Overview on improving the guidance of AASHTO R 80 and ASTM C1778 for ASR potential and prevention with SCMs

Anuj Parashar [(1)], Krishna Siva Teja Chopperla [(2)], Ardalan Ghanizadeh [(3)], Racheal Lute [(4)], Thano Drimalas [(5)], Michael Thomas [(6)], Kevin Folliard [(7)], Jason H. Ideker [(8)]

(1) Civil and Construction Engineering, Oregon State University, Corvallis, United States, parashan@oregonstate.edu

(2) Civil and Construction Engineering, Oregon State University, Corvallis, United States, chopperk@oregonstate.edu

(3) University of New Brunswick, Fredericton, Canada, aghaniza@unb.ca

(4) Civil, Architectural and Environmental Engineering, University of Texas at Austin, Austin, United States, racheal@utexas.edu

(5) Civil, Architectural and Environmental Engineering, University of Texas at Austin, Austin, United States, thano.drimalas@utexas.edu

(6) University of New Brunswick, Fredericton, Canada, mdat@unb.ca

(7) Civil, Architectural and Environmental Engineering, University of Texas at Austin, Austin, United States, folliard@mail.utexas.edu

(8) Civil and Construction Engineering, Oregon State University, Corvallis, United States, Jason.ideker@oregonstate.edu

Abstract

The paper presents the overview of collaborative research effort on evaluating the performance and potential of different supplementary cementitious materials (SCMs) and their combination for preventing alkali-silica reaction (ASR) using the accelerated laboratory-based test methods and benchmarking their performance against the field exposure blocks. This study was carried out in three different universities in the United States and Canada. A total of 11 SCMs including two class F fly ashes, one class C fly ash, one blended ash, one reclaimed ash, two natural pozzolans, two slags, one metakaolin, and one silica fume were used. Two different ordinary Portland cements including a low alkali and high alkali cements were considered for preparing the field exposure blocks. Two different regional reactive fine aggregates and four different common reactive coarse aggregates were used at each laboratory. The accelerated laboratory testing to evaluate the performance of SCMs in preventing ASR used included the concrete prism test (ASTM C1293), the accelerated mortar bar test (ASTM C1567), the miniature concrete prism test (AASTHO T 380), and the University of New Brunswick concrete cylinder test (UNBCCT). Around 150 concrete blocks of 380 x 380 x 380 mm were made by each laboratory. The concrete mixtures were designed to follow the structural classification category SC3 and SC4 as per ASTM C1778 and the parameters included were type of SCMs, cement content, and alkali loading. The concrete blocks were placed in six different exposure conditions including regional and coastal sites. In addition to benchmarking the newer accelerated laboratory test methods against the field blocks, the outcomes from this collaborative research study will be used to improve the current guidelines given in the standard guides (AASTHO R 80 and ASTM C1778) for ASR potential and prevention using SCMs.

Keywords: alkali-silica reaction, supplementary cementitious materials, accelerated laboratory test methods, field exposure blocks

1. INTRODUCTION

Alkali-silica reaction (ASR) was first reported by Thomas Stanton almost 80 years ago when he identified the reaction as the cause of cracking in numerous structures in Monterrey County in California [1]. Some 20 years later, Alkali-carbonate reaction (ACR) was discovered by Ed Swenson as the cause of abnormal cracking in sidewalks, curbs, floors and foundation walls in Kingston, Ontario, Canada [2]. A comprehensive review of both ASR and ACR, including details of reaction mechanisms, methods of testing and measures of prevention has been published [3–7].

The potential for an aggregate to cause deleterious ASR depends on a wide number of factors including the amount, type, distribution and habitat of the reactive silica present in the aggregate and the size of the aggregate [6]. Silica minerals such as opal, tridymite, cristobalite, volcanic glass, chert, cryptocrystalline (or microcrystalline) quartz and strained quartz are considered to be alkali- silica reactive [6]. These minerals may be found in shale, sandstone, silicified carbonate rocks, chert, flint, quartzite, quartz-arenite, gneiss, argillite, granite, greywacke, siltstone, arenite, arkose and hornfels. Generally, the rate of expansion increases as the particle size of the reactive aggregate decreases; however, if the particle size is reduced to a very fine size expansion does not occur. The other major factor that was considered quite critical for almost 8 decades is the cement alkali content. Stanton (1940) [1] demonstrated experimentally and concluded that the ASR can happen when the ordinary Portland cement (OPC) contains relatively higher alkali content. A lower intensity of ASR was reported for alkali content below 0.6%. Until recently, ASTM C150 Specification for Portland Cement had an optional requirement for low-alkali cement defined as cement with an equivalent alkali content of less than or equal to 0.6% Na_2Oe and a great many specifications worldwide adopted this requirement as an option to prevent deleterious ASR when reactive aggregates were used. But several studies reported the expansion of concrete produced with the same reactive aggregate (Spratt) and a wide range of cement contents, cement alkali levels and temperature [8, 9]. It can be concluded that the expansion is a function of the concrete alkali content which is calculated by multiplying the cement content of the concrete by the alkali content of the cement. Several standards such as Canadian standard practice for preventing damaging ASR (CSA A23.2- 27A, 2019), American Association of State Highway and Transportation Officials standard (AASHTO) R80-17 and ASTM C1778 -19 provide limitation on the maximum alkali content to increase “Levels of Prevention” in different ranges.

