Methods for Preventing ASR in New Construction

Results of Field Exposure Sites

December 2013

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16. Abstract As part of the FHWA ASR Development and Deployment Program, two sites were built to study ASR in new concrete construction. 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 on the island of Oahu and at a DOT storage facility in Lawrence, Massachusetts. The main purpose of these studies was to (i) provide information on the reactivity of local aggregates which could be used as a benchmark to calibrate standard laboratory tests, (ii) determine the efficacy of various preventive measures for controlling ASR expansion, and (iii) provide data to validate guidelines such as AASHTO PP65-11. This document presents the preliminary findings from the Oahu and Lawrence exposure sites.			
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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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1. INTRODUCTION

Alkali-silica reaction (ASR) is one of the principal forms of concrete deterioration in North America that can lead to the premature failure of concrete structures including highways, bridges, tunnels, barrier walls, and other components of transportation infrastructure. Although many details of the reaction are understood, there exists a need for further research to ensure the prevention of damaging ASR in new concrete structures and to help mitigate the effects of the reaction in existing ASR-affected structures. In 2006, FHWA initiated the FHWA ASR Development and Deployment Program to assist State transportation agencies in dealing with ASR by providing tools which included: guidelines for surveying and recognizing ASR in the field, protocols for the prevention, diagnosis, and repair of ASR, and educational materials (including a one-day workshop, webinar, and a Facts Book) for training State employees. The protocol for preventing ASR was used as the basis for developing a national specification (AASHTO PP65-11).

The program also included a number of field application and demonstration projects; these included nine sites (in eight different states) where existing ASR-affected structures were subjected to a range of treatments and subsequently monitored to evaluate the efficacy of the treatments, and two sites (one in Hawaii and the other in Massachusetts) to study ASR in new concrete construction. The findings from the nine studies on treating ASR-affected structures have been reported elsewhere (Thomas et al. 2013a; 2013b).

To study ASR in new construction, concrete blocks have been produced with a range of aggregates and cementitious materials and placed on outdoor exposure sites at the University of Hawaii in Manoa on the island of Oahu in Hawaii and at a Department of Transportation (DOT) storage facility in Lawrence, Massachusetts. The main purpose of these studies is to (i) provide information on the reactivity of local aggregates which can be used as a benchmark to calibrate standard laboratory tests (the results of which are often equivocal), (ii) determine the efficacy of various preventive measures for controlling ASR expansion, and (iii) provide data to validate guidelines such as AASHTO PP65-11.

The following chapter presents the preliminary findings from the exposure site in Oahu, Hawaii, and chapter 3 presents the same information for the site in Lawrence, Massachusetts.

2. EXPOSURE SITE IN OAHU, HAWAII

The exposure site in Hawaii was constructed in June 2011 and is situated at the Magoon Research and Instruction Facilities, which is part of the College of Tropical Agricultural and Human Resources at the University of Hawaii at Manoa (see Figure 1). A total of 40 concrete mixtures were produced (30 in 2011 and an additional 10 mixes in January 2013), and blocks (0.38 x 0.38 x 0.71 m, 15 x 15 x 28 in.) from these mixtures were placed on the exposure site. A number of local aggregates (coarse and fine) from various quarries on the islands and an imported sand from British Columbia, that is used by some Hawaiian concrete producers, were used together with cements of varying alkali, fly ash, and a lithium-nitrate admixture. Known reactive aggregates from three different sources were also used. These aggregates have been used to produce blocks on other exposure sites including the site in Lawrence, Massachusetts that was constructed under this program and other sites in Texas, Ontario, and New Brunswick. Having the same-size blocks with nominally identical composition on different sites will allow the effect of environmental exposure to be assessed. These blocks will be monitored periodically to determine the onset of cracking (by visual inspection) and length change. Laboratory tests have been conducted on these aggregates and the outcome of the tests will be compared when long-term test data (≥ 10 years) from the exposure site become available. At the time of writing, only two-year data are available from the exposure site. Continued monitoring of the blocks (beyond two years) will be performed by representatives of the University of Hawaii, Department of Civil Engineering.

Figure 1. Completed Exposure Site at the University of Hawaii at Manoa, Hawaii (January 2013)

2.1 Experimental Details

2.1.1 Materials

2.1.1.1 Aggregates

"Local" basaltic aggregates from six different quarries located on the Hawaiian Islands were included in the study; coarse aggregate and manufactured sand were available from each source. Note that two sources of coarse aggregate from the Halawa quarry were used; one of these, Halawa – Grade B, is not an approved DOT source. An imported siliceous sand (Orca) from British Columbia in Canada was also used as this sand has been used by some Hawaiian concrete producers. Details of these aggregates are given in Table 1 together with expansion data from the accelerated mortar-bar test (AMBT), ASTM C1260/AASHTO T303, and concrete prism test (CPT), ASTM C1293, conducted at the University of Texas. Note that coarse and fine aggregates from Waikoloa on the "Big Island" of Hawaii were used to cast one block in 2011 and further samples were collected to cast additional blocks in 2013.

Table 1. "Local" Aggregates (including Orca sand from British Columbia)

Agg. ID	Source	[1]AMBT at 14 days (%)	[2]CPT	
			1 year at 38°C (%)	60 days at 60°C (%)
Coarse Aggregates				
1	Halfway Bridge, Kauai	-	-	-
2	Ameron, Oahu	0.084	-0.003	-0.013
3	Hilo	0.633		
4	Halawa, Oahu	0.627	0.003	0.007
5	Halawa – Grade B	0.221	0.016	-
6	Waimea	0.015	-	-
7	Waikoloa (2011)		-	-
8	Waikoloa (2013)	-	-	-
Fine Aggregates				
9	Halfway Bridge, Kauai	-	0.018	
10	Ameron, Oahu	0.076	0.004	-0.001
11	Hilo	0.718	0.029	
12	Halawa, Oahu	0.526	0.019	0.230*
13	Waimea	0.007		
14	Waikoloa (2011)	0.522	0.287	
15	Orca (British Columbia)	0.222	0.003	0.001
16	Maui Dune Sand	0.015	0.011	0.014

[1] AMBT = Accelerated Mortar-Bar Test, ASTM C1260 or AASHTO T303

[2] CPT = Concrete Prism Test, ASTM C1293

*Expansion value at 6 months

In addition to the local aggregates, three known reactive aggregates were also used, and these are detailed in Table 2. Typical expansion data from tests conducted at the University of Texas at Austin are also shown for these aggregates.

Table 2. Imported (Known) Reactive Aggregates from the Mainland

Agg. ID	Source	Description	Typical expansion (%)	
			[1]AMBT at 14 days	[2]CPT at 1 year
Coarse Aggregates				
UT1	Placitas, NM	Rhyolitic volcanic rocks with quartz and granite	0.820	0.159
Fine Aggregates				
UT2	Jobe, TX	Mixed quartz/chert/feldspar sand	0.640	0.582
UT3	Wright, TX	Mixed quartz/chert sand	0.290	0.270
[1]AMBT = Accelerated Mortar-Bar Test, ASTM C1260 or AASHTO T303 [2]CPT = Concrete Prism Test, ASTM C1293				

2.1.1.2 Cementitious Materials

Two portland cements were used to produce the concrete mixtures; these are designated HAC (high-alkali cement) and LAC (low-alkali cement) with alkali contents of 1.20% and 0.55% Na_2Oe, respectively. For some concrete mixtures both cements were used and blended to produce intermediate alkali levels. Local fly ash from Hawaii (HFA) and an imported fly ash from China (CFA) were used in some of the concrete mixtures. Chemical analyses of the cementitious materials are given in Table 3.

