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Glass waste powder addition used as mitigator of concrete alkali-silica reaction

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Abstract. The recycled aggregates from demolition of concrete structures affected by alkali silica reaction as well as the potentially reactive natural aggregates are often a matter of great concern and fear in case of new structures construction. Thus, to encourage the recycling and use of some potential reactive aggregates under scientific basis, this paper presents an experimental study where suspected alkali-silica reactive recycled aggregates was used. The main goal of this study is evaluate the influence of waste glass powder addition as mitigator of the concrete expansive reaction. In a first phase, the level of expansibility of different aggregates was identified using accelerated tests in mortars bars, method ASTM C1260 and an adapted accelerated test on specimens of 40 x 40 x 160 mm. In a second phase, tests were performed on concrete mixtures, according to CMBT method, with 100% recycled reactive coarse aggregates and powder addition, such as the glass powder and metakaolin. The powder additions percentages were incorporated at 20%, 40% and 60% of cement weight. The results of mortars bars test showed opposite results according to the method applied, i.e. , the same aggregates considered as harmless by the adapted method are considered reactive by the ASTM method, if the same expansion limit of 0,10% for 16 days was adopted for both methods. Finally, the concrete results obtained with CMBT method showed that glass powder and metakaolin had a significant mitigation effect in alkali-aggregate reaction development.

1 Introduction

Recycling demolished concrete as aggregate in new concrete is also an option that not only reduces the amount of construction wastes disposed in landfills but also reduces the consumption of non-renewable resources, such as natural aggregate. However, the use of recycled concrete aggregate (RCA) in new structures requires thorough research to make sure that the durability of the new concrete is not compromised, especially if the old concrete was suffering from alkali–silica reaction. The degradation of concrete structures by alkali-silica reaction (ASR) is a problem that affects an increasing number of concrete structures around the world. The alkali-silica reaction (ASR) happens between the reactive silica present in some aggregates and the hydroxyl (OH^-) and alkaline (Na^+, K^+) ions in the cement paste. In the presence of enough water or high humidity, an alkali-silica gel is formed, and it can swell and cause cracking of the concrete [1]. Is well known that the use of pozzolanic materials as a partial cement replacement in mass can prevent the ASR reaction and a number of reviews have been published recently [2–5]. When a pozzolan is added to cement the Ca/Si molar ratio of the cement hydrates is reduced which causes more alkali to be retained by the hydrates, thereby producing a reduction in the amount of soluble alkali available for ASR. The production of low Ca/Si ratio C-S-H, characteristic of blended cements, also can specify the pore structure that should be further studied to understand the effect on ASR [6].

Glass is a common product that can be found in different forms, traditionally, most non-recyclable mixed-colour broken glass is coming from the bottling industry. The current waste management practice is still to landfill deposit most of the non-recyclable glass. Since glass is not biodegradable, deposit in landfills do not provide an environment friendly solution. Several recycling channels already exist for glass recovery, the main one being the manufacture of new glass products. However, most of the time, the collected glass is mixed and so unusable for the production of bottles of a given colour. One important channel for the recycling of mixed glass is cement-based materials. The determination of the oxide composition of selected glass waste samples indicates that, in accordance to NP EN 450 [7], the glass satisfies the basic chemical requirements for a pozzolan. However, it does not comply with the additional requirement for the alkali content because of the high percentage of Na2O in glass. Despite this situation, finely ground glass powders, higher than 250 m^2/kg Blaine specific surface, had very high pozzolanic activity [8]. It has been finding that only glass particles of more than 1 mm gave expansions related to alkali–silica reaction and no excessive crushing of glass particles was needed to obtain a satisfactory pozzolanic behaviour. In practice, it is means that the particles should be smaller than 120 μm [9].

Currently, there are a number of test methods used to evaluate the efficiency of pozzolans in terms of controlling expansion due ASR. The accelerated mortar bar test has as its main advantage a relatively short duration, but the price for speed seems to be a loss in reliability. However, it is possible to use the accelerated mortar bar test to determine the minimum amount of supplementary cementitious materials required to suppress expansion with a particular aggregate when that aggregate is used with high-alkali cement [10].

The Concrete Microbar Test has attracted interest recently [11, 12] as it offers the advantage of using larger aggregate sizes (mortar bar has a 40×40 mm^2 cross-section) and possibly a shorter duration.

