Construction and Building Materials 47 (2013) 489–495

Contents lists available at SciVerse ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

ASR of mortars containing glass

D. Serpa [a], A. Santos Silva [b], J. de Brito [c,*], J. Pontes [a], D. Soares [b]

[a] DECivil-IST, Technical University of Lisbon, Av. Rovisco Pais, 1049-001 Lisbon, Portugal
[b] National Laboratory of Civil Engineering, Av. do Brasil 101, 1700-066 Lisbon, Portugal
[c] Department of Civil Engineering, Architecture and Georresources, IST – Technical University of Lisbon, Av. Rovisco Pais, 1049-001 Lisbon, Portugal

HIGHLIGHTS

- The use of very particles of glass is viable in the production of cementitious materials.
- The greatest problem of this incorporation is the potential of alkali-silica reaction (ASR).
- The incorporation of glass as cement replacement or even as aggregate can decrease the ASR effects.
- The efficiency of this incorporation is related with the replacement ratio.

ARTICLE INFO

Article history:
Received 11 December 2012
Received in revised form 5 April 2013
Accepted 4 May 2013
Available online 7 June 2013

Keywords:
Alkali-silica reaction
Construction and demolition waste
Glass
Recycling

ABSTRACT

Glass is a material that raises environmental issues in terms of both recycling and dumping. Some studies have shown the potential of glass as pozzolan when used as fine powder. Its use as aggregate in cementitious materials may in certain circumstances lead to alkali silica reaction (ASR) related problems.

ASR is one of the most studied deleterious degradation mechanisms of concrete, which is particularly harmful. Once detected in a concrete structure, ASR is very difficult to stop. It is nowadays possible to use mineral additions like natural pozzolans or sub-products with pozzolanic reactivity to inhibit ASR in new concrete.

This work shows the results of using a Portuguese recycled glass material as aggregate or as pozzolan in cement based mortars, to ascertain their applicability in concrete. The incorporation of glass as cement replacement or even as aggregate can decrease the ASR effects and its efficiency is related with the replacement ratio.

1. Introduction

In the past decades there has been an attempt to increase the reuse of end-of-life materials in order to preserve the world's natural resources and the reuse of glass is no exception. In Portugal in 2010 425 thousand tonnes of glass were produced and only 192 thousand tonnes of waste glass were recycled [3]. So, the rest was deposited in dumping grounds, thus creating two problems, i.e. use of space in order to dispose of the waste and consumption of natural resources.

The solubility of the glass is dependent on the grain size of the glass particles, increasing with the reduction of the particle size. According to the literature when glass is used as finely powder material (size < 75 μm) the silica is quickly dissolved, reacting with free portlandite and acting as a pozzolanic material. On the contrary, when used as aggregate particles, glass grain suffers a partial dissolution, mainly localized in its boundaries, which causes the formation of silica gels that can expand, causing high distress [5]. In this same study it is observed that the glass expansion has a slower initial rate, growing in later ages.

The ASTM C 1260 [1] or ASTM C 1567 [2] mortar-bar expansion tests are universal test-methods used in the Alkali-Silica Reaction (ASR) field, namely to study the efficacy of a specific material to counteract ASR expansion. Several studies exist in the literature regarding the glass effect on ASR, but some discrepancies are detected, including its acceptable substitution content (Table 1) [1,17,9] and [8].

In Portugal the typical material employed in ASR mitigation is fly ash from coal combustion. However, the availability of this material tends to decrease due to environmental restriction related to CO_2 emissions. This situation forces the study of alternative materials to fly ash in ASR mitigation. To the authors knowledge few studies involving Portuguese recycled glass were developed in a concise way [11]. Literature data provides information on the positive effect of glass powder (GP) as a cementitious material replacement will mitigate the effects of the ASR has shown in

* Corresponding author. Tel.: +351 218419709; fax: +351 218497650.
E-mail addresses: diogo_serpa@hotmail.com (D. Serpa), ssilva@lnec.pt (A. Santos Silva), jb@civil.ist.utl.pt (J. de Brito), jorgempontes@gmail.com (J. Pontes), dsoares@lnec.pt (D. Soares).

0950-0618/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.conbuildmat.2013.05.058

Table 1
Literature results of ASR testing on mortars with GA.

Refs.	Glass type	Glass substitution (%)	ASR at 14th day (% expansion)
[17]	White glass	25	0.45
		50	0.60
		75	0.75
		100	0.83
[9]	Waste glass bottles	0	0.020
		15	0.035
		30	0.065
		45	0.085
[8]	White glass	0	0.022
		10	0.040
		15	0.050
		20	0.065

Table 2
Literature results of ASR testing on mortars with GA as mineral addition.

References	Aggregate type	Maximum particle size (μm)	Glass substitution as mineral addition (%)	ASR at the 14th day (% expansion)
[16]	Reactive spratt sand	100	0	0.55
			10	0.40
			20	0.22
			30	0.12
			50	0.08
[11]	CEN sand	50	0	0.18
			10	0.13
			20	0.04

Table 3
Chemical composition and pozzolanic reactivity (modified Chapelle test) of the cement and mineral additions used.

