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Outdoor exposure site testing for preventing Alkali-Aggregate Reactivity in concrete – a review.

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Abstract. Alkali-silica reaction (ASR) is a deleterious chemical reaction affecting the durability and service life of concrete structures worldwide. Specifications and recommendations were produced in many countries to ensure that non-reactive aggregates are used in concrete construction or, when reactive aggregates must be used, appropriate preventive measures are implemented. Such recommendations, especially those related to the use of supplementary cementitious materials (SCM) to prevent ASR, are generally based on laboratory investigations, but preferably on field performance surveys of concrete structures where such measures have been implemented. Over the past 50 years, outdoor exposure sites have been developed in several countries with the objective of validating data obtained from laboratory testing for various combinations of reactive aggregates and SCM, as well as for determining long-term performance of specific mix designs. This paper reviews worldwide efforts regarding outdoor exposure site testing for ASR prevention.

1 Introduction

It is well recognized that the risk of alkali-silica reaction (ASR) needs to be prevented prior to concrete construction. General approaches involving a selection of laboratory tests (petrographic examination, expansion testing on mortar bars and/or concrete prisms) have been implemented in many countries for determining potential alkali-reactivity of concrete aggregates and the efficacy of supplementary cementitious materials (SCM) to control ASR expansion [1-3]. Validation of laboratory test results, and recommendations to be provided in national standards for preventing ASR, can be obtained through field performance surveys of concrete structures or exposure blocks incorporating combinations of SCM and reactive aggregates. This paper highlights the efforts generated over the past 50 years in regards to outdoor exposure site testing for ASR prevention.

2 Studies in South Africa

Oberholster and Davies [4] and Oberholster [5] reported the results of testing of concrete cubes (300 mm in size) incorporating a reactive metasediment coarse aggregate and exposed outdoors for about 7.5 years. The cubes were made with 350 and 450 kg/m^3 of cementitious materials in which the portland cement was replaced (on a mass basis) by 7% silica fume (SF) or 50% milled granulated blast-furnace slag (MGBS). In some cases, NaOH was added to maintain the available alkali content in the mix (350+, 450+). A replacement level of 7% SF was effective in preventing “excessive” expansion (i.e. < 0.05%) for 7.5 years in concrete containing about 4 kg/m^3 Na_2Oe (i.e. mix 350+), but not 5 kg/m^3 Na_2Oe (i.e. mix 450+). The expansion trends also suggested that the 50% MGBS mix could exceed 0.05% expansion in the long term, at the 5 kg/m^3 active alkali content (450+).

3 Studies in Europe

3.1 Iceland

In 1987, six air-entrained concrete walls were made at the Icelandic Building Research Institute (Fig.1). Walls 1-5 incorporated sea-dredged coarse aggregates from Hvalfjörður, while coarse aggregates from Saltvík were used in Wall 6. The fine aggregate was a mixture of sea-dredged materials from different locations. Coarse aggregates were used unwashed. The cementitious materials content in the mixes ranged from 256 to 302 kg/m^3. Three cements were used, i.e. VP (1.6% Na_2Oe) with 7.5% SF and 3% ground rhyolite; HP (1.6% Na_2Oe) without SF, and PP with 10% SF and 25% ground rhyolite [6]. Visual survey of the walls and petrographic examination of extracted cores confirmed the alkali-reactivity of the Hvalfjörður aggregates; cracking and gel were also found in the wall made with the above aggregate and the VP cement. Using the Hvalfjörður

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aggregates with the PP cement appears effective in mitigating ASR, while the Saltvík aggregate appeared to be innocuous in combination with the VP cement [6].

Fig. 1. Concrete walls at the Icelandic Building Research Institute (picture by Fournier, 2014).

Wigum and Einarsson [7] reported the results of field/laboratory investigations aiming to predict the field performance of concretes made with selected reactive aggregates (Fig. 2). Concrete prisms [RILEM AAR-3 (38ºC); RILEM AAR-4.1 (60ºC)] and cubes (300 mm) were made with low/high alkali cements, with/without SF, and reactive aggregates. The authors concluded that:

- concrete prism testing reproduced the performance of low/high-alkali control cubes after 7 years outdoors;
- despite the beneficial effect of 4-6% SF in controlling expansion under laboratory test conditions, SF-containing concrete cubes are showing expansion > 0.10% after almost 8 years outdoors; and
- despite relatively long incubation time, higher expansion was obtained for the alkali boosted mix.

