



The current state of the accelerated concrete prism test

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ABSTRACT

Expansions due to alkali–silica reaction (ASR) in the accelerated concrete prism test (ACPT–60 °C) show a significant reduction at 13 weeks compared to 52 week testing in the standard concrete prism test (CPT–38 °C). Previous work indicated that increased leaching, higher mass loss and a reduction in the pH were observed when temperature was increased from 38 to 60 °C. After further investigation the authors have revealed that non-reactive fine aggregate from certain sources combined with the same reactive coarse aggregate exhibited further reduction in expansion in the ACPT. Expansion data for a wide range of reactive coarse aggregates in 38 and 60 °C testing regimes is shown. Data investigating the Spratt reactive coarse aggregate combined with seven different non-reactive sands will be shown to demonstrate the dramatic effect of the non-reactive sand. Selected pore solution analyses will be given to further elucidate this issue.

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1. Introduction

The concrete prism test (CPT) is generally regarded as the best indicator of field performance with regard to alkali–silica reaction (ASR), but it requires 1 year to evaluate aggregate reactivity and 2 years to evaluate preventive measures, such as supplementary cementing materials (SCMs) and chemical admixtures. The CPT involves expansion measurements of concrete prisms stored over water at 38 °C. This paper describes research performed on tests conducted at 60 °C to expedite the test; the test conducted at this elevated temperature is often referred to as the accelerated concrete prism test (ACPT). Since the early 1990 s the ACPT has received much attention as a viable alternative to the standard CPT due to its shortened test duration [1–3]. Current research and published literature suggest a three month testing period for determining aggregate reactivity with slight variation in expansion limits proposed by different researchers [4–6]. It has been suggested that the time period be extended to six months to determine the efficacy of supplementary cementing materials and/or chemical admixtures [5]. In fact one testing agency, Association Française de Normalisation (AFNOR), currently allows for and specifies testing at elevated temperature (60 °C); this standard also allows for the testing of combinations of reactive aggregates (e.g. reactive coarse and fine) [7].

In May of 2004 the authors published a paper presenting discrepancies between the standard concrete prism test (CPT) and the accelerated concrete prism test (ACPT) version [8]. This paper

highlighted a significant reduction in expansion in the ACPT compared to the CPT. The comparisons in this paper showed that the typical 13 week expansion at 60 °C was about 62% lower than the 52 week expansion for fine aggregates and about 53% for coarse aggregates [8]. A paper at the 2004 ICAAR presented by the current and additional authors highlighted the variability in the test method at accelerated temperature and proposed expansion limits [6]. This paper presented several possibilities for the dramatic reduction in expansion after 3 months time in the accelerated test including increased leaching of alkalies from the test prisms and an increase in the sulfate content of the pore solution of the prisms [6]. However, since that time further investigations by the authors has revealed additional inconsistencies with this test method. Namely, the use of the “non-reactive” fine aggregate for testing reactive coarse aggregates dramatically affects results at elevated temperature and even shows a pronounced effect at the standard temperature with certain aggregate types. Furthermore, the implications of alkali leaching, increase in sulfate concentrations in pore solution and mass loss are of more significance when coupled with the seemingly innocuous “non-reactive” fine aggregates [9].

This paper presents results specifically intended to highlight the crucial role the non-reactive (NR) fine aggregate plays in the ACPT with results from two laboratories: CANMET located in Ottawa, Ontario, Canada and The University of Texas at Austin (UT Austin) in Austin, Texas, USA. Results of expansion testing on a variety of reactive coarse aggregates tested in conjunction with two standard non-reactive fine aggregates will show the reduction in expansion at 13 weeks in the ACPT as well as a further reduction with one of the NR fine aggregates. Additional results from testing at UT Austin with one reactive coarse

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aggregate (Spratt: Ontario, Canada) and seven different NR fine aggregates will be presented to further evaluate the role of the NR fine aggregate. This includes expansion data and selected pore solution analyses. While no specific recommendations for aggregate selection or proposed expansion limits will be given, a brief discussion regarding the implication of these findings and future needs for accelerated testing are presented.

2. Materials and methods

2.1. Materials and mix design

Concrete prism testing at 38 and 60 °C was performed at two different laboratories (CANMET and UT Austin) with seven different alkali–silica reactive coarse aggregates from the same source. Each laboratory used their standard non-reactive sand confirmed by ASTM C 1260 or CSA A23.2–25A (accelerated mortar bar test) to have an expansion of less than 0.10% at 14 days [10,11]. In addition seven non-reactive sands (including the two standard laboratory sands) were used in conjunction with the Spratt reactive coarse aggregate. Table 1 shows the aggregate sources and a brief petrographic description of the reactive coarse and non-reactive fine aggregates used in the study. Table 2 shows the cement oxide analysis for the two cements used in this study: CM1 (CANMET) and CM2 (UT Austin).