Other than the OPC alkali content, the concrete exposed to alkali salts in service; examples include structures exposed to seawater, which is predominantly composed of sodium chloride (NaCl), or de-icing and/or anti- icing salts which might include NaCl, potassium acetate (CH_3COOK) or either sodium acetate ($NaCH_3COO$) or sodium formate (HCOONa) can also cause ASR. Sufficient moisture is also required to both sustain the chemical reaction and to provide for the expansion of the ASR gel. It is generally considered that the chemical reaction will cease if the internal relative humidity inside the concrete falls below 80%. Specifically, portions of the structure exposed to a constant or steady source of moisture (e.g., because of poor drainage or poor detailing) can exhibit significant ASR- induced damage, while other portions of the structure that remain essentially dry may show little or no damage.

The preventive measures for ASR include the limiting the alkali content of the concrete, by using the supplementary cementing materials (SCM) and the use of lithium-based compounds [3, 10]. The most commonly prevention is the utilisation of SCMs that have been reported well to the ability of SCMs to reduce the alkalinity (or pH) of the pore solution by incorporation of alkali in the calcium-silicate-hydrate gel (C-S-H) that forms as a result of the pozzolanic reaction [11–15]. It has also been shown that SCMs high in alumina (e.g., metakaolin, slags and certain fly ashes) also are more effective at reducing expansion. The creation of more C-A-S-H will also lower pore solution alkalinity, creating another benefit that reduces silica dissolution [14]. The amount of SCM required to prevent damaging ASR expansion generally depends on the type of SCM. Some of the studied also tried considering their bulk oxide compositions and reactivity as an important parameter for the replacement levels [3, 6, 16]. Since not all the SCMs react at same rate and the overall reactivity of an SCM can be dependent on many factors that is why, it might be worth relying on reactivity [17]. The utilization of lithium has been also reported in preventing ASR provided that the lithium-to-sodium-plus-potassium molar ratio are greater than 0.74, i.e., [Li]/[Na+K] > 0.74 [18]. The simplest and most used explanation is that lithium salts will react with reactive silica in a similar way to sodium and potassium salts, but the reaction product is an insoluble lithium silicate with little propensity to imbibe water and swell. The lithium silicate forms around reactive aggregate particles and protects the underlying reactive silica from “attack” by alkali hydroxides.

The recently developed AASHTO R 80-17 Practice (previously AASHTO PP65) and ASTM C1778-16 guide have significantly improved the way of aggregates assessment for potential alkali-aggregate reactivity (AAR) and subsequently guided on appropriate mitigation methods. Those standards were developed with the potential efforts by the some of the co-authors of this study based on various funded research project that resulted into the development of relation between long term exposure blocks and accelerated laboratory testing. As one of the limiting factors, the majority of the outdoor exposure blocks were made with mixture proportions matching ASTM C1293, with cement contents of 420 kg/m^3 (708 lb/yd^3) and high alkali cements (~0.8 to 1.25 $Na_2O_{eq.}$).

As the concrete in the outdoor exposure sites has further matured, it has been revealed that a great many of the mitigated mixtures that passed current accelerated laboratory tests (ASTM C 1293 – concrete prism test and/or ASTM C1260/1567 – accelerated mortar bar tests), and thus should have high resistance to ASR, are now showing deleterious expansion from ASR in the outdoor exposure blocks after 7-20 years of exposure (depending on the site location, mixture specifics, etc.). This represents a disconnect between laboratory and field experience that merits further investigation to determine the root cause(s) and identify potential improvements to accelerated test methods, specifications, and guidelines [5]. Figure 1.1 shows data that demonstrate the disconnect between the ASTM C1293 two-year concrete prism test and 10-year-old field exposure blocks at UTA for a highly reactive (R3 according to C1778 classification) fine aggregate with a wide variety of mitigation options (e.g., binary and ternary blends of SCMs and/or lithium nitrate). Over 60% of these mixtures passed the ASTM C1293 two-year concrete prism test (<0.04%) but have shown deleterious expansion in the exposure blocks. From the current inventory of exposure blocks, we now know that a reliable relationship between ASTM C1293 (with SCMs or lithium) and outdoor exposure blocks does not exist.