Fig. 2. MANNVIT exposure site (picture by Fournier, 2014).

3.2 PARTNER project

The EU PARTNER Project (24 partners/14 countries), initiated in the early 2000s, evaluated the reliability of RILEM and some regional test methods for evaluating the potential alkali-reactivity of a wide variety of European aggregates (22 types from 10 countries).

In addition to laboratory investigations, 100 cubes (300 mm) were made in five laboratories (13 aggregate combinations) and distributed on eight exposure sites across Europe (Fig.3) [8-12]. At the Boras site (Sweden), companion sets of cubes were placed alongside a highway and in a nearby forest to evaluate the potential effect of exposure to deicing salts. The RILEM AAR-3 mix design and a high alkali cement (1.26% Na_2Oe) were used in all mixes, without air entrainment. At each site, one cube was stored with its base in a tray filled with water (wet storage) and the other was exposed only to ambient rainfall (dry storage). Length change measurements were carried out regularly while avoiding extreme temperatures.

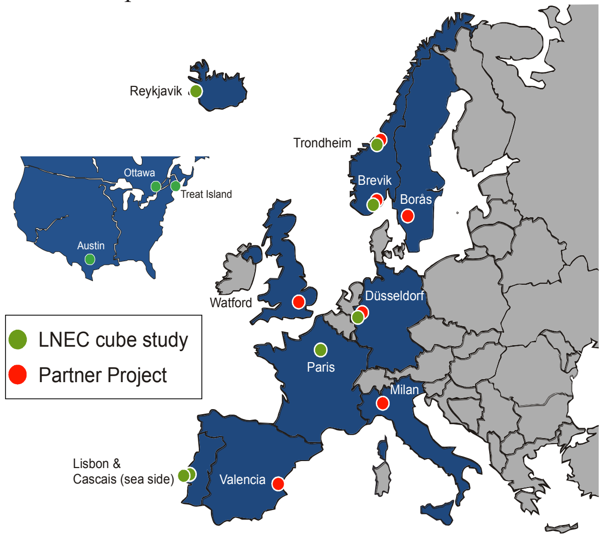

Fig. 3. Exposure sites for the PARTNER project (Trondheim, Brevik, Watford, Borås (2), Düsseldorf, Valencia and Milan) and the RILEM TC 258-AAA project (Trondheim, Brevik, Düsseldorf, Paris, Lisbon, Cascais, Reykjavik, Ottawa, Treat Island and Austin) (courtesy of I. Borchers).

A summary of the main findings from the PARTNER project can be found in [12]. In most cases, laboratory tests were reliable for "normally reactive" aggregates (reaction within 5-20 years under field conditions), but sometimes appear uncertain for "slowly-reactive" ones (deleterious reaction >15-20 years). Expansion methods produced better precision than petrographic examination, and RILEM AAR-2 and AAR-4.1 were the most repeatable and reproducible methods (despite some non negligible within and between laboratory variations) and most reliable for "slowly-reactive" aggregates.

Fig. 4 shows the expansion curves for concrete cubes made with reactive silicified limestone coarse and fine aggregates, which were stored on different sites [10]. All cubes expanded at the same rate up to 4 years, after what cubes stored under colder conditions expanded at higher rates (i.e. Borås – Sweden; Brevik – Norway). This suggests a contribution of frost action to the expansive process once ASR-cracking has developed.

Borchers and Müller [11] summarized the main findings from the field study as follows:

- "Normally reactive" caused cube expansion exceeding 0.04% on all exposure sites within 7 years.
- Most "slowly reactive" aggregates showed signs of reactivity within 7 years, mainly on hot climate sites.
- The response to difference in exposure conditions vary from one aggregate to another.
- No significant difference in expansion between the companion sets of cubes located on the Swedish sites is found after 7 years of exposure.