Accelerated mortar bar testing (AMBT) was performed following either ASTM C 1260 (UT Austin) or CSA A23.2–25A (CANMET) [10,11]. A thorough explanation of this test can be found in either standard test protocol. In brief, this test involves casting 25.4 × 25.4 × 285 mm mortar prisms followed by subsequent storage at 80 °C in 1 N NaOH. Fine aggregates were sieved, washed, dried and combined at specified amounts to meet the gradation requirements of the test method. Coarse aggregates were crushed in two phases initially using a Bico Chipmunk Jaw Crusher to reduce material to a nominal size of approximately 3–5 mm. This was followed by pulverizing in a Bico UA Pulverizer to obtain enough fine material to meet the fineness modulus requirements of ASTM C 1293 of (2.5–2.9). This material was sieved, washed, dried and then combined in specified amounts to meet the requirements of the respective test (ASTM C 1260 or C 1293). The main difference between the two standards is the CSA version of the test requires that cement with equivalent alkali content ($\text{Na}_2\text{O}_{\text{eq}}$) of $0.90 \pm 0.10\%$ be used, whereas ASTM does not specify a cement alkali level. Furthermore, the expansion limits of the tests for aggregate reactivity are slightly different. ASTM specifies a value of less than 0.10% at 14 days for non-reactive classification, whereas

Table 2
Cement oxide analysis.

Cement oxide analysis (%)	High-alkali cement	
	CM 1	CM 2
Silicon dioxide (SiO_2)	19.7	19.71
Calcium oxide total (CaO)	61.2	62.07
Aluminum oxide (Al_2O_3)	4.91	5.13
Ferric oxide (Fe_2O_3)	2.95	2.81
Magnesium oxide (MgO)	2.55	2.56
Sulphur oxide (SO_3)	3.32	3.94
Loss on ignition (LOI)	2.83	1.94
Equivalent alkali content	0.95	0.89

CSA specifies a value of less than 0.15% at 14 days for the same classification. However, both the CSA and ASTM version of the concrete prism test require the non-reactive fine aggregate to produce expansion values less than 0.10% at 14 days in the agencies respective AMBT.

Concrete prism testing followed either ASTM C 1293 (UT Austin) or CSA A23.2–14A (CANMET) mixture proportions [12,13]. A brief treatment of the slight differences between the mixture proportions in the two tests is given in another publication in these proceedings [14]. In general both methods involving casting concrete prisms (75 × 75 × 285 mm) with a cement content of 420 kg/m³ where the initial cement alkalies ($0.90 \pm 0.10\%$) are augmented to 1.25 $\text{Na}_2\text{O}_{\text{eq}}$ by adding sodium hydroxide to the mixing water. The w/cm ratio is kept between 0.42 and 0.45 to retain workability. The most significant difference in the two testing methods is that ASTM specifies a coarse aggregate oven-dry-rodded volume per unit volume of concrete of $70 \pm 2\%$ for all aggregate classes (low, normal and high density). The CSA version of the CPT retains the same value for low and high density coarse aggregates but for normal weight aggregates calls for a 60:40 ratio by mass of coarse aggregate to fine aggregate. Often mixtures are cast as part of a larger series incorporating concrete placed into outdoor exposure sites found at each laboratory. As a result, these mixtures must be air-entrained to resist the freeze–thaw cycles, particularly in Canada. Mixtures incorporating air-entrainment are noted as such where appropriate as AEA.

2.2. Methods for assessment and analysis

2.2.1. Expansion testing – Accelerated mortar bar test

As mentioned previously, the non-reactive fine aggregate used in the CPT is confirmed by testing in the AMBT (ASTM C 1260 or CSA A23.2–25A) [10,11]. An aggregate is classified as non-reactive if its expansion is less than 0.10 or 0.150% (ASTM C 1260 or CSA A23.2–27A, respectively) after 14 days of immersion in 1 N NaOH. For the purposes of this paper data will be reported to the nearest 0.001% and the appropriate expansion limit (ASTM or CSA) will be applied when discussing the results. Table 3 shows a summary of the suggested expansion limits for all testing presented in this paper. A further discussion of precision and bias statements for this test can be found in several references [11,15,16]. Expansion measurements are taken periodically up to 14 days of immersion in 1 N NaOH and then typically at 21 and 28 days for both laboratories in this study.