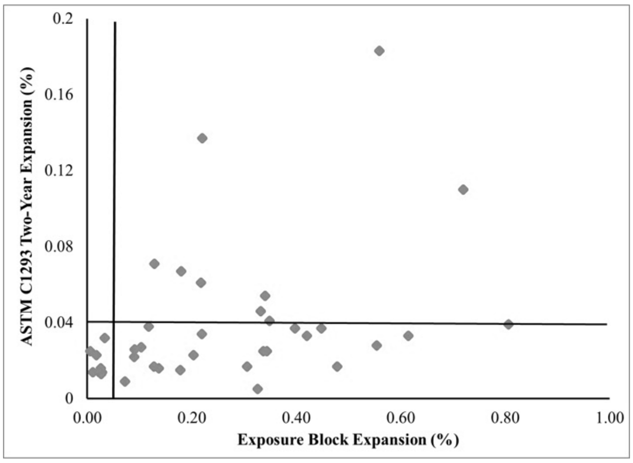

Figure 1.1: Exposure Blocks containing SCMs in Austin, TX showing the disconnect between ASTM C1293 to Exposure Blocks. Exposure block data is after 10 years on the UTA site.

It arises the questions about representative nature of these blocks: 1) do they accurately predict field concrete and 2) shouldn't we know what happens in blocks with a broader and lower range of alkali loadings? That is why, this study highlights the focuses on one of the project work conducted by the co-authors on improving the guidance of AASHTO R 80/ASTM C1778 for ASR potential and mitigation. ASR is a subclass of the larger category of AAR, which includes both ASR and ACR. The main objectives of the study are: 1) To construct and evaluate field exposure blocks with varying concrete materials placed in diverse environmental conditions to supplement the existing information and, 2) to enable improved benchmarking of current performance and job mixture tests that have been developed or are being developed currently.

The project is divided into six tasks that will include the literature review on existing laboratory test methods (task 2), materials procurement (task 2), exposure blocks preparation (task 3 and 4), laboratory testing (task 5) and preliminary modifications to guidance documents (task 6). This research project will be completed by a team of experts from three universities (Dr. Thano Drimalas (PI) and Dr. Kevin Folliard (Co-PI) – The University of Texas at Austin (UTA), Dr. Jason H. Ideker (Co-PI) - Oregon State University (OSU) and Dr. Michael D.A. Thomas (Co-PI) - University of New Brunswick (UNB) and one consultant (Benoit Fournier – Université Laval (ULA) along with their respective graduate research students.

2. MATERIALS AND METHODS

Through the knowledge gained from the literature (task 1 of the project), this section provides a detailed work plan, including a detailed test matrix, to meet the objectives of this study, based on an assessment and analysis of the current state of knowledge.

2.1 Aggregates

A range of aggregates reactivities were included which contain varying mineralogy and were sourced from throughout North America. Table 2.1 shows the aggregates that were considered for use in Tasks 4 and 5 of the research project. The non- reactive aggregates were considered to combine with the reactive aggregates in each mixture to be able to solely evaluate the reactive fine or coarse aggregate. At each University, 2 regional aggregates were selected, and an additional 4 aggregates were selected to be common between the three laboratories. Mineralogizes ranging from granitic gneiss, volcanic schist, greywackes, etc. were used to ensure the mixed mineralogizes to be used throughout the project. A detailed petrography analysis will be carried out by ULA for all the common and regional aggregates. In addition to the 10 aggregates, 4 aggregates will be procured for only laboratory tests (only for task 5).