Table 3. Details of Cementitious Materials

ID	Oxides (% mass)						
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2Oe
High-alkali cement (HAC)	20.2	4.3	3.0	61.3	3.4	3.7	1.20
Low-alkali cement (LAC)	-	-	-	-	2.93	2.59	0.55
Local fly ash (HFA)	-	-	-	25.99	-	9.85	1.26
Chinese fly ash (CFA)	49.54	35.71	4.85	4.41	1.06	0.53	1.07

2.1.1.3 Chemical Admixtures

A polycarboxylate high-range, water-reducing admixture (HRWA) meeting the requirements of ASTM C494 was used. Some concrete mixtures also contained a lithium-based ASR-suppressing admixture composed of a 30% solution of lithium nitrate ($LiNO_3$).

2.1.2 Standard Aggregate Expansion Tests

All of the local aggregates were tested in accordance with the standard accelerated mortar bar test (ASTM C1260/AASHTO T303), AMBT, and most were also tested in the concrete prism test (ASTM C1293), CPT; the CPT was conducted at the standard temperature of 38°C (100°F) and at 60°C (140°F). The expansion data from these tests are given in Table 1.

2.1.3 Concrete Blocks

Table 4 provides information on the type of aggregate, cement, fly ash, and presence of lithium for the 40 concrete mixtures produced during this study. With the exception of mix numbers 20, 23, and 30, the total cementitious materials content of the concrete mixtures was 420 kg/m^3 (708 lb/yd^3), the water-to-cementitious-materials ratio was w/cm = 0.42, and the coarse-to-fine-aggregate ratio was C/F = 60/40. The dosage of HRWA was adjusted for each batch to provide suitable workability for compaction (slump range 125 to 175 mm, 5 to 7 in.). Where lithium nitrate was used the dose was adjusted to provide a lithium-to-alkali-molar ratio of [Li]/[Na+K] = 0.74 based on the alkali available from the portland-cement component of the mixture only. This yields a dose of 4.6 liters of 30% lithium nitrate solution per kilogram of equivalent alkali, 4.6 L/kg Na_2Oe (0.55 gal/lb Na_2Oe). This is often referred to as the “standard” lithium dose required to control ASR for many reactive aggregate types.

Table 4. Details of Concrete Mixtures

Mix #	[1]Posn	Aggregate		Cement alkali (% Na_2Oe)	Fly Ash[2] or Lithium[3]	Expansion of Blocks (%)			
		Coarse	Fine			109/234 days[4]	265 days	571 days	805 days
1	29	Halfway Bridge	Halfway Bridge	1.20		0.003	0.005	-0.009	0.020
2	30	Ameron	Ameron	1.20		-0.034	0.000	-0.010	0.011
3	28	Hilo	Hilo	1.20		0.006	-0.008	0.003	0.006
4	14	Placitas	Halawa	1.20		0.146	0.224	0.375	0.438
5	24	Halawa	Jobe	1.20		0.021	0.024	0.035	0.049
6	27	Halawa	Wright	1.20		0.015	0.006	0.018	0.020
7	20	Halawa	Halawa	1.20		0.005	-0.005	0.002	0.012
8	19	Halawa	Orca	1.20		0.006	-0.003	0.005	0.010
9	22	Halawa	65/35 Halawa/Orca	1.20		0.016	-0.003	0.015	0.013
10	12	Halawa	Halawa	1.20	100 LiNx	0.011	0.001	0.014	0.014
11	7	Halawa	Halawa	1.20	125 LiNx	0.010	0.009	0.012	0.026
12	21	Halawa	Halawa	0.55		-0.007	-0.021	-0.002	0.000
13	13	Halawa	Halawa	0.75		0.000	-0.006	0.007	0.010
14	4	Halawa	Halawa	0.95		-0.015	-0.009	-0.015	0.013
15	6	Halawa	Halawa	1.20	20 CFA	-0.008	0.004	-0.028	0.013
16	15	Halawa	Halawa	1.20	30 CFA	-0.006	-0.002	-0.005	-0.013
17	11	Halawa	Halawa	1.20	20 HFA	0.007	-0.005	0.003	0.002
18	16	Halawa	Halawa	1.20	30 HFA	0.007	-0.005	-0.005	-0.003
19	18	Halawa	Orca	0.95		0.002	-0.007	0.003	0.007
20	9	Halawa Plant 3000-psi Mix				-0.012	-0.007	-0.001	0.004
21	17	Halawa	Jobe	1.20	30 HFA	0.006	0.001	0.003	0.008
22	3	Halawa	Wright	1.20	30 HFA	-0.008	0.003	0.015	0.026
23	8	Halawa Plant 7000-psi Mix				-0.007	-0.007	-0.006	-0.001
24	10	Halawa Grade B	Halawa	1.20		-0.014	-0.002	0.020	0.009
25	5	Halawa Grade B	Halawa	0.55		-0.003	-0.011	0.002	0.003
26	2	Halawa Grade B	Halawa	1.20	30 HFA	0.010	0.006	0.002	0.016
27	1	Waimea	Waimea	1.20		0.008	-0.001	0.014	0.016

28	23	Waikoloa	Waikoloa			0.004	-0.022	0.014	0.018
29	25	Maui	Maui			-0.022	-0.039	-0.029	-0.024
30	26	Halawa Plant Marine Mix				-0.024	-0.025	-0.029	-0.013
31	34	Waikoloa	Waikoloa	0.55		0.009			
32	33	Waikoloa	Waikoloa	0.80		-0.032			
33	32	Waikoloa	Waikoloa	1.20		0.013			
34	31	Waikoloa	Waikoloa	0.80	20 CFA	0.003			
35	39	Waikoloa	Waikoloa	0.80	20 FA + 50 LiNx	0.005			
36	36	Waikoloa	Waikoloa	1.20	20 CFA	0.007			
37	35	Waikoloa	Waikoloa	1.20	30 CFA	0.011			
38	38	Waikoloa	Jobe	1.20		0.278			
39	37	Placitas	Waikoloa	1.20		0.224			
40	40	Waikoloa	Waikoloa	1.20	100 LiNx	0.014			

[1] Position on exposure site (see Figure 3)

[2] Fly ash levels expressed as percentage by mass of total cementitious material

[3] Lithium contents expressed as percentage of standard dose – e.g. 100 LiNx: [Li]/[Na+K] = 0.74; 50 LiNx: [Li]/[Na+K] = 0.37

[4] First measurement at 109 days for blocks 1 to 30 (cast in June 2011) and at 234 days for blocks 31 to 40 (cast in January 2013)

Concrete for 27 of the first 30 mixtures was batched, mixed, and cast at Hawaiian Cement's Halawa Plant in June 2011. For each mixture 0.14 m^3 (5 ft^3) of concrete was mixed in a drum mixer, placed into the forms for the concrete blocks, and consolidated in two layers using an immersion vibrator. Stainless steel pins were cast into the blocks to permit measurements of length change to be made using a Demec-type strain gauge (see Figure 2). The blocks were cured under wet burlap and plastic for one day before the forms were stripped. The blocks were then moist-cured for a further (approximately) six days under wet burlap before being transported approximately 16 km (10 mi) to the Magoon Research Facilities in Manoa where they were placed on a layer of granular fill and exposed to the elements (see Figure 1), at which time the "zero-day" reference length-change measurement was carried out.