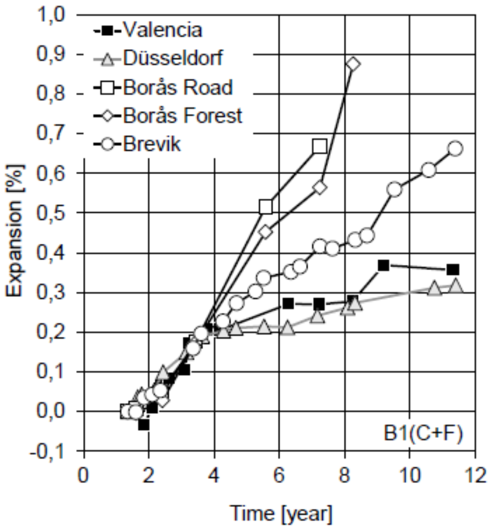

Fig. 4. Mean expansion of concrete cubes made with siliceous limestone B1(C+F) and exposed to ambient rainfall [10].

3.3 Studies in the United Kingdom

Outdoor exposure sites were established at the Building Research Establishment (BRE) in the UK to evaluate the effect of fly ash, slag, metakaolin and lithium-based admixtures on ASR (Fig.5). In the fly ash (FA) study, concrete blocks or cubes were made with two types of reactive aggregates (flint-bearing; crushed greywacke) and various levels of high-alkali cement and FA (25 and 40%). Test prisms were also cast from those mixes for expansion testing in the laboratory.

Fig. 5. BRE sites in the UK (left: picture by Fournier; 1990s, FA study; right: courtesy of M.D.A. Thomas).

Thomas et al. [13] reviewed the results from the FA study based on the 18-year exposure site data (time at which the site was unfortunately dismantled):

- Excessive expansion and/or cracking were observed in all "control" (no FA) field exposure specimens.
- The use of FA largely reduced expansion/cracking in field specimens, except with two flint-bearing mixes made with a relatively coarse FA and high concrete alkali contents. The specimens however showed limited expansion/cracking and similar specimens made with lower alkali contents did not show damage.
- There appears to be no contribution of alkali by the FA at the dosages tested;
- For a number of concrete mixes, a disconnect existed between the results of laboratory and field testing, significantly greater levels of alkalis being required to induce expansion in laboratory test prisms.
- Reasonable prediction of the amount of FA required to prevent expansion with flint aggregates can be obtained from 14-day accelerated mortar bar tests.

Blackwell et al. [14] and Thomas et al. [15] reported the early results of a study aiming at evaluating the effectiveness of lithium based products against ASR. Concrete blocks (300 x 300 x 500 mm) and laboratory test prisms were made from concrete mixtures incorporating three different reactive aggregates and $LiOH.H_2O$ / $LiNO_3$. The results from laboratory testing indicated that the amount of lithium required increased with increasing concrete alkali content, while the effective Li dosage will vary from one aggregate to another. Field specimens are still being monitored and 20-year expansion data will be available soon.

3.4 COIN project

Lindgård et al. [16] reported the preliminary results of the Norwegian R&D project "COIN" (2007-2014). In Phase I, the effect of various test conditions/parameters on concrete prism expansion was evaluated [17,18]. Testing showed the critical impact of alkali leaching, internal moisture state and testing temperature (38/60°C) on expansion rates and ultimate expansion values.

In Phase II, twenty concrete mixtures (RILEM AAR-3 mix design) were made with six aggregates, including the control reactive aggregates Ottersbo from Norway and Spratt from Canada. Four cement types [CEM I; CEM II/A-V - interground fly ash (20%) cement; CEM III/B -slag (68%) cement] were selected. The total alkali content of the above mixtures varied largely, i.e. 1.5 to 6.5 kg/m^3 Na_2Oe for CEM-I mixes, 5.0 & 6.5 kg/m^3 Na_2Oe for CEM-II/A-V mixes, 3.1 kg/m^3 Na_2Oe for CEM III/B mixes, and 4.0 & 5.0 for 50% CEM-1 / 50% CEMIII/B mixes [16]. Two field exposure sites were established for field/laboratory investigations: "warm" condition (Portugal) (Fig.6) and "cold" condition (Norway) (Fig. 7). Preliminary laboratory findings in Phase II confirmed the positive effect of increased prism cross-section to reduce the effect of alkali leaching on concrete prism expansion and the impact of concrete alkali content on expansion; field testing is in progress.