Table 2.1: Aggregate sources and reactivities for exposure blocks and laboratory tests

Location	Aggregate	Coarse/Fine	Reactivity
University of Texas (UTA)	UT Non-reactive	Coarse	R0**
	UT Non-reactive sand	Fine	R0**
	UT Regional aggregate - 1 (RA1)	Fine	R2
	UT Regional aggregate - 2 (RA2)	Fine	R1
Oregon State University (OSU)	UT Non-reactive rock	Coarse	R0**
	UT Non-reactive sand	Fine	R0**
	UT Regional aggregate - 1 (RA1)	Fine	R3
	UT Regional aggregate – 2 (RA2)	Coarse	R3
University of New Brunswick (UNB)	UNB non-reactive rock	Coarse	R0**
	UNB non-reactive sand	Fine	R0**
	UNB Regional aggregate - 1 (RA1)	Coarse	R3
	UNB Regional aggregate - 2 (RA2)	Coarse	R2
Common Aggregates (for task 3 in all labs)	Common aggregate - 1 (CA1)	Coarse	R1
	Common aggregate - 2 (CA2)	Coarse	R1
	Common aggregate - 3 (CA3)	Coarse	R1
	Common aggregate - 4 (CA4)	Coarse	R1
Laboratory only Aggregates (only for task 5)	Jobe	Fine	R3
	Spratt	Coarse	R3
	Placitas	Coarse	R3
	Sudbury	Coarse	R2

2.2 Cements and SCMs

The SCMs and lithium nitrate selected for this study are shown in Table 2.2. SCMs include three fly ashes (FA1, FA2 & FA-C), two slags (S1 & S2, imported sulphated slag from Asia and a North American slag), a silica fume (SF), a metakaolin (MK), off-spec (with respect to ASTM C618) fly ash (blended & reclaimed ashes, BA & RA), and two natural pozzolans (NP1 & NP2). A complete chemical and physical analysis of the cement and SCM was caried out using quantitative x-ray diffraction and x-ray fluorescence. All the SCMs were also tested for their reactivity using the pozzolanic reactivity test developed at OSU and the lime reactivity strength test developed at UNB [19, 20].

Table 2.2: Cementitious materials, SCMs and admixtures to be used on the project.

Cement	**Specific Material Property***
ASTM C150	$Na2O_{eq\,=}$ 0.5
ASTM C150	$Na2O_{eq\,=}$ 1.05
SCMs	

Class F Ash 1 (FA1)	6% CaO, $Na2O_{eq}$ = 1.6
Class F Ash 2 (FA2)	14% CaO, $Na2O_{eq}$ = 4.7
Class C Ash (FA-C)	25% CaO, $Na2O_{eq}$ = 1.8
Slag 1 (S1)	38% CaO, $Na2O_{eq}$ = 0.47
Slag 2 (S2)	43% CaO, $Na2O_{eq}$ = 0.4
Silica Fume (SF)	0.9% CaO, $Na2O_{eq}$ = 0.5
Metakaolin (MK)	0.1% CaO, $Na2O_{eq}$ = 0.37
Natural Pozzolan 1 (NP1)	1.2% CaO, $Na2O_{eq}$ = 6.7
Natural Pozzolan 2 (NP2)	1.8% CaO, $Na2O_{eq}$ = 5.7
Reclaimed Ash (RA)	2.6% CaO, $Na2O_{eq}$ = 1.8
Blended Fly Ash (BA)	16% CaO, $Na2O_{eq}$ = 2.3
Lithium Nitrate	30% lithium nitrate solution

** Values based on XRF data*

Table 2.3: Laboratory tests to be performed by each University for exposure block series

Laboratory	Current North American Test Methods in Guidance Documents		World-Wide Test Methods not in North American Guidance Documents			
	ASTM C1260 ASTM C1567	ASTM C1293	RILEM AAR-13 (Alkali-Wrapping)	RILEM AAR-10 (Larger Prism)	AASHTO T380 (MCPT)	Concrete Cylinder Test (UNB)
UTA	14 (Regional)	14 (Regional) 24 (Common)	38	38		
OSU	14 (Regional) 24 (Common)	14 (Regional)			54	
UNB	14 (Regional)	14 (Regional)				84

In addition to the above, the aggregate reactivity will also be evaluated with the recently developed TFAST test [21]. The outcomes from TFAST test will be compared with the exiting test methods such as ASTM C1260, ASTM C1293, AASHTO T380 and UNB concrete cylinder test (UNB-CCT) for benchmarking the reactivity of aggregates.

2.3 Field exposure blocks

To accomplish task 3 and 4 of the project, around 450 concrete exposure blocks will be placed on six exposure sites in North America and an additional select number of exposure blocks will be placed at two additional sites in Honolulu, HI and Lawrence, MA. The detailed list of exposure sites along with other details are listed in Table 2.4.

