Construction and Building Materials 112 (2016) 518–528

Contents lists available at ScienceDirect

Construction and Building Materials

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

The efficacy of accelerated test methods to evaluate Alkali Silica Reactivity of Recycled Concrete Aggregates

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HIGHLIGHTS

- The accelerated mortar bar test can evaluate reactivity of Recycled Concrete Aggregate.
- Following the right procedures to crush the coarse recycled aggregates is paramount.
- The Concrete Microbar Test (CMBT) can evaluate reactivity of Recycled Concrete Aggregate.
- For CMBT, using 5–10 mm aggregate produced higher expansion than 10–14 mm aggregate.

ARTICLE INFO

Article history:
Received 13 July 2015
Received in revised form 18 January 2016
Accepted 22 February 2016

Keywords:
Recycled Concrete Aggregate
Alkali-Silica Reaction
Accelerated mortar bar test
Expansion
Concrete Microbar Test
Preventive measures
Sample preparation

ABSTRACT

The effectiveness of accelerated tests in evaluating the Alkali-Silica Reactivity of Recycled Concrete Aggregates was evaluated. The accelerated mortar bar test was found effective for evaluating potential alkali-reactivity when the test variables, such as crushing method and absorption, are carried out in a well-defined process. The method of crushing was found to have significant impact on the expansion. The Concrete Microbar Test (CMBT) provides good correlation to the expansion of concrete prisms incorporating Supplementary Cementing Materials when an expansion limit of 0.10% at 56 days or 0.04% at 28 days were used, based on the limited number of tests carried out here.

1. Introduction

Alkali Silica Reaction (ASR) is a chemical reaction between the alkali hydroxide in concrete pore solution and reactive silica found in some aggregates, which react to form an amorphous gel. As this gel absorbs water and expands, internal tensile forces develop which eventually result in cracking. Over time, this cracking increases and will often result in the structure deteriorating beyond acceptable service requirements [1]. Less intensive ASR attacks are still dangerous since they provide ingress points for other deleterious substances to enter the concrete. This leads to severe reduction in resistance to chlorides, freeze-thaw, sulphate and carbonation [2].

The concrete prism test (CPT) is widely recognized as the most reliable laboratory test to evaluate reactivity of aggregates and efficacy of preventive measures [3]. The results at 1 year are reported in comparison to an expansion limit of 0.040% which has been specified as the limit of expansion with a low likelihood of deleterious effects in field conditions [4]. However, if the test is being conducted to study the efficacy of preventive measures including Supplementary Cementing Materials (SCM), the expansion limit of 0.040% applies at 2 years.

A shortfall of the CPT is alkali leaching which takes place during the test period. The leaching process, which involves washing away alkalis from the samples, reduces the alkali concentrations in the prisms over time until the ASR reaction stops. This limits the effective test duration and reliability [5–7]. Another limitation is the sensitivity to the storage conditions during testing; it was found that the expansion of specimens was lower when cured with a larger number of specimens in a single container [8]. However, the CPT still provides the best correlation to field blocks or structures with reactive aggregates [9].

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http://dx.doi.org/10.1016/j.conbuildmat.2016.02.155

In many cases, the test duration of the CPT is too long; for this reason, the accelerated mortar bar test (AMBT) was developed. Studies have shown the results of this test to have a good correlation with those from the CPT [10,11]; however, other studies showed a lack of correlation between the two tests [12]. The obvious advantage of the AMBT is its short duration which made it widely used as a screening test for evaluating reactivity of aggregates. Aggregates that failed the AMBT are recommended to be evaluated by the CPT to confirm the results [3].

The Concrete Microbar Test (CMBT) was developed from the Chinese accelerated mortar bar test, which used a fine aggregate size similar to the AMBT but using a larger specimen. However, it was found that larger aggregate sizes were more sensitive to ASR expansion [12]. This work led to the development of the CMBT using coarse aggregate sizes as defined in RILEM AAR 5 [13] which is used mainly to evaluate alkali-carbonate reactivity. To minimize the required aggregate, processing the largest possible aggregate size is required; however, this led to a decrease in sensitivity to expansion [3,14]. The research of Grattan-Bellew et al. [15,16] offered several different expansion limits, from 0.09% at 30 days for siliceous limestone to 0.040% for other reactive aggregates. Andic-Cakir et al. 2009 [14] suggested that the CMBT underestimates the expansion of an aggregate compared to the AMBT.

ASR can be severe enough to cause a concrete structure, or parts of it, to be demolished. The demolished structure would need to be disposed of in landfill unless the material can be diverted. The waste from the original structure can be used as Recycled Concrete Aggregate (RCA) to build new structures. In this case, the new structure may simply inherit the same ASR condition from latent reactive silica remaining in the original material. Moreover, stockpiles of RCA could contain materials from different sources and, in many situations, it may not be easy to know if the stockpile contained RCA produced from ASR-affected concrete. Petrographic examination offers the ability to examine RCA particles for evidence of ASR such as the presence of gel; however, the feasibility and cost effectiveness of this approach are subject to the feasibility of obtaining representative samples of the stockpile. Research showed that the expansion of RCA made from ASR-affected concrete exhibits equal and often greater expansion than that of the original concrete. Li & Gress [17] and Shehata et al. [18] reported that RCA derived from ASR-affected concrete exhibited similar expansion to virgin aggregate. Scott & Gress [19] and Grattan-Bellew [20] reported results where the expansion of RCA derived from ASR affected concrete was greater than the virgin aggregate. Li & Gress [17] suggested that the concerns of utilizing RCA produced from ASR-affected concrete are: (1) the reactivation of ASR due to the increased alkali content of modern cements; (2) the expansion of existing ASR products that were desiccated during the processing of the RCA, and (3) exposure of unused reactive silica in coarse aggregate during crushing.