Three of the first 30 blocks (mix numbers 20, 23, and 30) were produced using commercial mix designs and materials from the Halawa ready-mix concrete plant. These mixtures were batched in the plant and truck-mixed but otherwise the manufacture and subsequent treatment of the blocks was the same as the other 27 blocks.

Figure 2. Length-Change Measurements Using a Demec-Type Gauge

Length-change measurements of these 30 blocks were conducted again at 109, 265, 571, and 805 days. At 805 days (August 2013) representatives of the University of Hawaii (UH) Department of Civil Engineering also made length-change measurements using different Demec gauges. All future measurements will be performed by UH.

Concrete for the second series of 10 mixtures was batched, mixed, and cast at the University of Hawaii in January 2013. Similar procedures were used and the blocks were shipped to the exposure site at an age of 2 to 3 days when the zero-day measurement was made. These blocks were also measured in August 2013 by both the FHWA team and UH, at which time the blocks were 234 days old.

Figure 3 shows the location of the forty different mixtures on the exposure site.

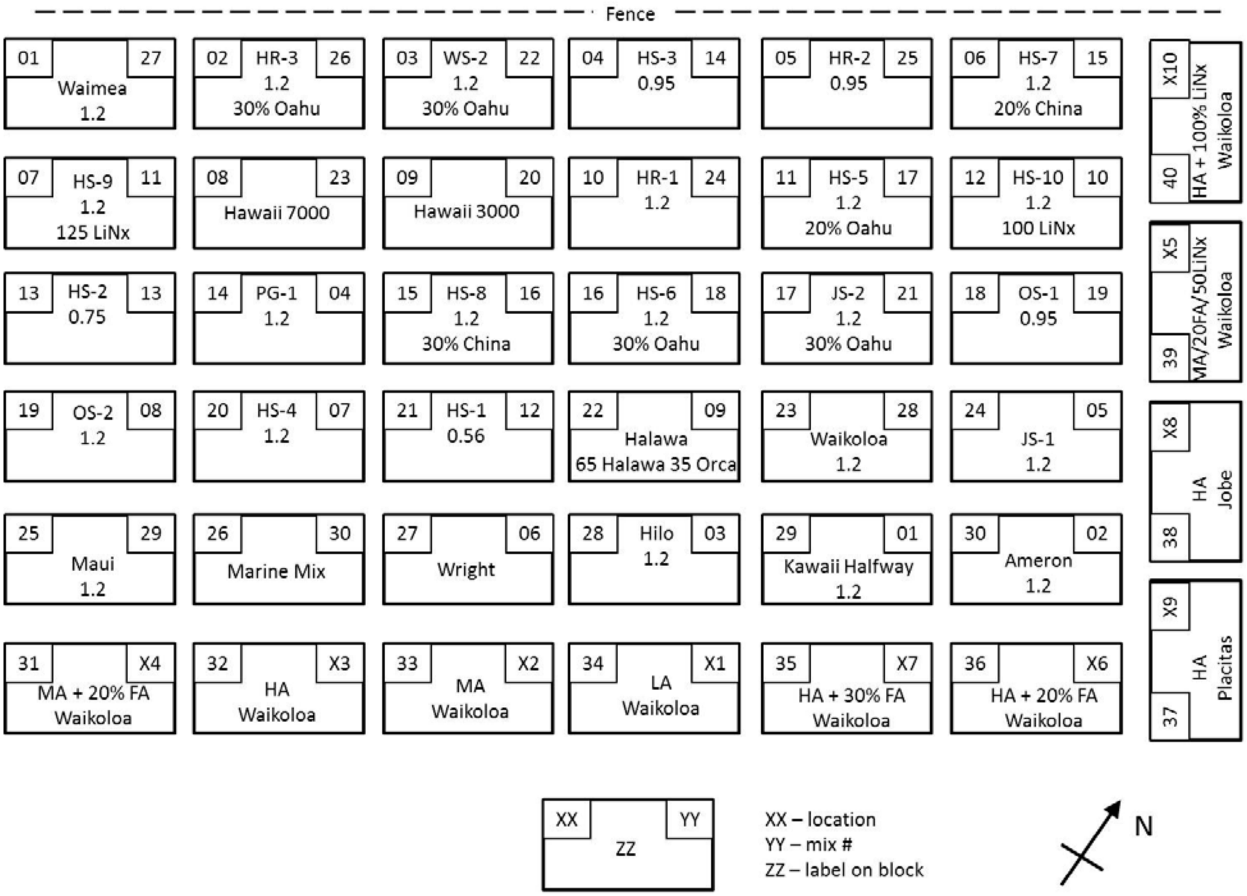

Figure 3. Map of Exposure Site

2.2 Results

The results of the laboratory expansion tests performed on the local aggregates collected for this study are presented in Table 1. All of the basaltic aggregates (coarse and fine) produced expansion in excess of 0.10% at 14 days in the accelerated mortar bar test (AMBT). However, with one exception these same aggregates did not produce deleterious expansion in the concrete prism tests (CPT) at 38°C (100°F). The fine aggregate from Waikoloa did produce damaging expansion in the CPT at this temperature although the coarse aggregate from the same source did not. As a result of this behavior, additional blocks were cast with the Waikoloa aggregate in January 2013 to confirm whether this source truly is reactive and to evaluate the efficacy of preventive measures (fly ash and lithium).

None of the blocks containing the local Hawaiian (basaltic) aggregates have shown deleterious expansion to date. Only one block, Mix 28 with Waikoloa aggregate, exhibited cracking at 805 days (see Figure 4) but this is not thought to be a result of ASR as the expansion is still less than 0.020% at this age. Consideration will be given to sampling the block at a later age and conducting a petrographic evaluation to determine whether there is any evidence of ASR.

Figure 4. Photograph of Block 4 at 805 days (August 2013)
(Photo on right is an enlargement of area in blue box on left)

Figure 5 shows the expansion of blocks containing the "imported" known reactive aggregates from Texas (Jobe and Wright) and New Mexico (Placitas). Of the blocks manufactured in 2011 only the block with Placitas (Mix 4) showed rapid expansion and cracking, and this is consistent with behavior observed for this aggregate on other exposure sites. The block containing Wright sand has not yet expanded, and this is not unexpected as this sand is more slowly reactive than the Jobe and Placitas. The behavior of the block with Jobe is surprising as this sand has produced very rapid expansion when combined with high-alkali cement in blocks on other exposure sites. To further investigate this apparent anomaly additional blocks were cast with Jobe and Placitas in January 2013. The data in Figure 5 show both blocks to expand rapidly this time, and the magnitude and rate of expansion of the 2013 Placitas block is very similar to the 2011 Placitas block. A corner of 2011 Jobe block was removed using a concrete saw and examined in the laboratory; this confirmed that the sand was indeed Jobe. It is suspected that an error occurred during the batching of the 2011 Jobe block and that low-alkali cement was inadvertently used instead of high-alkali cement. If this is indeed the case the block is expected to start expanding at some point in the future and, at that time, consideration will be given to removal of another small sample from this block for the purpose of determining the alkali content of the concrete.