However, it is essential that test methods and associated test limits be developed with consideration to appropriate benchmarks. This study is an attempt in that direction. The main objectives of the research presented in this paper were: (1) to investigate the reactivity of RCA produced from ASR-affected concrete containing highly reactive Portuguese aggregate, (2) to find out if current ASR tests including the accelerated mortar bar test are able to evaluate the reactivity of RCA and the efficacy of common preventive measures such as waste glass powder , and (3) to determine the type and levels of preventive measures that are needed to mitigate the expansion in new concrete containing ASR-affected RCA.

The glass powder mitigation performance is compared to mixtures containing similar replacement levels of a commercial metakaolin. Such a quantitative comparison between glass powder and metakaolin is expected to help material designers in choosing optimal dosages as well as lead to better confidence in the use of glass powder in concrete.

2 Materials and Methods

A commercial Portland cement type CEM I 42.5R conforming to European Standards EN–197-1 [13] with Na_2O-equivalent alkali content of 0.84%, a Blaine surface specific area of 400.9 m^2/kg and a density of 3160 kg/m^3 was used for all mixes. As supplementary cementitious materials a commercial metakaolin and recycled glass powder were used. The metakaolin has a Blaine surface specific area of 530.1 m^2/kg and a density of 2580 kg/m^3. The glass waste used in this study was obtained at the local waste management and disposal service of Cova da Beira Municipal Association, of the interior region of Portugal. The glass waste with density 2525 kg/m^3 was grounded first in a jaw crusher and a ball mill afterwards and, sieving to obtain the particle size smaller than 75μm. The Blaine surface specific area of the glass powder was 295.5 m^2/kg. The chemical compositions of metakaolin and glass powder, as shown in Table 1, were obtained by energy dispersive X-ray analysis (EDX) in scanning electron microscope (SEM).

Table1: Chemical compositions of metakaolin and ground waste glass (by weight percent).

Elemental composition	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	TiO_2
Metakaolin	0.096	0.161	27.00	61.26	0.325	0.048	6.622	0.159	0.994
Glass	9.94	0.75	2.57	74.07	-	-	1.14	11.53	-

The RCA used in this study was obtained from concrete blocks produced with high expansive alkali-reactive siliceous gravel coarse aggregate. The concrete blocks were submitted to accelerate aging process at 60ºC a 95% HR according to RILEM AAR-4 [14] in a climatic chamber during 3 months. Samples of the virgin aggregates originally used in the RCA were also collected. Granite and limestone crushed aggregates from Portuguese quarries in the central region of Portugal, with a maximum particle size of 10 mm were used as reference aggregates. Those aggregates were crushed to produce particles sizes according the test methods used.

The expansions provoked by the different natural and recycled aggregates were measured by the accelerated mortar bar test, according to the ASTM C1260 [15] and an adapted mortar bar test where the size of bars was 40 x 40 x 160 mm. After 24 h curing in a moist room, the mortar bars were demolded and their lengths were measured. After the initial length measurements the mortar bars were immersed in tap water in a closed container maintained at 80 ºC for 24 h. The reference reading of mortar bars were measured before its immersion in a 1 N sodium hydroxide solution in a closed container maintained at 80 ºC. Length bar readings were then taken every day for 28 days.

The ASR was also examined with the concrete microbar test. The protocol for the test is essentially the same as for ASTM C 1260, except for the size of the bars, the grading of the aggregate, the water to cement ratio and the length of the test. The concrete microbars are 40 by 40 by 160 mm. The aggregate is graded to pass a 12.5 mm sieve and be retained on a 4.75 mm sieve. The water to cement ratio is 0.33. The length of the test is 30 days in 1 M NaOH at 80°C. The experimental results obtained by Grattan-Bellew *et al* [11] show that this method is applicable to both alkali-carbonate and alkali-silica reactive aggregates.

Table 2 show the mortar mixtures compositions to produce mortar bars and in Table 3 are presented the mixtures compositions for the concrete microbar test. The series of mixtures for the microbar test has the incorporation of mineral additions used as ASR mitigator. One denoted as MK (metakaolin) that was incorporated in concrete produced with recycled reactive concrete aggregates (RRCA) in percentages of 20, 40 and 60% and another denoted GL (glass powder) replacing at the same percentage the metakaolin.

Table 2: Mixtures composition for accelerated mortar bar test ASTM C1260 method and adapted test (in g.)

Mixture	Cement	Granite aggregates	Natural reactive aggregate	Recycled reactive coarse aggregates	Recycled fine aggregates	Limestone aggregates	Water
REF	440	990	-	-	-	-	206,8
NRA	440	-	990	-	-	-	206,8
RRCA	440	-	-	990	-	-	206,8
RFA	440	-	-	-	990	-	206,8
LA	440	-	-	-	-	990	206,8

Table 3: Mixtures composition for concrete microbar test method CMBT (in g.)

