000) *Accelerated ASR testing of concrete prisms incorporating recycled concrete aggregate*, 11th International Conference on Alkali-Aggregate Reaction in Concrete, Quebec City, QC, Canada, June, pp. 1139-1148.

Larrañaga, M. E. (2004) "*Experimental study on microstructure and structural behaviour of recycled aggregate concrete*, Doctoral Thesis in Civil Engineering, Catalonia Polytechnic University, Barcelona, Spain.

Li, X. (2005). *Mitigating alkali silica reactions in recycled concrete*, Doctoral Thesis in Civil Engineering, University of New Hampshire, Durham, USA.

Scott, H. C. (2006). *Mitigating alkali silicate reaction in recycled concrete*, Master Thesis in Civil Engineering, University of New Hampshire, Durham, USA.

Scott, H. C.; Gress, D. L. (2004). *Mitigating alkali silica reaction in recycled concrete*, Recycling Concrete and Other Materials for Sustainable development, ACI SP-219, American Concrete Institute, Michigan, USA, pp. 61-76.

Shehata, M.; Christidis, C.; Mikhaiel, W.; Rogers, C.; Lachemi, M. (2008). *Reactivity of reclaimed concrete aggregate produced from concrete affected by alkali silica reaction*, 13th International Conference on Alkali-Aggregate Reaction in Concrete, Trondheim, Norway, pp. 1230-1239.

Stark, D. (1996). *The use of recycled-concrete aggregate from concrete exhibiting alkali-silica reactivity*, Research and Development Bulletin RD113, Portland Cement Association, Skokie, Illinois, USA.