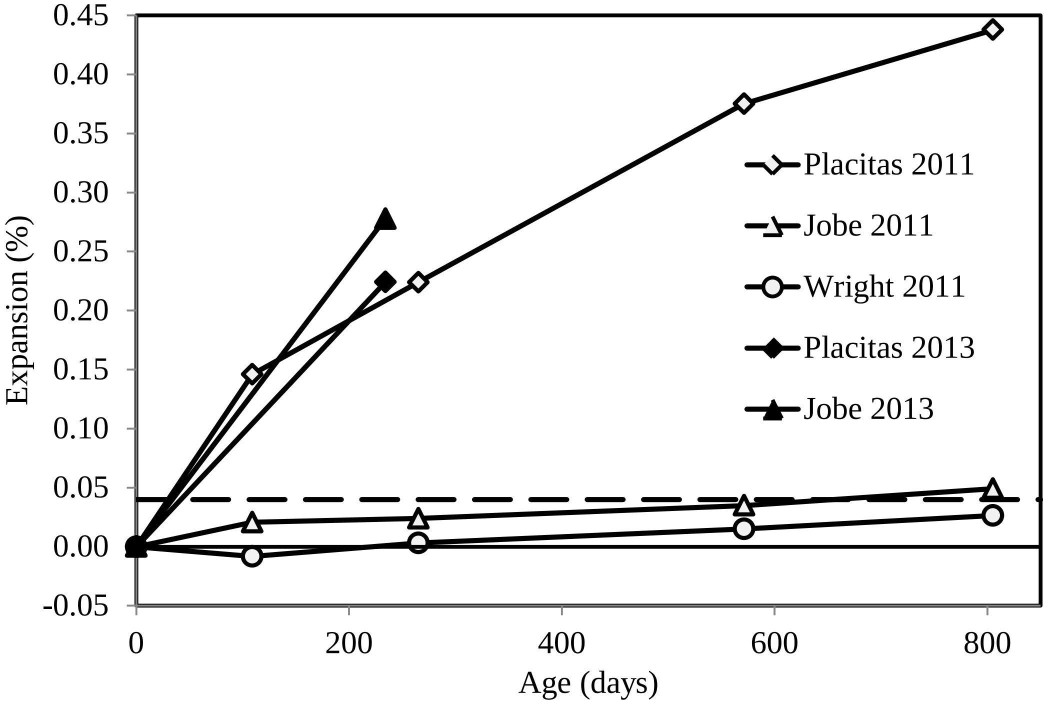

Figure 5. Expansion of Blocks with Imported Known Reactive Aggregates

Figure 6 shows the condition of some of the blocks with known reactive aggregates. The photographs were taken in August 2013 when the 2011 blocks were at an age of 805 days and the 2013 blocks were just 234 days old. The cracking exhibited in the blocks constructed with Placitas (2011 and 2013) and Jobe (2013) is symptomatic of ASR.

2.3 Discussion

Continued and regular monitoring of the blocks on the exposure site is required to produce a meaningful database that can be used to: (i) calibrate laboratory tests (both existing tests and new tests), (ii) evaluate the efficacy of preventive measures under field conditions, and (iii) test the current guidelines such as AASHTO PP65-11. The current plan is that ongoing monitoring will be conducted by representatives of the University of Hawaii Department of Civil Engineering.

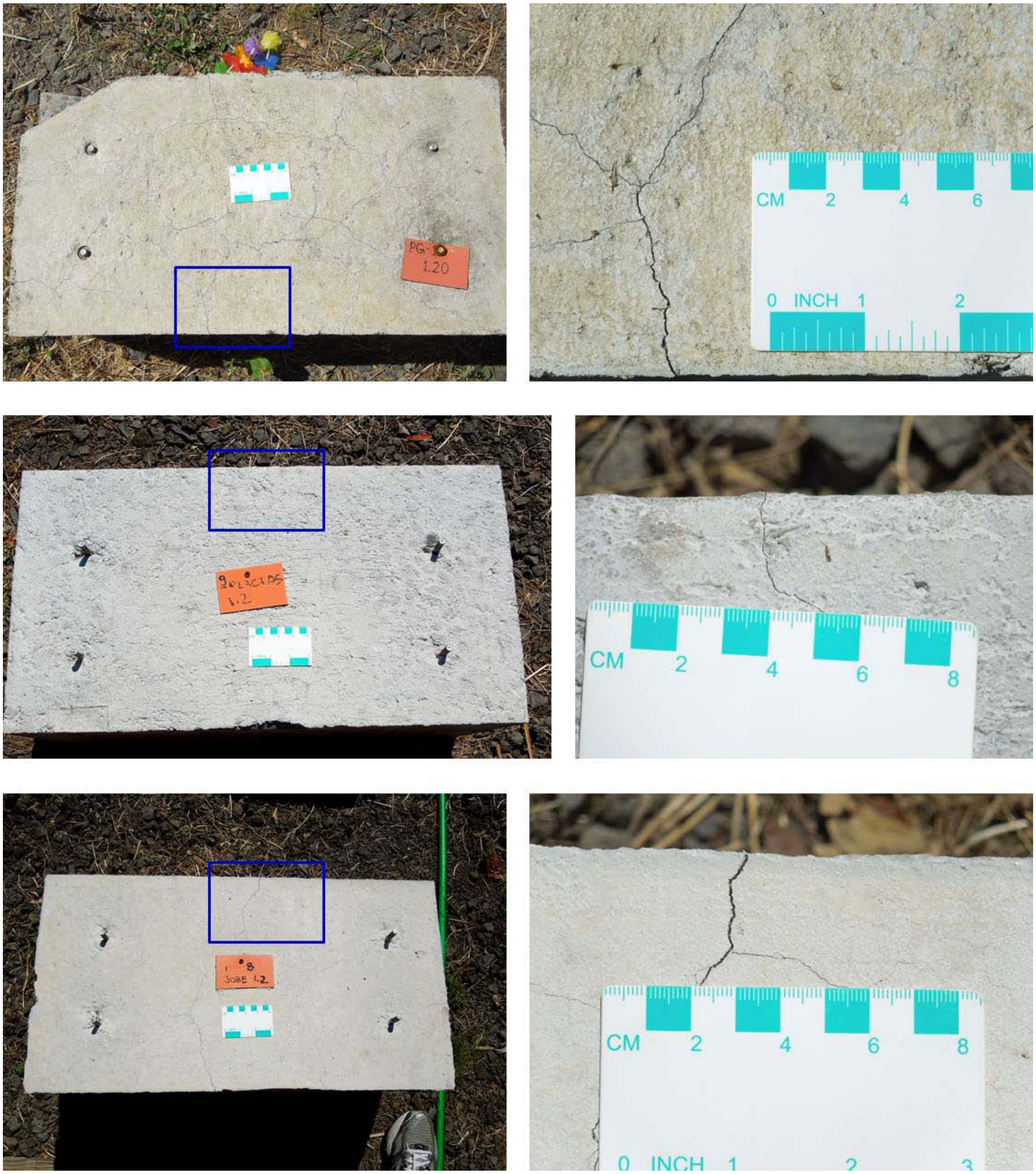

**Figure 6. Photographs of Cracked Blocks with Placitas Aggregate Cast in 2011 (top) and 2013 (middle) and Jobe Sand Cast in 2013 (bottom)
(Photos on right are enlargements of areas in blue box on left)**