Mixture	Cement	MK	GL	Granite aggregate	Recycled aggregate RRCA	Water	Superplasticizer (%)
REF	900	-	-	900	-	270	-
REF RRCA	900	-	-	-	900	270	-
RRCA MK 20	720	180	-	-	900	270	1.0
RRCA MK 40	540	360	-	-	900	270	1.5
RRCA MK 60	360	540	-	-	900	270	2.0
RRCA GL 20	720	-	180	-	900	270	-
RRCA GL 40	540	-	360	-	900	270	-
RRCA GL 60	360	-	540	-	900	270	-

The mixtures with metakaolin required the use of superplasticizer to adjust the workability.

3. Results and discussion

3.1. Accelerated bar test results

Fig. 1 shows the average results obtained with 3 bars for each mortars mixtures produced with aggregates of different origins and characteristics: natural (REF, NRA and LA), recycled (RFA and RRCA), reactive (NRA and RRCA) and non reactive (REF and LA), fine (RFA) and coarse aggregates (REF, NRA, RRCA and LA).

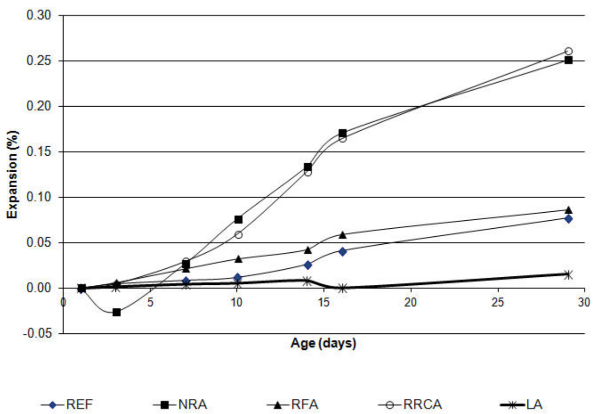

Fig. 1 – Average expansion results of accelerated mortar bar test

Taking into account the expansion limit of 0.10% at 14 and 16 days, the recycled reactive coarse aggregate (RRCA) and the natural reactive aggregate (NRA) are confirmed as potentially reactive aggregates. It is observed that the portion of fine aggregates recycled (RFA) from the crushed concrete blocks produced with reactive aggregates is not contaminated to become also potentially reactive. The evolution of the expansion results of RFA is quite similar to the natural granite aggregates (REF) used in this study as a reference mixture. These aggregates could be considered as innocuous at the point of view of alkali silica reaction as the limestone aggregates. The expansion measurements extended to 28 days also confirms the nature non reactive aggregates of the mixtures RFA, REF and LA.

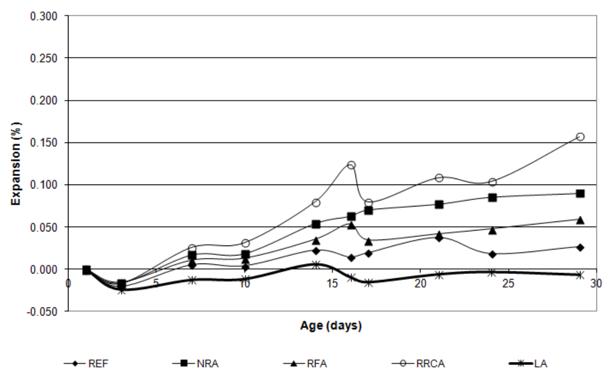

Fig. 2 – Average expansion results of adapted accelerated mortar bar test

If the expansion limited values of 0.10% at 28 days, proposed by Xu et al. [16], was take into account, only the aggregates of RRCA mortar would be consider as potentially reactive. But, it is necessary to deem that the limit of deleterious expansion depends at same test conditions of samples geometry. Fournier *et al* [17], proposed that the value to be consider as limit for a potentially reactive aggregate would be admeasured with the results obtained on samples submitted at real exposure conditions.

During the first expansion measurements, till 5 days, a slightly shrinkage was registered. The mixture NRA at 28 days attaints an expansion very near to 0.10%. This proximity could be an argument that the limited value proposed by Xu et al [16] needs perhaps to be reviewed.