Table 2.4: Climate conditions at six exposure sites (US Climate Data, 2018)

Managing laboratory	**Location**	**Average Low Temperature ºC (ºF)**	**Average High Temperature ºC (ºF)**	**Average Precipitation mm (in)**
UTA	Austin, TX	15.0 (59.0)	26.5 (79.8)	871 (34.3)
	Port Aransas, TX	22.5 (72.5)	25.5 (77.9)	884 (34.8)
OSU	Corvallis, OR	5.5 (41.9)	17.4 (63.4)	1088 (42.8)
	Newport, OR	6.7 (44.1)	14.7 (58.5)	1768 (69.6)
	Honolulu, HI	21.5 (70.7)	29.1 (84.5)	434 (17.1)
UNB	Fredericton, NB (CA)	-0.6 (30.9)	11.0 (51.9)	1100 (43.3)
	Treat Island, ME	1.8 (35.3)	11.4 (52.6)	1140 (44.9)
	Lawrence, MA	10.1 (50.2)	15.4 (59.8)	1310 (51.6)

The exposure blocks will measure 394 x 394 x 394 mm (15.5 x 15.5 x 15.5 in.) cube. These are half the size of the standard exposure blocks dimensions commonly used. These size blocks provide the same minimal dimension which will not affect leaching. Table 2.5 provides the testing matrix outlining the different aggregate reactivities with the varying cement alkali loadings and SCMs. Each SCM will be evaluated at the same alkali loading (using high alkali OPC) for which a control block is cast. The exact replacement levels will be determined based on the prescriptive specifications in AASTHO R80/C1778 and data from existing boosted exposure blocks. A subset of blocks will be cast and stored at the marine exposure sites, as summarized in Table 2.6. The marine exposure block matrix will use one regional aggregate and one common aggregate. Twenty-four exposure blocks will be placed at each exposure site.

Table 2.5: Mixture matrix for exposure blocks at main university sites

Aggregate	Alkali Loading (lb/yd^3)* Cement Content (lb/yd^3)* Cement Alkalis (Na_2O_{eq})				SCMs and Chemical Admixtures									
	3.1 564 0.56	4.0 708 0.56	5.3 564 0.93	6.6 708 0.93	F#	C	SF	S$	MK	N%	BA&	TB	L+FA1	Blocks per site
Non-Reactive			✓			✓					✓1			3
RA1	✓	✓	✓		✓1Y,1Z,2Z				✓					15
RA2		✓	✓		✓1Y, 1Z	✓	✓	✓1Y, 1Z,2Y	✓	✓1,2,				22
CA1	✓	✓	✓	✓		✓		✓1X	✓			✓	✓	24
CA2		✓	✓		✓1X, 1Y,2W			✓1W		✓1	✓1,2		✓	18
CA3	✓	✓	✓		✓1Y, 2Y			✓2X	✓			✓		18
CA4	✓		✓		✓1Y	✓				✓1,2	✓1,2			14
Total Blocks	4	5	7	1	24	9	7	14	13	18	5	8	6	114

** 1 lb/yd^3 = 0.59 kg/m^3*
 # 1 and 2 denote fly ash 1 or 2 from Table 2.2, and W,X,Y denote prescriptive amount from C1778
$1 and 2 denote slag 1 or 2 from Table 2.2, and W,X,Y, Z denote prescriptive amount from C1778
%1 and 2 denote natural pozzolans 1 or 2 from Table 2.2
&1 and 2 denote reclaimed or blended fly ash from Table 2.2

Table 2.6: Mixture matrix for exposure blocks at each marine site.

Aggregate	Alkali Loading (lb/yd^3)* Cement Content (lb/yd^3)* Cement Alkalis (Na_2O_{eq})				SCMs and Chemical Admixtures*#							
	3.1 564 0.56	4.0 708 0.56	5.3 564 0.93	6.6 708 0.93	F	C	SF	S	MK	NP1	BA	# of Blocks per site
Regional Aggregate (RA1)	✓	✓			✓ 1W, 2W	✓		✓1Y	✓			12
Common Aggregate 1 (CA1)	✓		✓		✓1Y	✓		✓2Y		✓1	✓	12
Total Blocks	1	1	2	0	6	4	0	4	2	2	2	24

** 1 lb/yd^3 = 0.59 kg/m^3*
 # 1 and 2 denote fly ash 1 or 2 from Table 2.2, and W,X,Y denote prescriptive amount from C1778
$1 and 2 denote slag 1 or 2 from Table 2.2, and W,X,Y denote prescriptive amount from C1778
%1 and 2 denote natural pozzolans 1 or 2 from Table 2.2
&1 and 2 denote harvested or blended fly ash from Table 2.2