2.4 Conclusions

1. An exposure site was developed on Oahu, Hawaii in June 2011.
2. Concrete blocks from 30 different mixtures produced with a number of local (basaltic) aggregates and 3 known highly-reactive aggregates, and with various preventive measures, are exposed on the site. An additional 10 blocks were added to the site in January 2013 to further investigate the behavior of aggregate from the Waikoloa Quarry on the island of Hawaii (“Big Island”).
3. At the time of writing the blocks are 805 or 234 days old and none of those produced with Hawaiian aggregates have shown expansion in excess of 0.040%.

The monitoring needs to be continued for at least 10 years to make best use of the data.

3. EXPOSURE SITE IN LAWRENCE, MASSACHUSETTS

The Lawrence exposure site was constructed in June 2012 at a Massachusetts Department of Transportation (MassDOT) storage facility in Lawrence, Massachusetts (see Figure 7). A total of 73 concrete mixtures were produced, and blocks (0.38 x 0.38 x 0.71 m, 15 x 15 x 28 in.) from these mixtures were placed behind the storage building. Eleven local aggregates (coarse and fine) were used together with cements of varying alkali, supplementary cementing materials (SCM), and a lithium-nitrate admixture. Known reactive aggregates from three different sources were also used. These aggregates have been used to produce blocks on other exposure sites including the site in Hawaii that was constructed under this program and other sites in Texas, Ontario, and New Brunswick. Having the same-size blocks with nominally identical composition on different sites will allow the effect of environmental exposure to be assessed. These blocks will be monitored periodically to determine the onset of cracking (by visual inspection) and length change. Laboratory tests are being conducted on similar mixtures, and the outcome of the tests will be compared when long-term test data (≥ 10 years) from the exposure site become available. At the time of writing, only one-year data are available from the exposure site. Continued monitoring of the blocks (beyond one year) will be performed by MassDOT.

Figure 7. Completed Exposure Site in Lawrence, Massachusetts (June 2012)

3.1 Experimental Details

3.1.1 Materials

3.1.1.1 Aggregates

Eleven sources of “local” aggregate were included in the study. The majority of the sources are located within the state of Massachusetts. Details of these aggregates are given in Table 5 together with historical expansion data from the accelerated mortar-bar test (AMBT), ASTM C1260/AASHTO T303, conducted by, or on behalf of, MassDOT. The last two columns in Table 5 present the results for testing conducted under this study, and these are discussed later in section 3.3.

Table 5. “Local” Aggregates

Agg. ID	Description	[1]MassDOT: AMBT 14 days (%)	[2]Univ. Texas	
			[3]AMBT 14 days (%)	[4]CPT 180 days (%)
Coarse Aggregates				
1	Diorite (mainly); granitic & volcanic (traces)	0.05 - 0.09	0.095	0.014
2	Mixed Diorite/gneiss/granite/ schist	0.04 - 0.09	0.066	0.035
3	Pinkish meta-granite	0.20 - 0.32	0.072	0.032
4	Mixed gneiss/granitic	> 0.1	0.324	0.113
5	Mixed gneiss/schist/quartzite	0.50 - 0.54	0.063	0.041
6	Greywacke/sandstone	0.58 - 0.62	0.573	0.127
Fine Aggregates				
7	Mixed gneiss/quartzite/quartz/ feldspar sand	0.09 - 0.10	0.066	0.018
8	Mixed quartzite/gneiss/quartz/ feldspar sand	0.20 - 0.21	0.147	0.053
9	Mixed gneiss/quartzite/quartz/ feldspar sand	0.20 - 0.26	0.239	0.016
10	Mixed gneiss/schist/quartzite/ quartz/feldspar sand	0.38 - 0.40	0.327	0.027
11	Mixed granitic/quartz/feldspar sand		0.037	0.023

[1] Range of results from tests conducted by, or on behalf of, MassDOT prior to the exposure-site study

[2] Results from tests conducted by the University of Texas on the aggregate samples used in the exposure-site study

[3] AMBT = Accelerated Mortar-Bar Test, ASTM C1260 or AASHTO T303

[4] CPT = Concrete Prism Test, ASTM C1293

In addition to the local aggregates three known reactive aggregates were also used, and these are detailed in Table 6. Typical expansion data from tests conducted at the University of Texas at Austin are also shown for these aggregates.

Table 6. Standard Reactive Aggregates

Agg. ID	Source	Description	Typical Expansion (%)	
			[1]AMBT at 14 days	[2]CPT at 1 year
Coarse Aggregates				
UT1	Placitas, NM	Rhyolitic volcanic rocks with quartz and granite	0.820	0.159
Fine Aggregates				
UT2	Jobe, TX	Mixed quartz/chert/feldspar sand	0.640	0.582
UT3	Wright, TX	Mixed quartz/chert sand	0.290	0.270

[1] AMBT = Accelerated Mortar-Bar Test, ASTM C1260 or AASHTO T303

[2] CPT = Concrete Prism Test, ASTM C1293

3.1.1.2 Cementitious Materials

Two portland cements were used to produce the concrete mixtures; these are designated HAC (high-alkali cement) and LAC (low-alkali cement) with alkali contents of 1.10% and 0.66% Na_2Oe, respectively. For some concrete mixtures both cements were used (50/50 blend) to produce a moderate-alkali cement (MAC) with an equivalent alkali content of 0.88% Na_2Oe. The following supplementary cementing materials (SCM) were used in some of the concrete mixtures: Class F fly ash (FA), slag (SG), and silica fume (SF). Chemical analyses of the cementitious materials are given in Table 7.

Table 7. Details of Cementitious Materials

ID	Oxides (% mass)						
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2Oe
High-alkali cement (HAC)	20.31	5.02	2.61	62.01	2.01	4.31	1.10
Low-alkali cement (LAC)	20.21	4.95	2.41	62.42	2.14	2.54	0.66
Fly ash (FA)	55.78	25.90	7.41	3.44	1.04	0.34	1.03
Slag (SG)	35.81	10.79	0.77	39.20	11.50	2.66	0.70
Silica fume (SF)	93.30	0.03	1.28	0.65	0.49	0.26	0.74

3.1.1.3 Chemical Admixtures

A polycarboxylate high-range, water-reducing admixture (HRWA) meeting the requirements of ASTM C494 and a synthetic air-entraining admixture (AEA) meeting the requirements of ASTM C260 were used. Some concrete mixtures also contained a lithium-based ASR-suppressing admixture composed of a 30% solution of lithium nitrate ($LiNO_3$).