Fig. 6. COIN cubes on the LNEC exposure site in Lisbon (Portugal) (picture by Fournier, 2015).

3.5 RILEM TC 258-AAA

As part of the Norwegian KPN project and of RILEM TC 258-AAA activities, a field/laboratory investigation was launched in the Spring of 2015. Five series of concrete mixtures were made in LNEC laboratories in Portugal, from which 81 concrete cubes (300 mm) were cast. The mixtures had a nominal cementitious materials content of 420 kg/m^3 and consisted of the following:

- Control high-alkali mixes incorporating the extremely-reactive New-Mexico (NM) (USA) gravel and the highly-reactive Ottersbo cataclasite (Ott) (Norway);
- 20% and 30% Class F fly ash mixes incorporating the the Ottersbo aggregate;
- Non-reactive control mix (low-alkali cement and control non-reactive coarse aggregate from Portugal).

The control high-alkali and fly ash mixes were made with a high-alkali cement (1.25% Na_2Oe) from Norway. All concrete mixes were made with a non-reactive control sand from Norway; an air-entraining admixture was used to reach a target air content of 6-7%. Concrete prisms were also made from the same mixtures for laboratory testing (AAR-3 (38°C) and AAR-4 (60°C)).

The cubes were then distributed to the participants in the study for expansion monitoring at 10 exposure sites across Europe and North America (e.g. Figs. 3,6-8).

Fig. 7. SINTEF (left - Trondheim, Norway) and VDZ (right – Düsseldorf, Germany) outdoor exposure sites. Cubes are from various projects (PARTNER, COIN Part II, or RILEM TC258-AAA) (photos by Fournier 2016, Borchers 2016).

Fig. 8. ASR blocks at low-tide level on the Treat Island cold water marine exposure site. Most recent RILEM TC258-AAA cubes (5) are in the left inside, while CANMET ASR blocks are aligned further down (photo by Fournier, 2017).

Figs. 9 and 10 present the preliminary expansion results from the control mixes incorporating the NM and Ott aggregates, respectively.

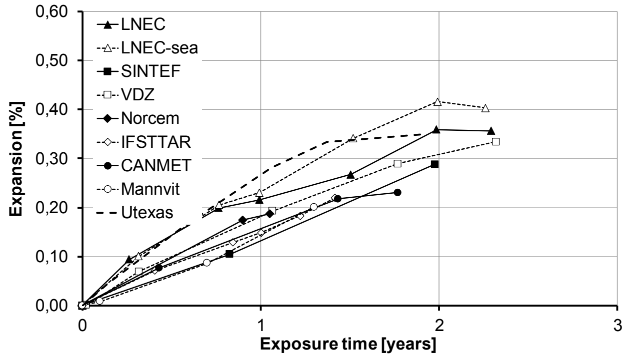

Fig. 9. Expansion of control cubes incorporating the NM aggregate (RILEM TC258-AAA study).

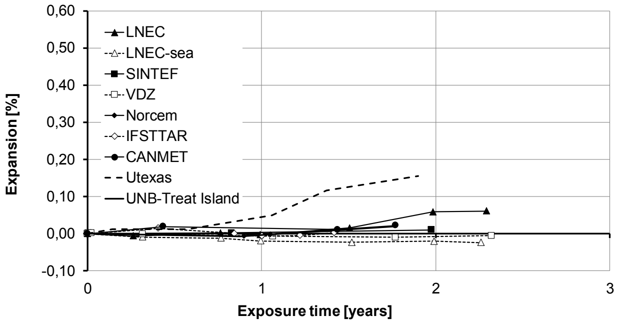

Fig. 10. Expansion of control cubes incorporating the highly reactive Ott aggregate (RILEM TC258-AAA study).