2.2.2. Expansion testing – Concrete prism test at 38 °C and 60 °C

Concrete prisms were covered after casting and cured in a fog room (moist cure) for 23.5 ± 0.5 h (ASTM), then demolded and measured for initial length. Prisms were then stored at either 38 ± 2.0 °C or 60 ± 2.0 °C and measured periodically for a period of 52 weeks or 13 weeks, respectively. It is typical for the laboratories in this study to continue storage and measurement to a period of 104 weeks for prisms stored at 38 °C and 52 weeks for prisms stored at 60 °C. Prisms are stored in plastic buckets inside large walk-in ovens with circulating

Table 1
Fine and coarse aggregates used in ACPT and CPT.

Designation	Petrographic description	Processing	AMBT 14 day expansion (%)
<i>Fine aggregate</i>			
S1 (NR CAN)	Natural granitic sand	Natural sand	0.032
S2 (NR UT)	Limestone	Manufactured sand	0.053
S3	High purity limestone	Crushed coarse	0.003
S4	Non-reactive trap rock	Crushed coarse	0.056
S6	Limestone	Crushed coarse	0.018
S7	Not available	Natural sand	0.094
S8	Limestone	Manufactured sand	0.023
<i>Coarse aggregate</i>			
C7 (Spratt)	Limestone	Quarried coarse	0.368
C8 (Sudbury)	Mixed mineralogy gravel	Natural stone	0.314
C10	Rhyolitic volcanics quartz and granite	Natural stone	0.822
C13	Quartzite	Quarried coarse	0.121
C14	Mixed volcanics	Natural stone	0.229
C16	Granitic gneiss	Quarried coarse	0.063
C17	Greywacke	Quarried coarse	0.442

Table 3

Reactivity levels based on expansions in AMBT (14 day weeks) according to CSA and ASTM standards.

	CSA AMBT	CSA CPT		ASTM AMBT	ASTM CPT
Non-reactive	<0.150%	<0.040%	Non-reactive	<0.10%	<0.04%
Moderately reactive		0.04%–0.120%	May be innocuous or deleterious	0.10%–0.20%	
Highly reactive	>0.150%	>0.120%	Reactive	>0.20%	>0.04%

fans to move hot air efficiently inside the oven. There has been some debate as to the proper type of storage container for testing these prisms and a paper in the 2004 ICAAR presented a comparison between expansions obtained for the same concrete mixtures in both the CPT and ACPT that utilized a wide variety of containers (“reactor-type”, steel box, plastic pail) and no noticeable difference was observed [6]. Prior to any length change measurements prisms were brought to 23 ± 2.0 °C for 16 ± 4 h (ASTM). Length change measurements were performed at 1, 4, 8, 13, 26, 39, 52, 78 and 104 weeks. An expansion limit of 0.040% at 1 year or 3 months (38 or 60 °C test, respective) will be utilized in this paper for interpretation of results with expansions reported to the nearest 0.001%. Table 3 shows the expansion limits for the concrete prism test according to CSA and ASTM; these suggested limits will also be applied to accelerated concrete prism testing for interpretation of results. Precision and bias statements do not exist for the ACPT but are reported for the CPT in ASTM and CSA and are given treatment in another publication by the authors of this paper [12,15,16].

2.2.3. Pore solution extraction and analysis

A detailed explanation of how pore solution is obtained from concrete test prisms and further analyzed can be found in a previous publication by the authors [9]. In brief, 25.4 mm slices were taken from concrete prisms using a diamond saw, at discrete ages in each testing environment. The concrete slice was placed inside several plastic freezer-type bags and broken into small fragments (~9.5 mm). Coarse aggregate was removed to a reasonable extent to maximize the amount of pore solution that could be obtained from each 25.4 mm slice. The remaining “mortar” fraction was placed inside a pore solution extraction device that expresses the pore solution under high pressure (typically up to 1100 MPa). Typically between 2 and 5 ml of pore solution were obtained from each sample with decreasing amounts as sample age increases.

The pH of the pore solution samples was measured within several hours after obtaining the solution using a Metrohm 716 DMS Titrino with pH electrode. Pore solution samples were acidified in a matrix of 2% HNO₃ and 3% HCl solution prior to analysis in inductively coupled plasma-optical emission spectroscopy (ICP-OES). Ion chromatography (IC) was used for later age samples due to unavailability of the ICP-OES machine and is noted in the results as (IC).