3.1.2 Standard Aggregate Expansion Tests

All eleven of the local aggregates were tested in accordance with the standard accelerated mortar bar test (ASTM C1260/AASHTO T303), AMBT, and concrete prism test (ASTM C1293), CPT. The 14-day expansion data for the AMBT are given in Table 5. The latest expansion data for the CPT are also reported in Table 5; note that this is a one-year test and thus the data are incomplete at this time.

3.1.3 Concrete Blocks

Table 8 provides information on the type of aggregate, cement, SCM, and presence of lithium for the 73 concrete mixtures produced during this study. In all cases the total cementitious materials content of the concrete mixture was 420 kg/m^3 (708 lb/yd^3), the water-to-cementitious-materials ratio was w/cm = 0.42, and the coarse-to-fine-aggregate ratio was C/F = 60/40. The dosage of admixtures (HRWA and AEA) were adjusted for each batch to provide suitable workability for compaction (slump range 125 to 175 mm, 5 to 7 in.) and an air content in the range of 5 to 8%. Where lithium nitrate was used the dose was adjusted to provide a lithium-to-alkali-molar ratio of [Li]/[Na+K] = 0.74 based on the alkali available from the portland-cement component of the mixture only. This yields a dose of 4.6 liters of 30% lithium nitrate solution per kilogram of equivalent alkali, 4.6 L/kg Na_2Oe (0.55 gal/lb Na_2Oe). This is often referred to as the “standard” lithium dose required to control ASR for many reactive aggregate types.

The mixture proportions, particularly the level of SCM, were selected to bracket the recommended replacement levels in AASHTO PP65-11. Also each of the local aggregates was used in control mixes without prevention with three different cement alkali levels to determine the threshold alkali required to produce damaging ASR.

Table 8. Details of Concrete Mixtures

Mix #	Aggregate	Portland Cement		SCM/Lithium	Expansion of Blocks (%)	
		Type	% Na_2Oe		91 days	371 days
1	3	LAC	0.66	Control	-0.021	0.008
2		MAC	0.88	Control	-0.014	0.022
3		HAC	1.10	Control	-0.010	0.016
4				20% FA	-0.016	0.011
5				30% FA	-0.018	0.013
6				35% SG	-0.018	0.014
7				50% SG	-0.008	0.017
8				15% FA + 4% SF	-0.013	0.010
9				20% SG + 4% SF	-0.019	0.016
10				Lithium	-0.012	0.016
11	9	LAC	0.66	Control	0.004	0.009
12		MAC	0.88	Control	-0.004	0.007
13		HAC	1.10	Control	-0.004	0.011
14		HAC	1.10	Control	0.007	0.020
15	UT1 - Placitas	HAC	1.10	Control	0.024	**0.107**
16	5	LAC	0.66	Control	-0.002	0.010
17		MAC	0.88	Control	-0.004	0.008
18		HAC	1.10	Control	-0.004	0.012
19				20% FA	-0.015	0.009
20				30% FA	-0.013	0.004
21				35% SG	0.003	0.025
22				50% SG	-0.016	0.012
23				15% FA + 4% SF	0.000	0.018
24				20% SG + 4% SF	0.003	0.025
25				Lithium	0.000	0.013
26	2	LAC	0.66	Control	0.002	0.004
27		MAC	0.88	Control	0.004	0.017
28		HAC	1.10	Control	-0.002	0.017
29	10	LAC	0.66	Control	0.005	0.018
30		MAC	0.88	Control	0.001	0.017
31		HAC	1.10	Control	0.006	0.021
32				50% Slag	-0.008	0.004
33				20% FA	-0.017	0.004
34				30% FA	-0.029	-0.008
35				35% SG	-0.017	0.002
36				15% FA + 4% SF	0.000	0.011
37				20% SG + 4% SF	-0.006	0.035
38				Lithium	0.010	0.027
39	7	LAC	0.66	Control	0.002	0.015
40		MAC	0.88	Control	0.004	0.013
41		HAC	1.10	Control	-0.001	0.016

42	8	LAC	0.66	Control	-0.001	0.016
43		MAC	0.88	Control	0.012	0.018
44		HAC	1.10	Control	0.005	0.011
45	4	LAC	0.66	Control	0.018	0.018
46		MAC	0.88	Control	0.010	0.023
47		HAC	1.10	Control	0.009	0.026
48	UT2 - Jobe	HAC	1.10	Control	**0.137**	**0.370**
49	UT3 - Wright	HAC	1.10	Control	0.003	0.028
50	1	LAC	0.66	Control	0.006	0.018
51		MAC	0.88	Control	0.020	0.019
52	6	LAC	0.66	Control	0.017	0.007
53		MAC	0.88	Control	0.007	0.018
54		HAC	1.10	Control	0.007	0.038
55				20% FA	-0.013	0.001
56				30% FA	0.005	0.004
57				35% SG	0.001	0.009
58				50% SG		-0.019
59				15% FA + 4% SF	0.008	0.015
60				20% SG + 4% SF	0.003	0.006
61				Lithium	0.001	0.004
62		MAC	0.88	20% FA	0.004	0.009
63				30% FA	-0.004	0.007
64				35% SG	-0.005	0.012
65				50% SG	-0.009	0.005
66	5	MAC	0.88	20% FA	-0.004	0.001
67				30% FA	0.000	0.000
68				35% SG	0.004	0.016
69				50% SG	-0.019	-0.001
70	3	MAC	0.88	20% FA	0.005	0.014
71				30% FA	0.003	0.012
72				35% SG	0.000	0.012
73				50% SG	-0.003	0.009

Concrete was batched, mixed, and cast on the exposure site. For each mixture 0.14 m^3 (5 ft^3) of concrete was mixed in a drum mixer, placed into the forms for the concrete blocks, and consolidated in two layers using an immersion vibrator. Stainless steel pins were cast into the blocks to permit measurements of length change to be made using a Demec-type strain gauge (see Figure 8). The blocks were cured under wet burlap and plastic for one day before the forms were stripped. The blocks were then moist-cured for a further (approximately) six days under wet burlap before being placed on a layer of granular fill and exposed to the elements (see Figure 7) at which time the “zero-day” reference length-change measurement was carried out.

Length-change measurements were conducted again at 91 and 371 days. At 371 days representatives of MassDOT also made length-change measurements using different Demec gauges. All future measurements will be performed by MassDOT.

Figure 8. Length-Change Measurements Using a Demec-Type Gauge

3.2 Results

The results of the laboratory expansion tests performed on the eleven local aggregates collected for this study are presented in Table 5. The results from the AMBT conducted at the University of Texas (UT) are in broad agreement with the range of data provided by MassDOT for tests conducted on samples from the same source at various times prior to this study. The exceptions are the results for the sands from samples 3 and 5. The test data for these two aggregates tested at UT indicate the aggregates to be innocuous (14-day expansion below 0.10%) whereas data supplied by MassDOT indicated both aggregates to be potentially deleteriously reactive. The discrepancy is largest for aggregate 5.

At the time of writing, the CPT was not complete; this is a 1-year test and only 180-day expansion data are available. However, the data available do confirm that aggregates 4, 5, 6, and 8 are deleteriously reactive as the 180-day expansion value already exceeds the 1-year expansion limit of 0.040%. Both aggregates 2 and 3 show expansion values in excess of 0.030% at 180 days and, based on experience, it is highly likely that these aggregates will exceed the 0.040% limit at 1 year. One or more of the other local aggregates will probably exceed the limit at one year also.