The NM cubes showed two-year expansions ranging from 0.28 to 0.42%. The Texas and LNEC sites were the only locations where an expansion was recorded after about two years with the Ott control cubes. None of the cubes incorporating 20 or 30% fly ash showed noticeable expansion after about 2 years of outdoor exposure.

4 Studies in North America

4.1 Ontario Hydro and MTO sites

Since the 1960s, Ontario Hydro has been carrying out studies aiming to validate the results of laboratory tests against field performance and the behaviour of concrete specimens exposed outdoors. Investigations included, through other things, the effects of freezing and thawing and deleterious aggregates on concrete durability [19]. In the case of ASR, the effect of fly ash for preventing ASR was a topic of particular interest.

In 1985, the Ontario Ministry of Transportation (MTO) constructed six air-entrained concrete sidewalk sections, 3.7 x 1.2 m in size, in Kingston (Canada) to study the reactivity of argillaceous dolomitic limestone aggregates from the Pittsburg quarry [20] (Fig.11).

Fig. 11. Sidewalk sections dedicated to ACR testing in Kingston (Canada) (photo by Fournier, 2005).

The aggregate is known to generate excessive expansion in concrete due to "alkali-carbonate" reaction (ACR), which has been the topic of debate over the past two decades [21,22]. Concrete mixes had total cementitious materials content of about 310 kg/m^3 and consisted in control high-alkali and low alkali concretes, and 25% and 50% slag concretes. All sidewalk sections expanded excessively in the field [≈ 0.30 (low-alkali section) to 0.70% (high-alkali section) after 5 years], confirming the high-reactivity level of the aggregate also identified under laboratory conditions.

In 1991, MTO constructed a second exposure site on the same premises but using alkali-silica reactive Spratt limestone to manufacture unreinforced / reinforced (steel area of 1.41%) concrete beams (0.6 x 0.6 x 2 m) and pavement slabs (0.2 x 1.2 x 4 m) (Fig. 12). Six concrete mixes were made with high-alkali (HA) or low-alkali (LA) cements, SCM (fly ash, silica fume or slag), a cementitious materials content of 420 kg/m^3, and w/cm of 0.40. They consisted of the following:

1) HA+50% slag (tot alk: 3.0 kg/m^3, Na_2Oe)
2) HA+18% F FA (tot alk: 3.0 kg/m^3, Na_2Oe)
3) HA+25% slag (tot alk: 3.1 kg/m^3, Na_2Oe)
4) HA+25% slag + 3.8% SF (tot alk: 3.3 kg/m^3, Na_2Oe)
5) LA control (tot alk: 1.9 kg/m^3, Na_2Oe);
6) HA control (tot alk: 3.3 kg/m^3, Na_2Oe).

Fig. 12. Concrete specimens incorporating Spratt limestone, Kingston outdoor exposure site (photo by Fournier, 2017).

Concrete prisms were also manufactured from the above mixtures and tested under high humidity and temperature (38^{o}C). Accelerated mortar bar testing (AMBT) was also carried out using the same mix proportions. MacDonald et al. [23] and Hooton et al. [24] reported the results of the expansion monitoring after 20 years (Fig.13). Somewhat similar results were obtained from the unreinforced concrete slabs and beams; lower expansions were obtained in "reactive" reinforced concrete beams (Fig. 13). The 14-day AMBT results actually correlated well with the 20-year data in concrete blocks made with SCM.

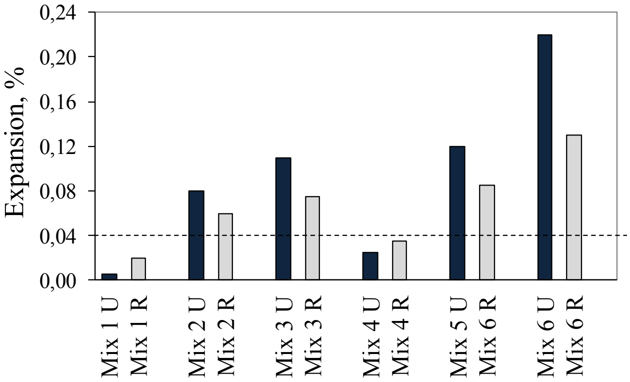

Fig. 13. 20-year expansions of unreinforced (U) and reinforced (R) concrete blocks incorporating the Spratt limestone, Kingston outdoor exposure site (adapted from [22]).