Another subset of exposure blocks is proposed for the exposure sites that the research team previously developed in Lawrence, MA and Honolulu, HI. These mixtures are shown in Table 2.7. UNB will cast the exposure blocks for Lawrence, MA using their regional aggregate (RA1). OSU will cast exposure blocks for Honolulu, HI with their regional aggregate (RA1). A smaller series of blocks will be cast following traditional ASTM C1293 mixture proportions (420 kg/m^3 (708 lb/yd^3) cement and 1.25% alkali loading). The traditional exposure block mixtures will replicate mixtures already known to the team to fail in exposure blocks but will contain SCM replacement dosages at higher amounts. This series of blocks will be placed in Austin, TX so they can be compared to the long-term blocks at that site cast with regional aggregate RA1.

Table 2.7: Additional exposure blocks: ASTM C595 blended cement series and Hawaii and Massachusetts exposure sites

Location	Alkali Loading (lb/yd^3)* Cement Content (lb/yd^3)* Cement Alkalis (Na_2O_{eq})				SCMs and Chemical Admixtures*#							
	3.1 564 0.56	4.0 708 0.56	5.3 564 0.93	6.6 708 0.93	F	C	SF	SC	M	NP	BA	# of Blocks per site
Honolulu, HI		✓	✓		✓	✓		✓				8
Lawrence, MA		✓	✓		✓	✓		✓				8
Austin, TX		✓#	✓#		✓			✓	✓			8
Total Blocks	0	3	3	0	6	4	0	6	2	0	0	24

** 1 lb/yd^3 = 0.59 kg/m^3*
#alkali loading for C595 will vary slightly from that in the table.

3. RESULTS

3.1 SCMs reactivity

The SCMs reactivity were characterised by pozzolanic reactivity test developed at OSU that uses the isothermal calorimeter for cumulative heat release and thermogravimetry analyser for CH consumption [19]. The paste samples for the testing contained CH to SCM ratio of 3:1 and potassium hydroxide solution to powder ratio of 0.9. The potassium hydroxide solution concentration was 0.5M and the samples were tested at 50 °C up to 10 days. The cumulative heat release and CH consumption at 10 days were compared and are plotted in Figure 3.1. The results categorise the ranges of reactivity of different SCMs used in the study.

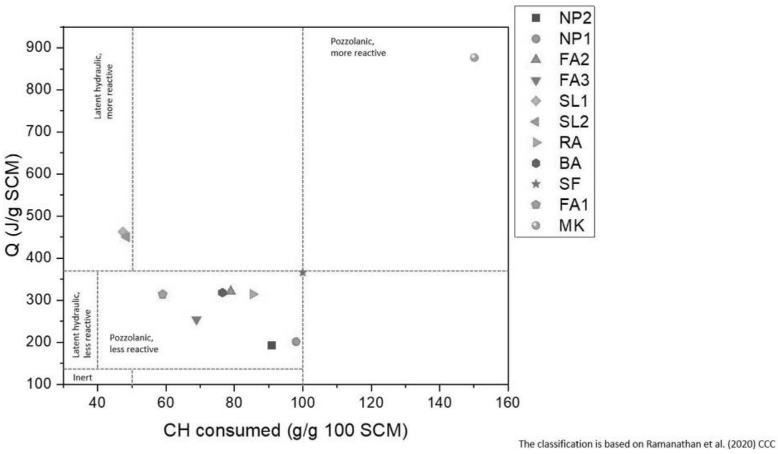

Figure 3.1: Reactivity of SCMs measured using pozzolanic reactivity test at OSU with their classification [22].

Another reactivity test developed at UNB that measure the compressive strength of lime mortar cubes was also used. The test simply measures the compressive strength of CH-mortar cubes (5 cm in size) cured at 50 °C. The mix design details for this test can be found in literature [20]. The results shown in Figure 3.2 once again highlight different ranges of reactivity in the SCMs used for this study.