The relationship between expansion and time for the 11 aggregates tested in the CPT are presented in Figure 9. Although the tests are not sufficiently advanced for definitive statements to be made regarding the reactivity of the aggregates, the spread of data do confirm that the 11 aggregate samples selected represent a wide range in terms of alkali-silica reactivity (as intended).

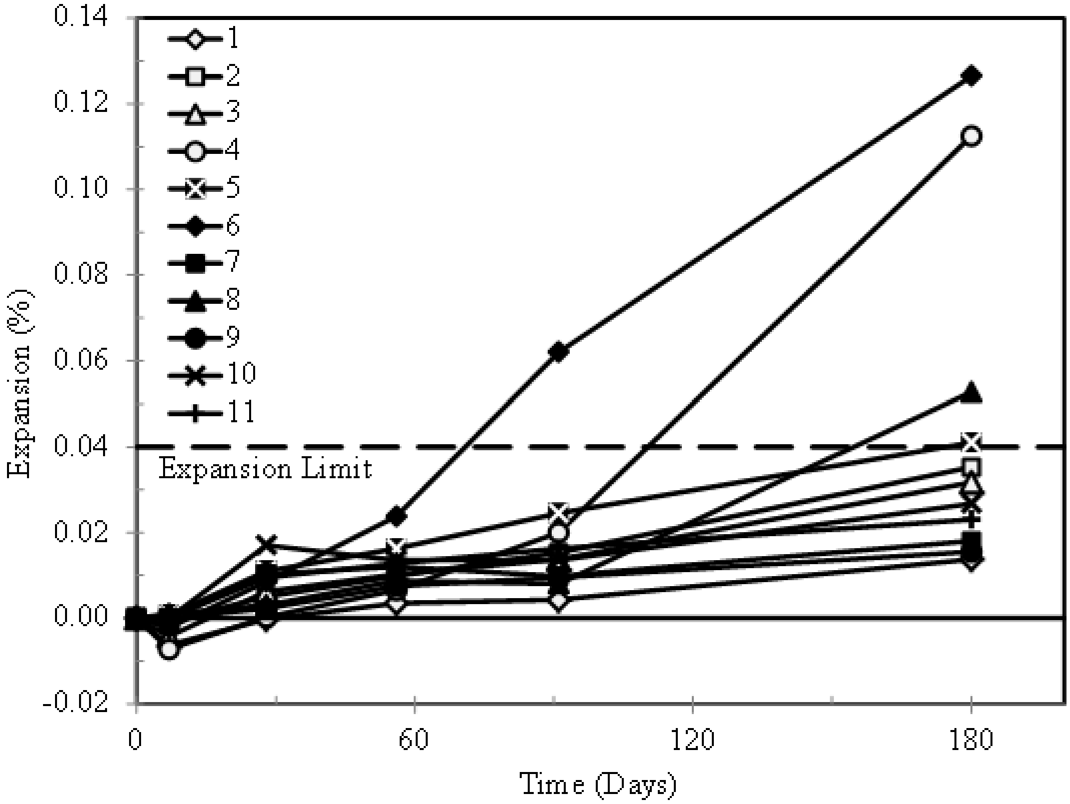

Figure 9. Expansion of Local Aggregates Tested in Concrete Prism Test (ASTM C 1293) – Data to 180 days only (Note: specified test duration is 1 year)

The results of the laboratory expansion tests performed on the three known reactive aggregates collected for this study are presented in Table 6. The results of the AMBT and CPT confirm that these aggregates are reactive, the reactivity ranging from highly-reactive to very-highly-reactive based on the criteria in AASHTO PP65-11.

The expansion values for the concrete blocks after three months and one year on the exposure site are presented in Table 8. Figure 10 shows the expansion versus age for the three known reactive aggregates together with aggregate 6. Aggregate 6 was selected because it shows the highest expansion among the 11 local aggregates and has been implicated as a contributor to ASR in a number of structures in New England. The Jobe aggregate, which is considered to be one of the most, if not the most, reactive aggregates in North America, produces expansion in excess of 0.040% after just 91 days on the exposure site. After 1 year, the Placitas aggregate has also produced expansion in excess of 0.040%, but none of the other blocks have reached this level of expansion at this age. However, the block with aggregate 6 and high-alkali cement has expanded by 0.038% at 1 year. Significant expansion of the blocks produced with local aggregates is not expected after one year. Damaging expansion and cracking due to ASR often takes 5 to 10 years, and sometimes even longer, to occur under field conditions. Indeed in many cases the blocks exhibit shrinkage (negative values in Table 8) during the first year, and this is expected behavior.

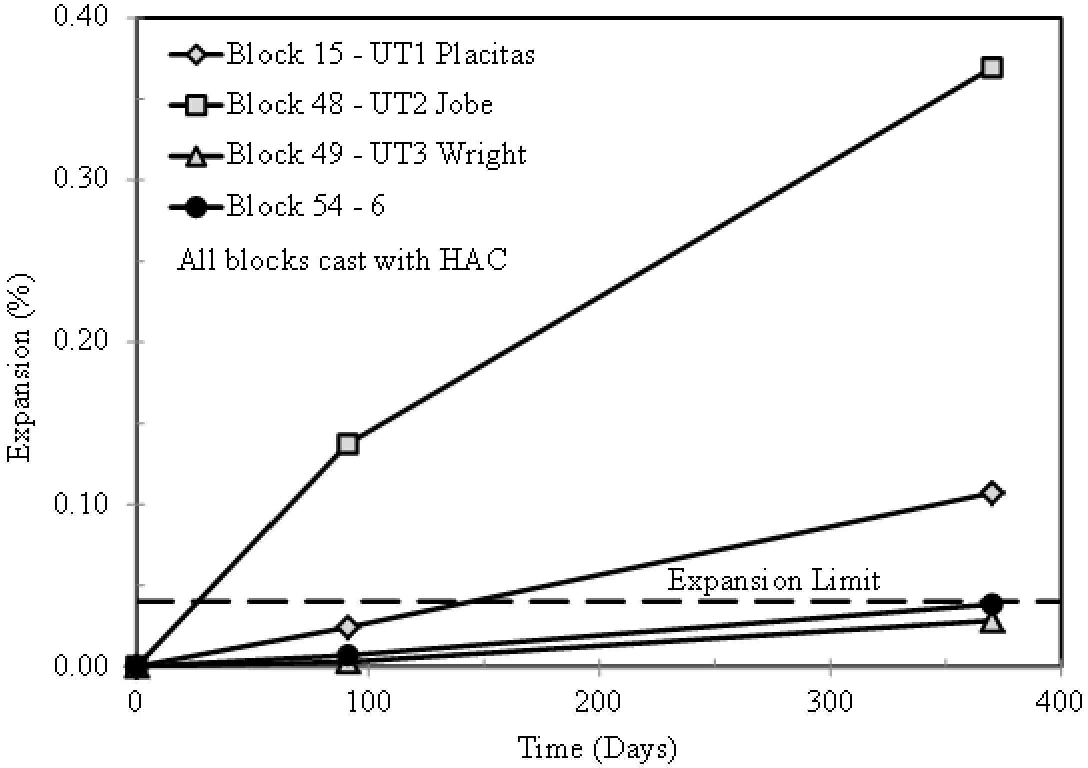

Figure 10. Expansion of Blocks on Exposure Site in Lawrence, Massachusetts

Visual inspection of the blocks at one year revealed significant cracking in four blocks (Figure 11); these were: Block 15 with Placitas, Block 48 with Jobe, Block 49 with Wright, and Block 54 with aggregate 6. Note that at 91 days only Block 48 with Jobe showed any signs of cracking. All of these blocks were produced with the high-alkali cement (HAC) without either SCM or lithium.