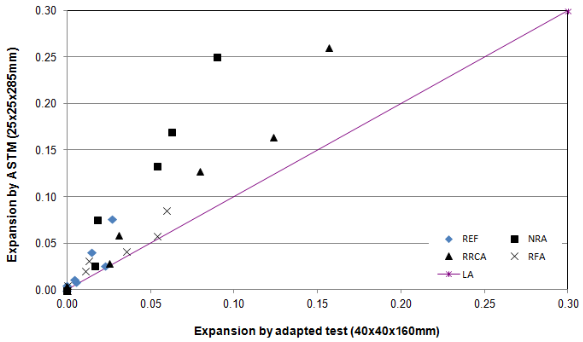

Fig 3. Expansion results of accelerated mortar bar tests ASTM C 1260 x adapted method

A comparison of the results obtained by the both methods can be analysed by Fig 3. It is observed any significant influence of samples size on the results of expansion for values inferiors of 0.05%. However, for superior values the results obtained by the ASTM C1260 method, in general, increase more rapidly than the adapted test. The results above the equality line indicate that the expansion limit criteria used to ASTM C 1260 cannot be directly applied to the adapted method. This fact needs a further admeasurements study to be developed with concrete samples exposed a long term in real conditions.

3.2. Concrete microbar test (CMBT) results

Fig 4 retakes the 30 days expansion results determined by the CMBT method confirming the reactivity of the concrete recycled aggregates and the innocuous characteristics of natural granite aggregates.

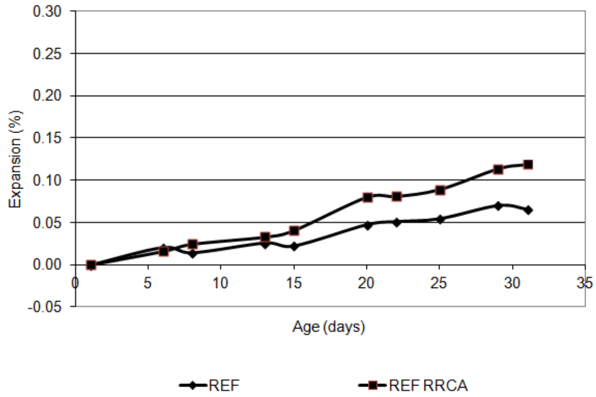

Fig 4. Expansion results (CMBT method) for references mixtures REF and RRCA

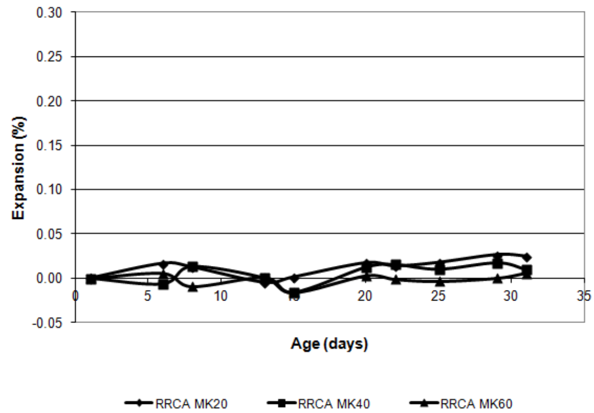

Fig 5. Expansion results (CMBT method) for mixtures with different percentage of metakaolin MK incorporation

The metakaolin is a known ARS mitigator largely applied in concrete production by its pozzolanic action and was used in this study to compare the glass powder efficiency on ASR mitigation. In fact, Fig 5 shows that the lowest percentage of metakaolin addition is sufficient to maintain the expansion at the very low values attesting its mitigation capacity.

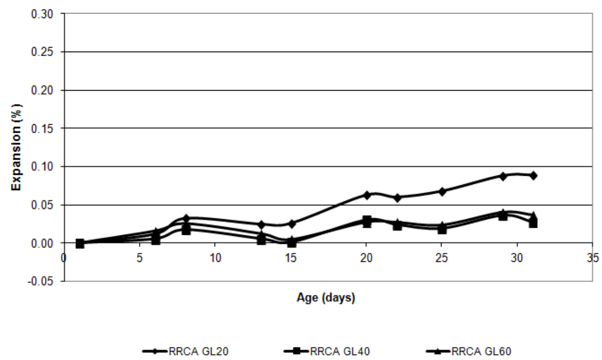

Fig 6. Expansion results (CMBT method) for mixtures with different percentage of glass powder GL incorporation

If the results presented in Fig. 6 are compared with then presented in Fig. 5 it is possible to recognize the mitigation capacity of the glass powder obtained from the urban wastes. In this case, the effect of mitigation increases with glass powder percentage from GL20 till GL40 and is maintained constant at GL60. At 40 and

60% of GL incorporation the efficiency is similar to that observed with RRCA MK mixtures. Figs 7, 8 and 9 shows in more details the results comparing the GL and MK addition at the same percentage incorporated in the concrete mixtures. Analysing the results it is possible to identify the 40% as an optimal GL percentage to have MK similar efficiency to mitigate the alkali silica reaction of recycled reactive concrete aggregates.