Content (%)	Cement	G	FA	MK	BFA
SiO_2	18.81	74.28	53.22	54.66	25.10
Al_2O_3	5.15	2.01	23.20	37.98	0.07
Fe_2O_3	3.18	0.11	5.85	1.22	5.18
CaO	63.70	9.60	5.36	0.01	0.42
SO_3	2.69	–	1.00	0.01	–
$TiO_2 + P_2O_5$	–	–	1.87	–	2.64
MgO	1.5	3.38	1.63	0.46	6.63
Na_2O	0.19	10.85	0.44	0.00	3.61
K_2O	1.02	0.24	1.42	3.09	2.07
$Na_2O_{eq.}$	0.86	11.01	1.37	2.03	4.97
LOI	3.18	0.97	5.16	0.94	10.35
Pozzolanic reactivity					
CaOH consumed [mg]	–	364	504	860	276

G – glass; FA – fly ash; MK – metakaolin; BFA – biomass fly ash.

Table 2 [11,12] and [16]. Concerning this, it was observed that the finer the glass powder, the better it will perform in counteracting the ASR expansion effects [7]. This behaviour of glass is comparable to other types of reactive fine powders [4].

This paper is part of a wider study that was designed to evaluate the mechanical and durability-related [3] performance of concrete and mortars incorporating recycled glass aggregate in order to check the long-term behaviour of the aggregate. Mortars incorporating Portuguese recycled glass as aggregate or cement replacement were evaluated and compared with mortars with coal fly ash, metakaolin and biomass fly ash.

2. Experimental

The materials and their characteristics, as well as the standards and methods used in this study are presented below.

2.1. Materials

Mortars were prepared with Portland cement CEM I 42.5R. Table 3 presents the chemical composition of the cement and additions used. The pozzolanic reactivity of the additions according to the modified Chapelle test is also presented [13]. In Table 4 it can be observed that the glass used in the present work, by comparison with other glass types, has the highest content of silica and lowest content of Na_2O_{eq}. As for CaO present, the glass used has similar content to that of others used in various studies.

2.2. Mixes

Mortars were prepared according to the ASTM C 1567 standard, equivalent to ASTM C 1260. This test method allows the detection of the potential of deleterious alkali-silica reaction of combinations of cementitious materials and aggregate in mortar bars.

Three types of aggregates were selected: one quartzitic and alkali-reactive (expansion > 0.20% at 14 days, according to ASTM C 1260) called AR, and other two non-reactive ones, one siliceous and the other limestone (expansions < 0.10% at 14 days), called AS-NR (siliceous sand) and AC-NR (limestone sand). Each aggregate type was, respectively, replaced by 5% and 20% of glass particles (replacement by mass), in order to assess the aggregates' influence in terms of mineralogical nature and reactivity.

Also, mixes with 20% and 30% incorporation of glass powder (GP) (grain size < 125 μm) as replacement of cement (% by mass) were prepared in order to study their performance in terms of inhibiting the ASR-related expansion relative to a mix with AR only. Table 5 identifies all the mixes analysed.

2.3. Tests performed

The experimental programme was divided in two stages. In the first one expansion tests were performed in order to characterize the glass-aggregate mixes as reactive or non-reactive, according to the appropriate standards. In the second stage the microscopic performance of the specimens was evaluated using SEM/EDS, to put the results of the first stage into perspective.

2.4. Expansion test

Mortar prisms ($25 \times 25 \times 285$ mm^3) were prepared according to the ASTM C 1567-08 standard. They were demoulded 24 h after casting, and after were immersed in water at 23 °C and stored in a climatic chamber at 80 °C for 24 h. After this period, the initial length of each prism was measured (zero point or initial point), after which the prisms were immersed in a NaOH 1 M solution at 80 °C for 14 days. During this period of time, regular length measurements were taken at various ages to check the progress of the expansion. According to the test limits a mix that has an expansion at 14 days below 0.10% is considered non-reactive and is considered reactive if that expansion is higher than 0.20%. In this study measurements were extended up to 28 days to evaluate the performance of the mortars at a later age and compare it with that observed by [5].

2.5. SEM/EDS analysis

The microstructure of the mortars was observed at the end of expansion tests using a scanning electron microscope (SEM) JEOL JSM-6400 coupled with an OXFORD energy dispersive spectrometer Si(Li) X-ray detector (EDX). The samples were obtained by fracture, and were sputtered with gold in a Baltec sputter-coater in order to render the surface conductive.

3. Results and discussion

The effect of using recycled glass aggregate in different replacement contents of natural aggregates, as well as cement replacement content, is discussed below.

3.1. Expansion results

Section 3.1.1 studies the effects of ASR due to the use of glass as aggregate. Section 3.1.2 studies the mitigating effects on ASR of using glass powder as cement replacement.

3.1.1. Glass as aggregate

Fig. 1 shows the results of a mix with 100% recycled glass aggregate. It can be seen that glass has a slow and delayed reaction to alkalis. This result is in agreement with a previous study [5]. [9] also observed that for higher substitution ratios "serious expansion