4.2 Picton site (Ontario, Canada)

In 1998, seven outdoor exposure pavement slabs (250 mm think) were constructed at the Picton cement plant using the highly-reactive Spratt limestone. The total cementitious material content was 420 kg/m^3, with w/cm of 0.42 (water-reducing admixture was dosed to adjust proper workability on site) [25,26]. The mixtures consisted of the following (total concrete alkali content, as kg/m^3 Na_2Oe, given in bracket):

1) 100% HA cement (3.95);
2) Blended SF cement (8% SF) (4.07);
3) 65% HA / 35% slag (2.57);
4) 50% HA / 50% slag (1.97);
5) 25% HA / 50%blended SF cement / 25% slag (3.02);
6) 75% blended SF cement / 25% slag (3.05); and
7) 65% blended SF cement / 35% slag (2.65).

Hooton et al. [24] reported that, after 6 years of field exposure, the only concrete exhibiting visual ASR cracking and petrographic signs of ASR (in accordance with the *Damage Rating Index* (DRI) method) was the HA control mix. The 8% silica fume mix (blended SF cement), did not show visual cracking in the field but some petrographic features of ASR at the microscale. Cores were recently extracted (2016) for testing (Fig.14).

4.3 UofT (Leaside) site

Researchers from the University of Toronto (UofT) are operating an outdoor exposure site located at St. Marys Cement head office in Leaside, where blocks are exposed to weather fluctuations in Toronto (Canada). In her recent PhD work, Einarsdóttir [27] stored a number of air entrained concrete cubes (300 mm) incorporating reactive Sudbury or Spratt aggregates (Fig. 15). The work focused at evaluating the effectiveness of SCM in concrete mixes with low total alkali contents. The mixtures consisted of the following: 100% low-alkali cement, low-alkali cement and 25% slag replacement, and low-alkali cement and 15% fly ash replacement. The Sudbury aggregate was also used in concrete mixture with high-alkali cement. After 3 years of field exposure, all exposure blocks showed an expansion ≤ 0.02%. Testing was also carried out in the laboratory for test prisms cast from the above mixes and prisms cast from non air-entrained concretes with 40% alkali boosting.

Fig. 14. Coring at the Picton site (left) and surface cracking on the HA pavement section (15 years) (courtesy of R.D. Hooton).

Fig. 15. Concrete specimens on the Leaside outdoor exposure site (courtesy of R.D. Hooton).

4.4 CANMET studies

A field/laboratory investigation was initiated in 1991 at CANMET to evaluate the reliability of laboratory tests for determining the potential alkali-reactivity of concrete aggregates and the efficacy of SCMs and lithium-based admixtures in preventing ASR [28-30]. Air-entrained (target 6% air) binary and ternary concrete mixtures were made with a nominal cementitious materials content of 420 ± 10 kg/m^3, low- (LA) and high-alkali (HA) cements, with/without added alkalis (NaOH; in HA mixes), a variety of reactive aggregates and SCM (Class F & C fly ashes, slag, silica fume) and Li-based products ($LiOH.H_2O$ and $LiNO_3$). Test prisms (75 x 75 x 300 mm), exposure blocks (0.40 x 0.40 x 0.70 m) and slabs (0.70 x 0.70 x 0.15 m) were cast from each of the concrete mixtures (> 250). After 7 days of curing, the specimens were transported to the outdoor exposure site located in Ottawa, Canada (Fig. 16). Field specimens are monitored for cracking development and length changes annually. The various combinations tested in concrete were also tested in the Accelerated Mortar Bar Test.

Fig. 16. CANMET exposure site. Blocks and slabs subjected to ASR expansion testing (photo by Fournier, 2015).