3. Results

3.1. Aggregate reactivity (coarse and fine)

Table 1 shows the 14 day AMBT expansion results for all aggregates in the study. Expansion results exceeding 0.10% (ASTM) at 14 days are shown in bold. It can be seen that reactivity (using this expansion criteria) is confirmed for all but one of the coarse aggregates in this study, C16 (14 day expansion = 0.063%). The range of expansion values is from 0.063 to 0.822%. As expected, all non-reactive fine aggregates in the study exhibit expansions less than 0.10% at 14 days with a range from 0.003 to 0.094%. Concrete prism test results for the alkali–silica reactive coarse aggregates in this study are also shown in Table 4 for exposure at 38 °C and 60 °C, respectively. Expansions for coarse aggregate C16 are shown to be just above and below the 0.040% limit (0.047%–UT Austin or 0.039%–CANMET respectively), at 52 weeks of testing in 38 °C exposure conditions. In

accelerated testing this aggregate produced an average expansion of 0.077% (UT Austin) and 0.097% (CANMET) and would fail the 0.040% criterion for this test method. The remainder of the coarse aggregates exhibited expansions above the 0.040% expansion threshold that are indicative of deleterious ASR related expansion in both test methods.

Fig. 1 shows a plot of the 52 week expansions in the CPT versus the 13 week expansions in the ACPT for CANMET (grey triangle) and UT Austin (black diamond) results. The line of equity is shown where values at 52 weeks of exposure to 38 °C should (according to previous work) match very closely to 13 weeks of exposure at 60 °C. However, this figure demonstrates the departure from equity and a shift toward a reduction in expansion in the 60 °C version of the concrete prism test. However a further reduction in expansion is evident when the non-reactive fine aggregate used at UT Austin (S2) is combined with the same reactive aggregates used in testing at CANMET in combination with NR fine aggregate S1.

3.2. Non-reactive sands tested with Spratt coarse aggregate

To further investigate the role of the selected NR fine aggregate a separate study was initiated at both laboratories. It was decided to focus on two reactive coarse aggregates: Sudbury and Spratt as these are standard alkali–silica reactive aggregates often used for confirmation testing world-wide. For brevity only the results of testing at UT Austin with the Spratt coarse aggregate will be given. Results for a range of non-reactive fine aggregates tested in combination with the Spratt reactive coarse aggregate in the CPT and ACPT are given in Table 5. Unless otherwise noted the cement used in this testing was

Table 4

Expansions for reactive coarse aggregates combined with non-reactive fine aggregates S1 and S2 in the CPT and ACPT.

Coarse agg ID	Fine agg ID	AEA	% expansion	
			CPT 52 weeks	ACPT 13 weeks
C10	S1	•	0.320	0.239
C10	S2		0.159	0.086
C10	S2		0.178	0.104
C10	S2	•	0.184	0.100
C13	S1	•	0.118	0.157
C13	S2		0.098	0.092
C7	S1	•	0.257	0.160
C7	S1	•	0.217	0.144
C7	S2		0.204	0.085
C7	S2	•	0.201	0.086
C7	S8	•	0.168	0.052
C8	S1	•	0.171	0.138
C8	S2		0.144	0.058
C8	S2	•	0.126	0.058
C14	S1	•	0.156	0.140
C14	S2		0.109	0.069
C14	S2	•	0.102	0.078
C16	S1	•	0.039	0.097
C16	S2		–	0.070
C16	S2	•	0.047	0.077
C17	S1	•	0.263	0.177
C17	S2		0.162	0.050
C17	S2	•	0.167	0.045

The round bullet indicates that mixture includes AEA. The “en dash” symbol indicates that this data does not exist.

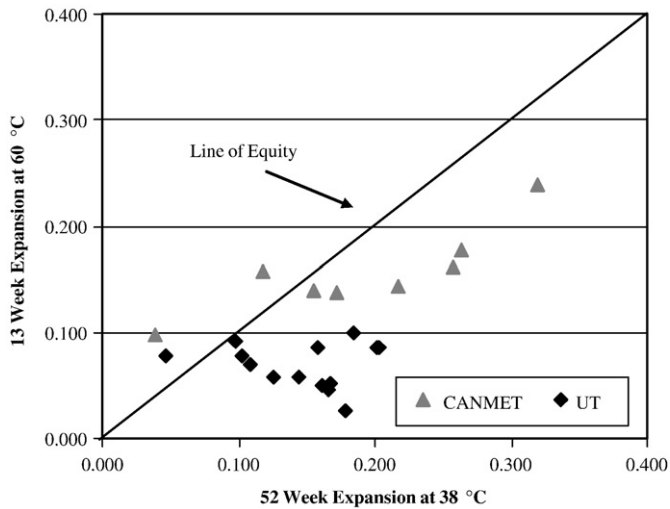


Fig. 1. Comparison of expansion at 52 weeks in the CPT at 38 °C versus expansion at 13 weeks in the CPT at 60 °C: CANMET and UT laboratory results.