Using scanning electron microscopy, Shehata et al. [18] showed that processing old concrete to produce RCA produces microcracks within the virgin reactive aggregates which provided access for alkalis to fresh silica within the particles. In addition, the level of preventive measures required was higher in the case of concrete containing reactive RCA compared to that in concrete with the same virgin reactive aggregates used in the RCA [18].

As is the case with virgin aggregate, an accelerated test to evaluate reactivity of RCA and efficacy of preventive measures is needed. In an earlier study [18], a good correlation was found between the 14-day expansion of the AMBT modified to take the absorption of RCA into consideration and the one or 2-year expansions of the CPT. The one year expansion for the CPT was used in case of samples without preventive measures and the 2 years expansion for samples with preventive measures. However, the study covers only one source of RCA which was produced from a test block containing a siliceous limestone reactive aggregate from Ottawa, Ontario (Spratt). At a later stage, a study by Adams et al. [21] proposed a detailed AMBT procedure for testing RCA. The main change in the procedure compared to the standard ASTM C1260 was addressing the high absorption capacity of RCA, and providing a standard procedure for washing RCA, as excessive washing can reduce the alkali content of the particles. Using the proposed procedures, six different RCA sources were tested, four of which were tested at four different laboratories to evaluate the inter-lab variability. The results showed the AMBT to be effective in predicting the reactivity of RCA from different sources [21].

The CMBT addresses some of the limitations of the CPT and the AMBT. It allows the use of coarse aggregate which addresses issues associated with processing coarse RCA in terms of obtaining material that is non-representative of the original RCA with respect to stone-to-residual paste ratio. Comparing CMBT to CPT, the main advantage of the CMBT lies in its shorter test duration. There is a lack of available research on the effectiveness of the CMBT in evaluating reactivity of RCA. Shehata et al. [18] provided limited results which showed the CMBT to produce promising results in evaluating the reactivity of RCA. However, the expansion values at 28 days were lower than what would be expected based on expansion values obtained by CPT and AMBT.

This paper focuses on examining the effects of variability in major steps of sample preparation in the AMBT on the expansion of specimens prepared with RCA. The examined testing steps are method of crushing, possible error in the tested absorption values, and the effect of washing the processed RCA prior to use. This is done in an attempt to identify the significance of each of the steps on the obtained results, and highlight the importance of developing and following standardized procedures. In addition, the efficacy of the concrete microbars in testing ASR, and evaluating the reactivity of RCA and efficacy of preventive measures is also examined.

2. Materials and experimental details

2.1. Materials

Four of the RCA types used in this study were produced from test blocks that were part of an outdoor exposure site, administered by Canada Centre for Mineral and Energy Technology (CANMET), in Ottawa, Ontario, Canada [22]. These aggregates were used as part of an inter-laboratory testing program reported in Adams et al. [21]. The AMBT and CPT expansions of the virgin aggregates used in these blocks are listed in Table 1 [21,23]. The processed RCA samples were delivered in 3 gradations that meet the grading requirements of the concrete prism test, ¾″–½″ (¾ RCA), ½″–⅜″ (½ RCA) and ⅜″–¼″ (⅜ RCA). A fifth RCA type was produced from a bridge in Quebec City, Quebec, Canada, that was demolished in 2010 at the end of its service life. The bridge was severely deteriorated mainly due to ASR. This RCA was processed to meet the same three gradations described above. The properties of the RCA samples are shown in Table 1. Also, non-reactive granitic sand was used to produce mortar bar samples with blends of RCA and non-reactive aggregate.

The concrete elements, test blocks or large concrete rubbles from the demolished bridge, were broken up using mechanical equipment on site into pieces less than 100 mm in diameter. These were then crushed using a crushing facility to pieces smaller than 19 mm. Material finer than 5.0 mm (sand size) was labelled crusher's fines and material between 5.0 mm and 19 mm was labelled coarse RCA. For testing in the AMBT, coarse RCA was re-crushed to produce the gradation required by ASTM C1260 [24]. For CMBT, the coarse RCA was sieved to meet the specific sizes used in the CMBT: 5.0–10.0 mm (⅜ RCA) or 10–14 mm (½ RCA).

A virgin reactive aggregate, Spratt, from Ottawa, Ontario was used as part of the CMBT experimental program to evaluate the capacity of the test in evaluating ASR. This aggregate was chosen since the authors have a database of CPT expansions of concrete samples containing this aggregate. The CPT results were used as benchmark to evaluate the efficacy of CMBT to evaluate ASR. In addition, a non-reactive dolostone was also used in this study. For evaluating the efficacy of CMBT to test preventive measures, RCA produced from 12-year old concrete blocks containing Spratt [18] was used. This RCA was produced in a manner similar to that of the RCA from CANMET blocks. The cementing materials used in this study are listed in Table 2 along with their chemical composition. Different shipments of GU Portland cement were used as the testing was carried out at different stages over the duration of the project.