Fig. 17 provides 20-year exposure block expansions for concretes mixes incorporating highly-reactive Spratt limestone and moderately-reactive Su gravel. The mixes consisted of control low-alkali (LA) and high-alkali (HA) concretes, and concretes with replacement, by mass, of the HA cement by silica fume (SF; 7.5, 10 & 12.5%), class F fly ash (FA; 20 & 30%) and ground granulated blastfurnace slag (Sg; 35 & 50%). Results are given for mixtures with and without added alkalis. The total alkali content of mixes in Fig. 17, as kg/m^3 Na_2Oe (excluding alkalis in SF, FA and Sg), is given below:

- LA: 1.68; HA: 3.78; HA+: 5.25
- SF: 7.5(+): 3.50(4.86); 10(+): 3.40(4.73); 12.5(+): 3.31(4.59).
- FA: 20(+): 3.02(4.20); 30(+;++): 2.65(3.68;4.12);
- Sg: 35(+): 2.46(3.41); 50(+:++): 1.89(2.63;3.36).

The efficacy in reducing ASR expansion varies from one SCM to another, the dosage used, the concrete alkali content and the reactivity level of the aggregate tested. The concrete prism and accelerated mortar bar tests were effective in predicting the potential alkali-reactivity of the aggregates selected. Concrete prism testing in accordance with CSA A23.2-28A reliably predicts the efficacy of SCMs for preventing short term exposure block expansions (~10 years); however, the correlation is decreasing afterwards. Extending the testing period in the "control" laboratory condition or exposing concrete prisms to a source of external alkalis can sometimes improve correlations, but the beneficial effect varies from one aggregate and one SCM to another [29-30].

4.5 UNB site and Mactaquac

Researchers from the University of New Brunswick (UNB) are operating an outdoor exposure site located on the UNB campus in Fredericton (Canada). Concrete blocks of different types are exposed to local weather conditions and include HA control and fly ash concretes. Specimens were also made to evaluate various remedial treatments on ASR-affected concretes (Fig.18).

A research program was initiated in 2005 at UNB to evaluate options for the concrete mixtures that could be used for the potential reconstruction of the Mactaquac Generating Station, heavily affected by ASR [31,32].

Five monolithic (3 x 3 x 3 m) concrete blocks were made with the highly reactive Springhill greywacke (similar to Mactaquac aggregate) and installed in the vicinity of the generating station (Fig.19).

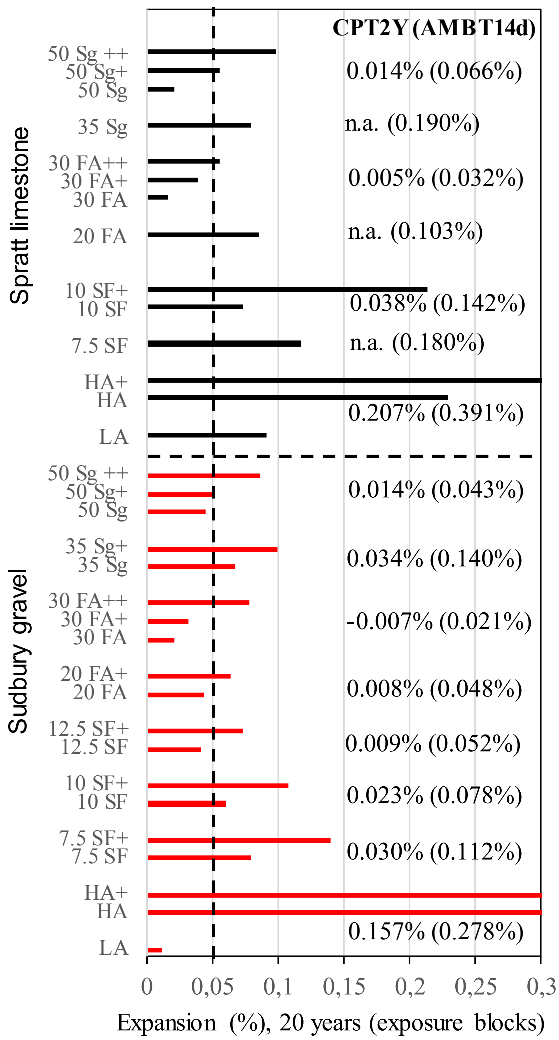

Fig. 17. 20-year expansions of concrete blocks made with Sp limestone and Su gravel (mixtures with (+) and without added alkalis). The maximum expansion of Sp HA+ block is 0.356%; it is 0.375% for Su HA and 0.651 for Su HA+. Laboratory test results are also given for 1) concrete prisms cast from the alkali boosted mixes (**CPT**; 38°C, RH > 95%) (2 years, alkalis raised to 1.25% Na_2Oe per cement mass), and 2) the accelerated mortar bar test (**AMBT**) (mixes without added alkalis).