C2 (UT Austin). These non-reactive fine aggregates are comprised of natural and manufactured sands, as well as non-reactive coarse aggregates that were crushed, washed, dried and graded to meet and fineness modulus requirements of ASTM C 1293.

While it was expected to see significant variation at 60 °C, it was surprising to see the large variation in expansion results at 52 weeks in the standard CPT at 38 °C exposure. Expansions in this testing regime range from 0.150 to 0.320% for a total difference of 0.170%. In Fig. 2 it can be seen that SP + S2 and SP + S6 give the lowest expansion at 52 weeks of testing. Fine aggregate S2 and S6 are both non-reactive manufactured sands from the state of Texas and both have been used as standard laboratory non-reactive fine aggregate at UT Austin. The highest expansions are observed with SP + S7, SP + S1 + C2 and SP + S1 + C1. Fine aggregate S7 also gave the highest expansion in AMBT testing at 0.094 (just less than the 0.10% criterion). Fine aggregate S1 is a natural granitic sand from Ontario, Canada and is used as the standard non-reactive fine aggregate at CANMET. It is interesting to note that when using two different cements with similar oxide contents (C1 and C2) expansions vary by 0.070% at 52 weeks.

The 13-week expansion data in the ACPT (60 °C exposure) ranged from 0.069 to 0.193% which is less than the range at 52 weeks in the

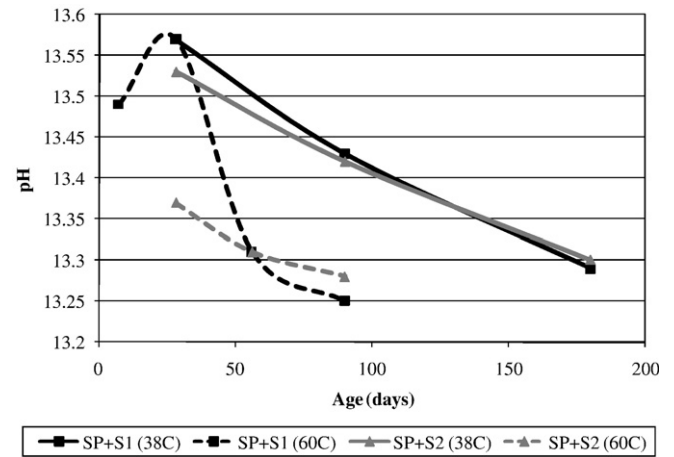


Fig. 2. Evolution of pore solution pH in the CPT (38 °C) and ACPT (60 °C) with Spratt Coarse Aggregate and S1 or S2.

test at 38 °C exposure. Similar to testing at 38 °C the highest expansions are seen with SP + S7 and SP + S2 + C2 and the lowest expansions are seen with SP + S2.

3.3. Pore solution analysis

Detailed results of pore solution analysis can be found in a 2006 publication by the authors [9]. However, a brief treatment of this critical information will provide a possible explanation for the discrepancy observed in testing with various non-reactive fine aggregates combined with the Spratt coarse aggregate. Fig. 2 shows the evolution of pore solution pH over time with SP + S1 and SP + S2 at 38 °C and 60 °C testing. These two sands were selected for further investigation as they represent the highest and lowest expansions obtained in both the CPT and ACPT. Fig. 2 indicates a higher pore solution pH initially with SP + S1 at 7 and 28 days of testing in the ACPT, falling to a value of 13.3 at 56 days of testing commensurate with SP + S2 at this time. Pore solution pH stays higher for a longer period of time in the CPT and falls to a value of just below 13.15 after 1 year of testing with SP + S1. Table 6 show the pore solution composition as function of time in CPT and ACPT testing. It appears that especially in the ACPT that the levels of K^+ in the pore solution remain higher up to 28 days of testing with SP + S1. This trend, although not as pronounced is also seen with testing in the CPT also up to 28 days. After this time the concentration of K^+ and Na^+ in the pore solution is more consistent between the two testing temperatures and sands

Table 5

Expansion of Spratt coarse aggregate with various non-reactive fine aggregates in the CPT at 38 and 60 °C.