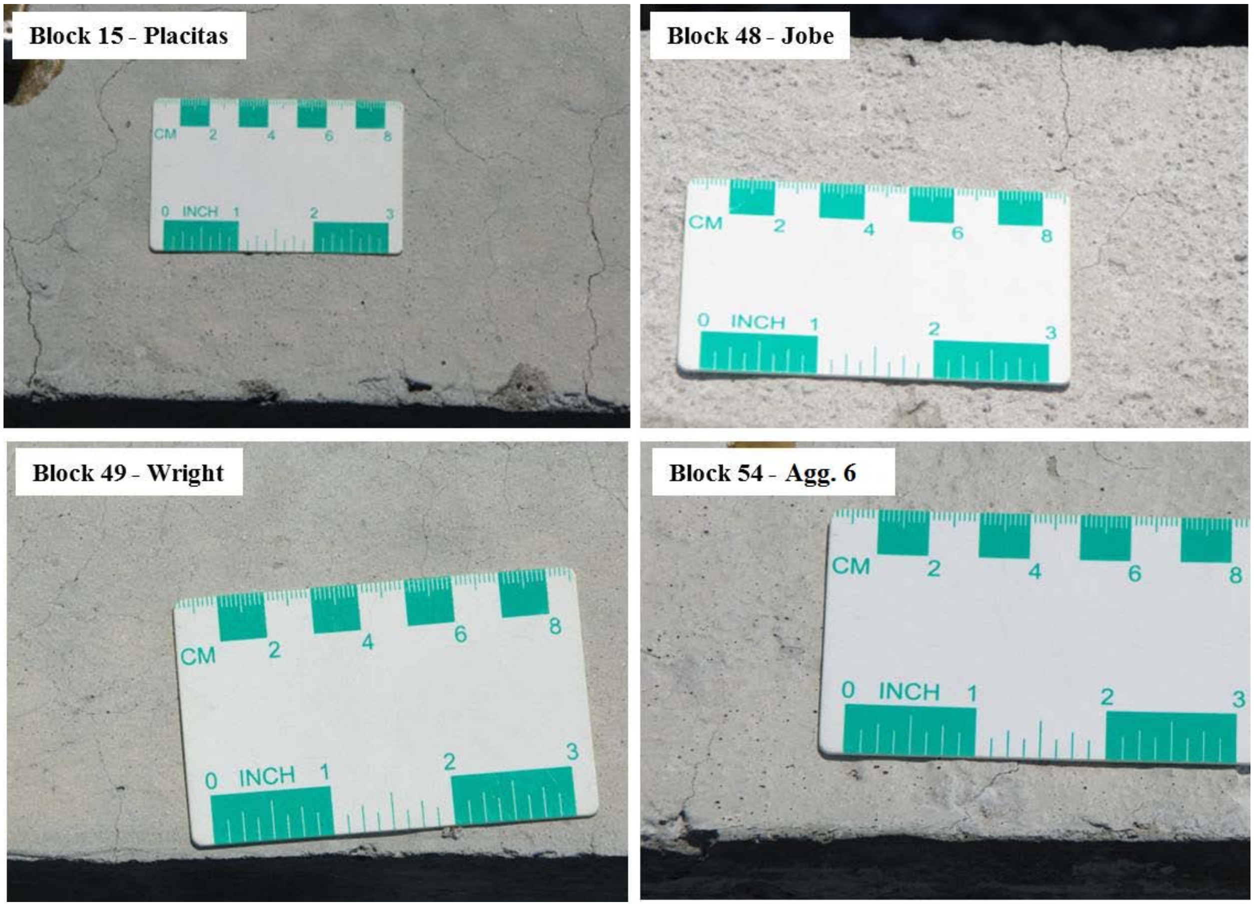

Figure 11. Cracking in Blocks on Exposure Site after One Year

3.3 Discussion

As the concrete prism tests are only six months old and the concrete blocks are just one year old, it is too soon to draw many inferences from the data at this time. However, the six-month prism expansion data has confirmed that four of the local aggregates are certainly deleteriously alkali-silica reactive, having already exceeded the one-year expansion limit. The indications are that at least two or more of the remaining aggregates are likely to fail the limit at one year. The concrete prism test data also reveal that the different aggregates exhibit a significant range of reactivity. The aggregates were selected on the basis of existing mortar-bar test results and petrographic data to provide a suite of aggregates of varying composition and reactivity; this selection appears to have been successful.

There is some discrepancy between the accelerated mortar-bar test (AMBT) data collected by MassDOT at various periods before the commencement of the study and the data from the testing performed at the University of Texas (UT) on the aggregates collected for the study. Furthermore, there is some disagreement between the AMBT and concrete prism test (CPT) data for the same aggregates tested at UT, as some of the aggregates that do not produce deleterious expansion in the AMBT (expansion < 0.10% at 14 days) have already exceeded the limit (0.040%) for the CPT at 6 months or look likely to do so before 1 year. It may be necessary to repeat the AMBT for some of these cases to check the incongruity.

Two of the highly reactive “standard” aggregates (Placitas and Jobe) have already produced excessive expansion in blocks on the exposure site which confirms that the exposure conditions are conducive to ASR. The greywacke aggregate (number 6) produces an expansion of 0.038% in the control block with high-alkali cement, and some slight cracking is already in evidence.

Continued and regular monitoring of the blocks on the exposure site is required to produce a meaningful data base that can be used to: (i) to calibrate laboratory tests (both existing tests and new tests), (ii) evaluate the efficacy of preventive measures under field conditions, and (iii) test the current guidelines such as AASHTO PP65-11. The current plan is that ongoing monitoring will be conducted by representatives of MassDOT.

It is expected that MassDOT will conduct further AMBT and CPT tests using the same aggregate-SCM/lithium combinations used in the blocks for the purpose of evaluating these tests as methods for determining the efficiency of preventive measures (i.e., by comparing the laboratory data with the long-term performance of blocks). It is also recommended that the same combinations be tested in other promising laboratory performance tests such as the mini-concrete-prism test currently being developed at Clemson University under a FHWA-funded research program.

3.4 Conclusions

1. An exposure site was developed in Lawrence, Massachusetts in June 2012.
2. Concrete blocks from 73 different mixtures produced with 11 local aggregates and 3 known highly-reactive aggregates, and with various preventive measures, are exposed on the site.
3. After 1 year 2 of the blocks have shown expansion in excess of 0.040%.
4. The monitoring needs to be continued for at least 10 years to make best use of the data.

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