Fig. 18. General view of the exposure site on the UNB campus (photo by Fournier, 2017).

Fig. 19. Monolithic blocks for ASR research at the Mactaquac Generating Station (photo by Fournier, 2017).

The specimens consisted of the following: control HA cement, HA concrete with 30, 40 and 50% low CaO (or Class F) fly ash, and a block containing 50% of reclaimed FA (Fig. 19). After 7 years of field monitoring, only the control HA block showed significant expansion (0.27%) [33].

4.6 University of Texas and Texas DOT

The University of Texas at Austin (USA) exposure site was developed in 2001 and includes over 400 concrete exposure blocks with the aim of linking laboratory testing to field performance. This field/laboratory test program was initiated for the Texas Department of Transportation (TxDOT) to evaluate aggregates within the state of Texas and now involves exposure blocks for several agencies around the world (Fig. 20). It is known to produce expansions in exposure blocks quicker than other known ASR exposure sites due to the warm local weather [34,35] (e.g. Figs. 9&10).

Exposure blocks, 400 x 400 x 700 mm in size, were made from concrete mixtures incorporating 35 different reactive aggregates from USA & Canada (20 coarse & 15 fine aggregates), low and high-alkali cements, and various types of SCM (three Class F and four class C fly ashes, slag, silica fume and metakaolin). Most mixes had a total cementitious materials content of 420 kg/m^3, a coarse-to-fine aggregate ratio of 70:30 by volume and a fixed w/cm of 0.42. NaOH was added in the majority of the concrete mixes to increase their total alkali content to 1.25% Na_2Oeq (by cement mass) [36,37]. Expansion measurements are carried out twice a year. Results to date have shown that many of the current laboratory tests, although efficient in evaluating potential alkali-reactivity of concrete aggregates, sometimes fails to reliably evaluating preventive measures against ASR by underestimating amounts of SCM needed to mitigate the reaction, as least in high alkali concretes [37].

Fig. 20. General view of the University of Texas at Austin ASR exposure site (courtesy of T. Drimalas).

TxDOT is also performing extensive field testing on a site located in Cedar Park (Texas) where more than 1300 blocks incorporating a large variety of aggregates are being monitored for potential alkali-reactivity [34].

4.7 Other sites in the USA

Two sites were built in the early 2010's, as part of FHWA's (Federal Highway Administration) ASR Development and Deployment Program [38] (Fig. 21).

Concrete blocks were produced with a range of aggregates and cementitious materials and placed on outdoor exposure sites at the University of Hawaii in Manoa (Oahu Island) and at a DOT facility in Lawrence, Massachusetts (USA). The main purpose of these studies was to provide information on the potential reactivity of local aggregates, to determine the efficacy of preventive measures for controlling ASR expansion, and to validate guidelines produced as part of the project [39].

An exposure site was established in 2011 at the Oregon State University. Exposure blocks (380 x 380 x 720 mm) are under investigation for ASR and mitigation efficacy by fine lightweight aggregates [40].

Fig. 21. FHWA ASR exposure sites; Massachusetts (USA) (top); Hawaii (USA) (bottom) (photos by Fournier, 2011-12).

5 Conclusions

Studies involving outdoor exposure site testing have been and are still being carried out for improving concrete durability, and especially for preventing the deleterious effects of alkali-silica reaction (ASR). Such studies are producing invaluable data for validating testing performed under accelerated laboratory conditions, and for improving national standards and specifications for ASR prevention. A more extensive State-of-the-art report on the topic is currently being prepared through the activities of RILEM TC-258-AAA.

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