Time in weeks									
Sample ID	1	4	8	13	26	39	52	78	102
S1 38 °C	0.006	0.013	0.090	0.153	0.231	0.265	0.298	0.326	0.335
S1 + C1 38 °C	0.003	0.005	0.060	0.120	0.184	0.211	0.236	0.260	0.267
S2 38 °C	−0.001	0.001	0.048	0.080	0.114	0.130	0.155	0.163	0.171
S3 38 °C	0.002	0.013	0.048	0.096	0.126	0.148	0.170	0.193	−
S4 38 °C	0.002	0.014	0.066	0.108	0.145	0.162	0.194	0.228	−
S6 38 °C	0.001	0.012	−	0.087	0.127	0.146	0.150	0.165	0.177
S7 38 °C	0.000	0.014	0.097	0.156	0.247	0.298	0.320	0.318	0.335
S8 38 °C	−0.008	0.014	0.061	0.101	0.158	0.183	0.199	0.195	0.214
S1 60 °C	0.002	0.128	0.173	0.184	0.199	0.194	0.204	0.217	0.234
S1 + C1 60 °C	0.023	0.099	0.134	0.145	0.164	0.167	0.174	−	−
S2 60 °C	0.006	0.047	0.068	0.069	0.076	0.088	0.096	0.105	0.105
S3 60 °C	0.009	0.078	0.092	0.100	0.100	0.104	0.125	0.133	−
S4 60 °C	0.010	0.112	0.134	0.142	0.145	0.158	0.181	0.200	0.211
S6 60 °C	0.019	0.078	−	0.102	0.109	0.089	0.111	0.128	0.159
S7 60 °C	−0.002	0.138	0.181	0.193	0.216	0.225	0.241	0.236	0.251
S8 60 °C	0.005	0.063	0.078	0.090	0.101	0.088	0.120	0.108	0.126

Data shown in bold indicates the 13 week and 52 week, values that fail the ACPT or CPT criterion, respectively.

Table 6

Pore solution composition in the CPT (38 °C) and ACPT (60 °C).

Temperature	38 °C		60 °C	
Specimen ID	Na ⁺ (ppm)	K ⁺ (ppm)	Na ⁺ (ppm)	K ⁺ (ppm)
SP + S1(7D)	–	–	4110	7788
SP + S1(28D)	5490	7210	3712	8402
SP + S1(56D)	–	–	4025	4453
SP + S1(90D)	4319	4392	4025	3835
SP + S1(180D)	4185	4590	–	–
SP + S1 (365D)	5996 (IC)	5350 (IC)	–	–
SP + S2(7D)	–	–	–	–
SP + S2 (28D)	5000	5450	4245	5350
SP + S2 (56D)	–	–	3925	2900
SP + S2(90D)	4310	3761	3715	3900
SP + S2(180D)	3665	4100	–	–
SP + S2 (365D)	4065 (IC)	4259 (IC)	–	–

investigated with a slight decrease in concentration with the evolution of time. The increased K^+ concentration and subsequent elevated pore solution pH at early-age in SP + S1 is likely the main cause for an increase in expansion observed with SP + S1 over SP + S2. These initially elevated levels of alkali and pH in the initial 28 to 56 days with sample SP + S1, provide additional reactants to promote increased alkali–silica reaction in samples containing the Sand 1 (S1). This early pore solution composition has a significant influence on long-term expansions in both testing regimes.

4. Discussion

4.1. Reactive coarse aggregate testing in the AMBT, CPT and ACPT

Testing presented in this paper has confirmed the overall reduction in expansion from the CPT to the ACPT for reasons evocated in previous research (e.g. mass loss, leaching and an increase in sulfate concentration in the pore solution) in addition to a further reduction observed with incorporation of certain non-reactive fine aggregates. Increased mass loss was associated with rapid drying of prisms at early-age (i.e. initial 28 days of testing) at elevated temperatures (60 °C) compared to the standard 38 °C testing temperature. At later age the higher temperatures also promoted increased leaching at 60 °C [8,9]. The reduction in expansion in the standard CPT was not observed when alkali–silica reactive fine aggregates were tested under the same testing conditions (e.g. with various non-reactive coarse aggregates). The results presented in this paper demonstrate that selection of the NR fine aggregate plays an important role in expansion results in both the CPT and ACPT.

While the results are certainly interesting the implications for interpreting results are important to enumerate. CSA 23.2–27A defines certain levels of reactivity based on CPT results to aid the end-user in determining appropriate mitigation measures for moderately reactive or highly reactive aggregates. ASTM C 1260 and C 1293 provide suggested limits for aggregate reactivity and further guidance is provided in ASTM C 33. These suggested limits are outlined in Table 3 [11,12,16]. To provide better clarification Table 7 gives a summary of the predicted levels of expansion for aggregate testing presented in this paper based on the limits given in Table 3. Results from testing at 13 weeks in the ACPT are compared to CPT expansion limits since the aim of accelerated testing is to provide results at 13 weeks that are comparable to results at 52 weeks in the standard version of the test.

