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)

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	% Na₂Oe		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).
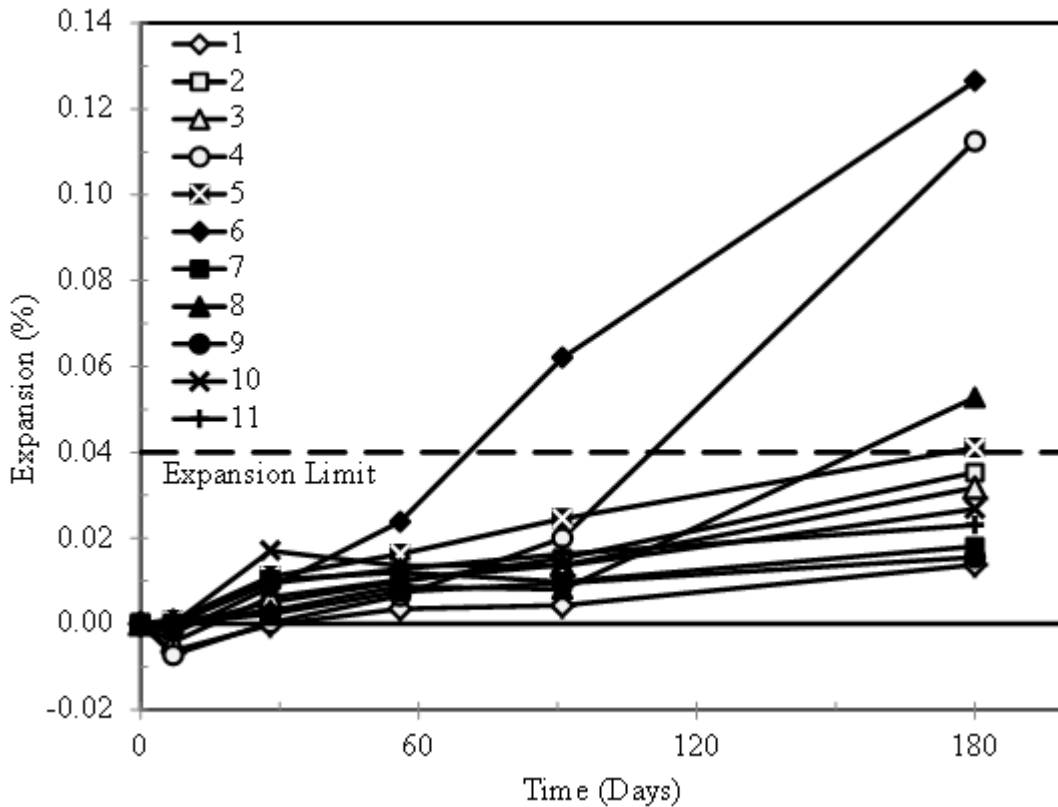

Figure 9. Expansion of Local Aggregates Tested in Concrete Prism Test (ASTM C 1293) – Data to 180 days only (Note: specified test duration is 1 year)

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.
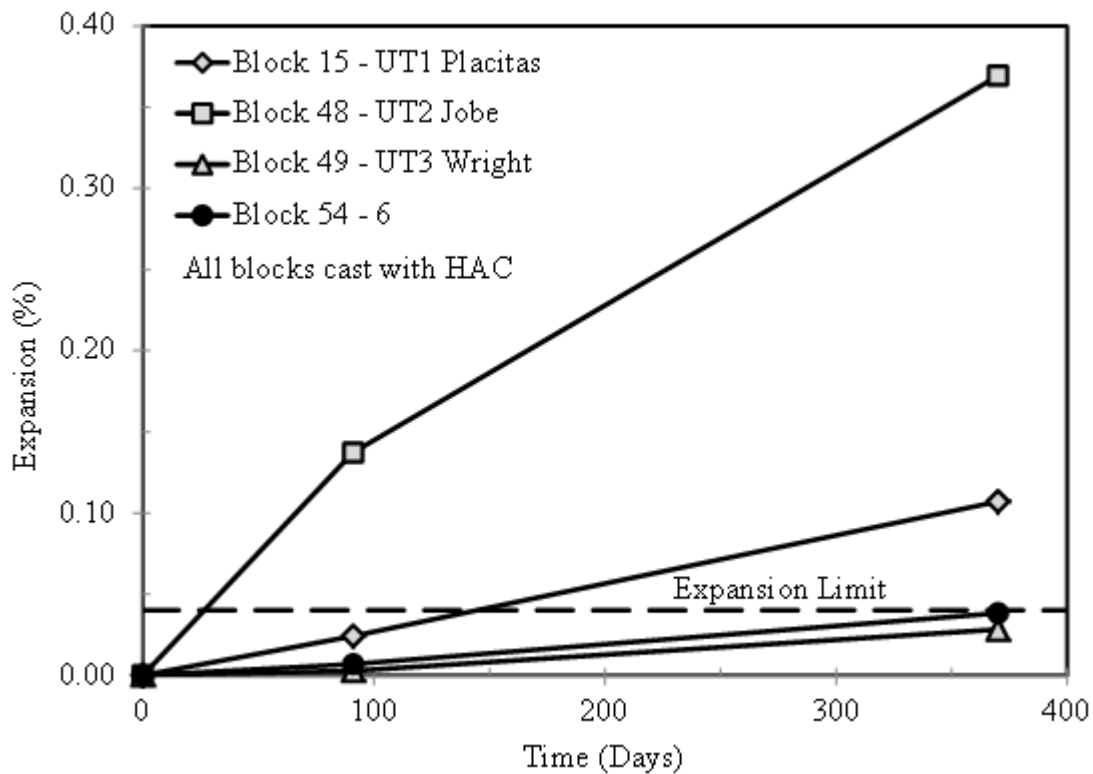

Figure 10. Expansion of Blocks on Exposure Site in Lawrence, Massachusetts

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.