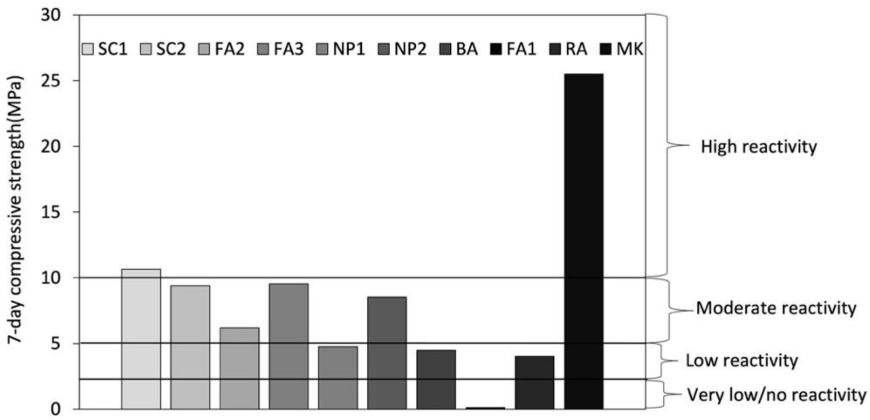

Figure 3.1: Reactivity of SCMs measured using lime reactivity test at UNB with their classification.

3.2 Aggregates reactivity

The reactivity of all the rocks and sands used in the study checked with the mortar bar test are reported in this section. Testing procedure specified under ASTM C 1260 was followed and the high alkali OPC was used. The rock samples were cursed using a jaw crusher and then sieved to get the required fractions of sand. The results highlighting the reactivity at 14 days are reported in Table 3.1. As reported earlier, all the common aggregates were moderately reactive (R1 reactive) and the regional aggregates were and medium highly reactive (R2 and R3 reactive) as per ASTM C1778. The results confirms that a wide verity of reactive aggregates from different location in North America were considered for the project.

Table 3.1: Expansion results at the age of 14 days for all the regional and common aggregates.

Source	Aggregate	Coarse/Fine	14-days expansion (%)
University of Texas (UTA)	UT Regional aggregate - 1 (RA1)	Fine	0.30
	UT Regional aggregate - 2 (RA2)	Fine	NA
Oregon State University (OSU)	OSU Regional aggregate - 1 (RA1)	Fine	0.80
	OSU Regional aggregate – 2 (RA2)	Coarse	0.60
University of New Brunswick (UNB)	UNB Regional aggregate - 1 (RA1)	Coarse	0.57
	UNB Regional aggregate - 2 (RA2)	Coarse	0.37
Common aggregates	Common aggregate - 1 (CA1)	Coarse	0.15
	Common aggregate - 2 (CA2)	Coarse	0.22
	Common aggregate - 3 (CA3)	Coarse	0.27
	Common aggregate - 4 (CA4)	Coarse	0.165

4. OVERVIEW OF THE RESEARCH PROJECT

Between ASTM, AASHTO, CSA and FHWA the general approach to identifying potential alkali-aggregate reactivity is publicised from the ASTM C1778 guidance document, which is germane to this project.

Once the potential for reactivity is known three general approaches are possible to proceed for concrete construction: 1) If the aggregate is deemed non-reactive it can be used without preventive measures in concrete construction. 2) If the aggregate is deemed potentially alkali-silica reactive it can be used following either a prescriptive approach or a performance-based approach for reducing the risk of deleterious alkali-silica reaction. 3) If the aggregate is deemed potentially alkali-carbonate reactive it should not be used in Portland cement concrete construction.

It should be noted that the preventive measures such as SCMs, lowering alkali loading, use of lithium nitrate, etc. only reduce the risk of ASR. In no document in North America is a guarantee given that ASR can be completely avoided. Certainly, having SCMs present generally reduces damage that would occur from using the aggregate solely on its own without any preventive measure. In the “prescriptive approach” the exposure environment, level of risk of having ASR, aggregate reactivity and structural classification are considered to try and address this issue – reducing the risk of ASR to a level appropriate for the structure. For the “performance-based approach” testing generally following ASTM C1567/C1293 for mitigation efficiency evaluation is done. In the performance-based approach the acceptable risk of ASR occurring, e.g., considering exposure conditions, structural importance, etc., is not taken into account. The user relies on combinations of materials that pass (e.g. fall below the expansion limit in the respective test), to determine if the mixture will not exhibit deleterious reaction due to ASR. This is an inherent challenge in these standards currently and an area that merits attention in the future with projects such as the one herein.