4.1.1. Standard Concrete Prism Test (CPT) at 38 °C exposure and AMBT (14 days exposure at 80 °C in 1 N NaOH)

Based on CSA four of the seven reactive coarse aggregates presented in this study are predicted to be reactive in both the AMBT

and CPT (regardless of the non-reactive fine aggregate tested). These aggregates are also classified as reactive according to the counterpart standards in the U.S. (e.g. ASTM C 1260 and C 1293) [11,12].

However, the remaining aggregates produce conflicting results in these standard testing methods. For instance when aggregate C14 is combined with S1 in the CPT expansion results would characterize it as a highly reactive aggregate according to CSA. Conversely, when C14 is tested with S2 in the CPT expansions of 0.109 and 0.102% would determine this aggregate as moderately reactive according to CSA. Certainly this presents a case where two different testing agencies may ultimately determine different mitigation strategies for this reactive aggregate type. Unfortunately, the selected non-reactive fine aggregate for the test may not even be the fine aggregate used in conjunction with the reactive coarse aggregate in the field, so the true effectiveness of the selected mitigation strategy may never be realized in a field application. This aggregate is predicted to be reactive in the AMBT and CPT according to both standards. Aggregate C13 and 16 also produce conflicting results as indicated in Table 7.

4.1.2. Accelerated Concrete Prism Test (CPT) at 60 °C exposure

If we now turn attention to results from the ACPT at 60 °C, expansion results are more highly conflicted. In this test an expansion limit of 0.040% at 13 weeks is commonly applied. If we apply this suggested expansion limit, six of the seven aggregates (C7, 8, 10, 13, 14, and 17) produce expansions with S1 at 13 weeks that would predict these aggregates as highly reactive according to CSA. However, when tested with aggregate S2, these six aggregates would be predicted to be moderately reactive according to the same standard. Only one aggregate produces results that agree in this test with both non-reactive sands tested and this aggregate would be classified as moderately reactive if CSA A23.2–27A is followed [16]. While the ACPT and CPT do produce results that predict aggregates to be potentially alkali–silica reactive, the levels of reactivity between the two testing regimes vary significantly and have strong impact on the type of mitigation that would be selected based on these reactivity levels according to CSA A23.2–27A.

4.2. Non-reactive fine aggregate tested in combination with Spratt reactive coarse aggregate in CPT and ACPT

To further clarify the effects of the non-reactive fine aggregate, two reactive coarse aggregates were evaluated with a variety of non-reactive fine aggregates. For brevity only the results with the Spratt coarse aggregate are shown in Table 5. All of the non-reactive fine aggregates investigated are predicted to be non-reactive in AMBT by both CSA and ASTM (expansions less than 0.10% at 14 days). It is evident from the wide spread of expansion results in both the CPT and ACPT that the selected non-reactive fine aggregate has a profound impact on expansion results with the Spratt coarse aggregate. Similar observations with the Sudbury coarse aggregate were found and will be presented in a future publication. According to CSA A23.2–14A the Spratt aggregate may be used as a reference aggregate and should produce an expansion between 0.12 and 0.23% at 52 weeks of testing [13]. In Table 5 it can be seen that the majority of the “non-reactive” fine aggregates do produce an acceptable expansion value between these limits. However, when the Spratt reactive aggregate is combined with fine aggregate S7, expansion values are 0.320% at 52 weeks of testing and this falls out of the range recommended by CSA A23.2–14A [13]. However, this aggregate does meet the requirements for a non-reactive fine aggregate to be used in combination with potentially alkali–silica reactive coarse aggregates. Interestingly when SP + S2 is combined with the standard high-alkali laboratory cement at UT Austin an expansion of 0.298% is produced which would also exceed the recommended value in the CSA standard. All of the results at 38 °C do predict a level of high reactivity

Table 7
Predicted reactivity levels in AMBT, CPT and ACPT according to CSA and ASTM standards.