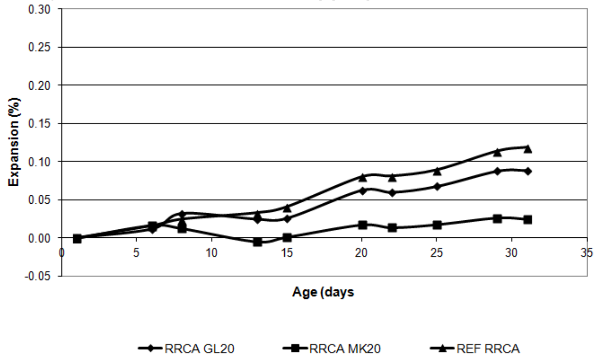

Fig 7. Expansion results (CMBT method) for mixtures with 20% of glass powder GL and metakaolin MK

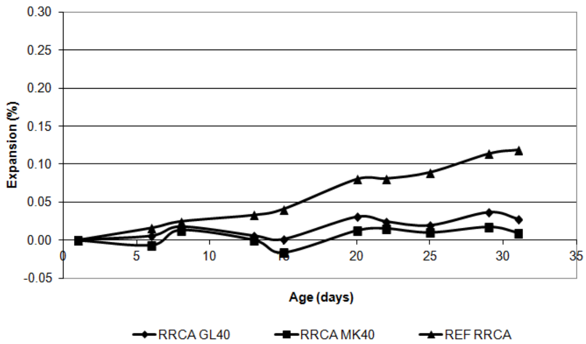

Fig 8. Expansion results (CMBT method) for mixtures with 40% of glass powder GL and metakaolin MK

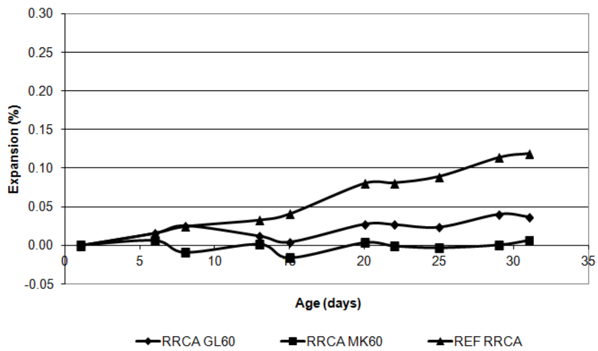

Fig 9. Expansion results (CMBT method) for mixtures with 60% of glass powder GL and metakaolin MK

4. Conclusions

Firstly, the results of alkali silica reaction expansion measured by different methods: ASTM C 1260 and an adapted method, to identify the potential reactivity of different aggregates, could confirm that:

- the natural granite aggregates as well natural limestone aggregates are considers as innocuous by both accelerated mortar bar test, at the same time these methods confirm the potential reactivity of natural reactive aggregates and recycled reactive concrete aggregates.

- the fine material portion separated by sieving from the aging concrete blocks produced with reactive aggregates was considered not contaminated by these reactive aggregates, which permit with some precaution to reuse as recycled material in mortars or concretes mixtures.

- the results obtained by the adapted mortar bar test were lowest at 16 days when comparing with the ASTM C 1260 method. Since the known natural reactive aggregates used in this study attained an expansion value inferior of 0.1% at 16 days, it is permit to state that the deleterious limit for the adapted accelerated mortar test needs to be admeasured by the way of a long term test of samples exposed at real conditions.

As this study also aimed to evaluate the preventive role of pozzolanic glass powder in counteracting the deleterious effect of alkali-reactive concrete recycled aggregates, it has been shown that the use of this type of additions is pertinent. The main results were that:

- the CMBT results also confirm that natural granite aggregates are innocuous and the recycled reactive concrete aggregates are potentially deleterious, corroborating the precedent conclusions established by the mortar bar test to these type of aggregates.

- in general, the increase of mineral additions as metakaolin and glass powder reduces the alkali silica reaction expansion observed at 30 days.

- the lowest metakaolin percentage was sufficient to mitigate the alkali silica reaction expansion on the recycled reactive concrete aggregates mixtures.

- the glass powder addition revealed to be efficient as alkali silica reaction mitigator demonstrating an optimal incorporation percentage around 40%.

Finally, taking into account the results here presented, it is possible to assume that the glass powder obtained from urban wastes disposals could be employed in concrete production leading to environmental and economic benefits, when the aggregates are suspicious to be reactive.

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