4.1 Anticipated deliverables

Currently, the prescriptive approach in ASTM C1778-16 only allows FA <18% CaO, slag cement, SF, and blends of these materials. These new exposure block results and the parallel laboratory testing may allow for broader prescriptive guidance on the use of other SCMs such as FA >18%CaO and MK. This would be a significant improvement to the current guides. In addition to traditional SCMs (FA, S, SF, and MK), the research team will cast exposure blocks with NPs. Two off-spec ash (high LOI) will be tested in combination with two aggregates (low and highly reactive). Finally, a subset of exposure blocks will be cast using lithium nitrate as a chemical admixture. Lithium nitrate will be tested in combination with two aggregates (low and highly reactive) and three dosage rates (to be determined based on previous data). The research team will continue to monitor these specific blocks over the next years. The research team will conduct crack mapping of exposure blocks, gather any long-term expansion data if available, ultra-sonic pulse velocity (compare moderate alkali mixtures to known non-ASR blocks) and Scanning Electron Microscopy/Petrography).

The products expected from this research project will take several forms. The primary form of the background scientific results (laboratory, field, etc.) will be a technical research report/publication. It will be written so that major results are easily found and understood by both practitioners and researchers. The report/publications will be comprehensive and provide a complete overview of the research, the findings, and the recommendations resulting from the research. Figure 4.1 provides the overview of the study and how it will be able to provide both long-term data from exposure blocks and be able to provide modifications to current guidance documents on AAR using laboratory tests. There are five specific deliverables that will be developed as outlined below. All five products from the research include:

- A final report/publication that documents results, summarizes findings, and draws conclusions.
- An extensive database fully documenting information from field-exposure blocks and laboratory testing in an easily usable format and made available on the project webpage.
- Proposed revisions to AASHTO R80 and ASTM C1778 and their referenced material standards.
- Recommendations for improving current and emerging test methods; and
- A draft TRNews article highlighting the products of this research and their implementation.

Accordingly, the research team will target the nature and scope of the project deliverables to the audiences most likely to use each deliverable.

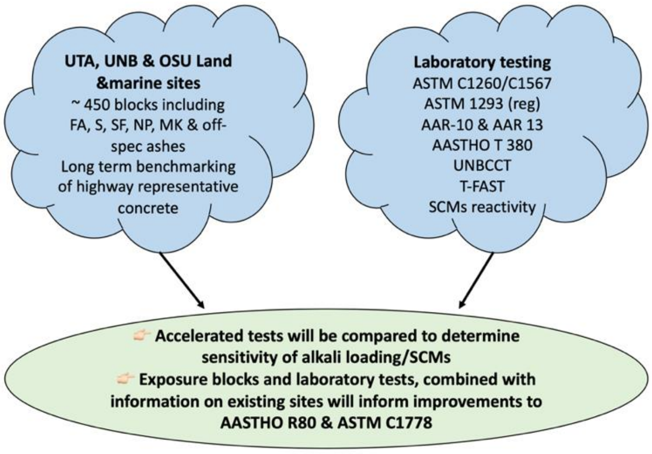

Figure 4.1: Overview of NCHRP Project 10-103 and approach to gather long-term exposure block data and make improvements within the timeframe of this project on current AAR guidance documents

4.2 Current progress

The task 1 to task 4 has been completed around 85% by all the labs. The concrete exposure blocks at the OSU, UNB and UTA land sites can be seen in Figure 4.2, 4.3 & 4.4 respectively. The blocks measurement is carried out periodically.

Figure 4.2: Land exposure site at OSU.

Figure 4.3: Land exposure site at UNB.

Figure 4.4: Land exposure site at UTA.

5. CONCLUSION

This paper highlights the collaborative research work undergoing at three universities. The research project targeted improving the guidance of AASTHO R80/ASTMC 1778 for ASR that provides the prescriptive and performance-based approaches. Both the approaches have their own limitations and the utilization of some SCMs such as natural pozzolans, MK, high alkaline and calcium fly ashes are not yet prescribed. Furthermore, the utilization of non-conventional fly ashes to mitigate ASR is also not well studied.

The disconnect between the accelerated laboratory testing and field concrete have been presented and the need of more descriptive approach for testing field mixes is highlighted. An intense laboratory testing at all three laboratories will help to establish the relation with field expansion. The outcomes from this study will be of great scientific importance because it will develop the long-term expansion behaviour of the highway representative concrete blocks in 8 different environmental conditions and correlate the expansions with laboratory tests.

The target audience for the findings of this research will be incredibly broad as ASR can affect nearly every structure that is exposed to the environment. In particular the audience would include: AASHTO Subcommittee on Materials and Pavements (COMP), ASTM C09, ACI (201, 221, 301, 318, 350), FHWA, RILEM, FAA, Corp of Engineers, all State DOTs, concrete, aggregate, cement and ready-mix concrete producers and owners of transportation structures (e.g. pavements, bridges, ports, airports) and other important concrete structures including dams, foundations, mass concrete, critical structures, etc.

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