CSA A23.2–27A			ASTM C 1260	CSA A23.2–27A			ASTM C 1293	
AMBT				Agg.	CPT	ACPT	CPT	ACPT
C7	HR	R		C7 + S1	HR	HR	R	R
				C7 + S2	HR	MR	R	R
C8	HR	R		C8 + S1	HR	HR	R	R
				C8 + S2	HR	MR	R	R
C10	HR	R		C10 + S1	MR	HR	R	R
				C10 + S2	HR	MR	R	R
C13	NR	R		C13 + S1	MR	HR	R	R
				C13 + S2	MR	MR	R	R
C14	HR	R		C14 + S1	HR	HR	R	R
				C14 + S2	MR	MR	R	R
C16	NR	NR		C16 + S1	NR	MR	NR	R
				C16 + S2	MR	MR	R	R
C17	HR	R		C17 + S1	HR	HR	R	R
				C17 + S2	HR	MR	R	R

according to the CSA standards and are also reactive according to ASTM standards.

In 60 °C testing the results are less uniform. Most importantly fine aggregates S2, S3, S7 and S8 exhibited only half the expansion at 60 °C (after 13 weeks) as they exhibited at 38 °C (after 52 weeks). Fine aggregates S1, S4 and S6 also showed a reduction in expansion at 60 °C, but it is not as dramatic as that with the other aggregates. Of more concern is that when the Spratt coarse aggregate (which is well established to be highly reactive) is combined with fine aggregates S2, S3, S6 and S8 it is predicted to be a moderately reactive aggregate according to CSA. Furthermore with aggregate S2 the expansion level at 13 weeks (0.069%) is approaching the limit of 0.040%. It takes little conjecture to realize that with more slowly reacting and lower reactivity aggregates they may actually pass this accelerated version of the test while showing deleterious expansion in the standard CPT and in the field. Further extrapolation of the non-reactive sand issue to testing with supplementary cementing materials in the 60 °C version of the CPT intensifies this issue and will be the subject of a future publication by the authors.

Limited results of pore solution extraction on specimens representing the two extreme cases of reactivity (SP + S1 highest expansion and SP + S2 lowest expansion) indicate a higher pH in the pore solution at 60 °C testing with SP + S1 and is further supported by higher levels of potassium in the pore solution up to 28 days of testing in the 60 °C version of the test. This initial period of roughly 4 weeks with elevated pH and subsequently higher potassium concentrations may be responsible for augmenting expansion in the 60 °C version of the test. However, similar levels of cation (Na^+ and K^+) in the 38 °C version of the test do not necessarily explain the higher expansions obtained with this aggregate (SP + S2) in the standard CPT. Further work including pore solution analysis across a wide range of non-reactive aggregates is underway by the authors. In addition aggregate characterization including petrography, SEM and chemical analysis is also currently underway. Furthermore, SEM characterization of the concrete samples in the CPT and ACPT is also being conducted to further elucidate the mechanisms by which the non-reactive sands may augment or suppress expansions in these crucial ASR testing methods.

5. Conclusions

It has been shown that selection of the non-reactive fine aggregate plays a crucial role in long-term (after 52 weeks at 38 °C or 13 weeks at 60 °C) expansion both in the standard CPT and in the ACPT. This difference was first noted during a large scale study where the same alkali-silica reactive coarse aggregates were tested at different laboratories as part of a larger project investigating the progression of ASR in laboratory and field exposure [8]. The main conclusions from this research are as follows:

- A significant reduction in expansion was observed when known reactive coarse aggregates were tested in the ACPT and compared to the standard CPT.
- For one of the laboratories in the study a further reduction in expansion in the ACPT prompted in-depth investigation and elucidated the significant impact on expansion resulting from selection of the non-reactive fine aggregate.
- A reduction in expansion occurred even in the standard CPT due to the selected non-reactive fine aggregate.
- Despite an overall reduction in expansion, the contribution of alkalis from one of the “non-reactive” fine aggregate sources resulted in increased K^+ concentrations in pore solution, elevated pore solution pH and a higher rate of expansion at early-age compared to other “non-reactive” fine aggregates in this study
- Significant reductions in expansion in accelerated testing may lead to inaccurate predictions as to aggregate reactivity and consequently non-conservative approaches to mitigating deleterious ASR.

While it is not the authors' desire to work toward specifying a standard “non-reactive” fine aggregate for ASR testing in the CPT or ACPT it is important to note that in North America the two most relied upon standards (AMBT and CPT) both have inherent problems highlighted in this and other publications [6,8,9,15]. While we cannot simply abandon tests like the CPT and AMBT we must recognize the potential discrepancies that exist in these testing methods. Efforts should be directed towards refining and improving these commonly used testing regimes while seeking to develop new and innovative test methods that predict field performance. Any test method should be done in a timely manner, provide accurate and reliable results, correlate to field performance and eliminate many of the challenges in current testing methods which are now well-identified and more clearly understood.

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