

APPENDIX C

Data Obtained from Testing Concrete Mixtures Produced in the Laboratory

Table C-1. Repeatability of the measurements using fixed-focus optical microscope and flatbed scanner.

Analysis scenario		Data based on all chords			Data based on chords longer than 30 microns			
Hardened sample	Fresh air (%)	Hardened air (%)	S.F. (in.)	S.S. (in. ⁻¹)	Hardened air (%)	S.F. (in.)	S.S. (in. ⁻¹)	
Fixed-focus optical microscope	Test 1	3.5	4.4	0.009	611	4.2	0.014	372
	Test 2		4.5	0.010	540	4.4	0.015	344
	Test 3		4.7	0.008	638	4.5	0.013	385
	Test 4		4.8	0.009	544	4.6	0.015	350
	Avg.		4.6	0.009	583	4.4	0.014	363
	STD		0.2	0.001	42	0.2	0.001	17
	COV (%)		3.4	7.1	7.2	3.4	4.6	4.6
Fixed-focus optical microscope	Test 1	7.5	9.1	0.003	1,027	8.6	0.005	698
	Test 2		9.1	0.003	1,141	8.5	0.005	750
	Test 3		9.0	0.003	1,117	8.4	0.005	732
	Test 4		8.7	0.003	1,150	8.1	0.005	730
	Avg.		9.0	0.003	1,109	8.4	0.005	727
	STD		0.2	0.000	56	0.2	0.000	22
	COV (%)		2.0	4.0	5.1	2.6	3.3	3.0
Flatbed scanner	Test 1	3.6	3.3	0.020	293	3.1	0.027	227
	Test 2		3.2	0.018	331	3.6	0.026	214
	Test 3		3.5	0.020	288	3.2	0.026	233
	Test 4		3.4	0.020	295	3.4	0.025	230
	Avg.		3.3	0.019	302	3.3	0.026	226
	STD		0.1	0.001	17	0.2	0.001	7
	COV (%)		3.1	4.1	5.6	6.3	2.4	3.2
Flatbed scanner	Test 1	6.9	8.3	0.003	1,160	8.3	0.005	751
	Test 2		8.7	0.003	1,091	8.0	0.005	768
	Test 3		9.2	0.003	1,067	7.7	0.005	777
	Test 4		8.6	0.003	1,187	8.0	0.005	747
	Avg.		8.7	0.003	1,127	8.0	0.005	761
	STD		0.4	0.000	57	0.2	0.000	14
	COV (%)		4.5	3.2	5.0	3.1	2.1	1.9

Note: S.F. = spacing factor, S.S. = specific surface, Avg. = average, STD = standard deviation, COV = coefficient of variation.

Table C-2. Sample fixed-focus optical microscope data: comparison between all chords data and data based on chords longer than 30 microns.

Analysis scenario		Data based on all chords*				Data based on chords longer than 30 microns		
		Fresh air (%)	Hardened air (%)	S.F. (in.)	S.S. (in.-1)	Hardened air (%)	S.F. (in.)	S.S. (in.-1)
Non air-entrained mixtures	Test Mix 1	3.0	5.1	0.008	621	4.9	0.014	370
			5.1	0.012	414	5.1	0.015	334
	Test Mix 2	3.5	4.5	0.010	558	4.4	0.016	345
			4.9	0.013	407	4.8	0.016	324
	Test Mix 3	2.6	2.4	0.010	723	2.3	0.014	513
			3.6	0.006	953	3.4	0.011	573
	Test Mix 4	2.7	4.8	0.008	695	4.6	0.012	431
			4.8	0.008	695	4.6	0.012	431
Sample mixtures investigated in this project	Mix 27	3.9	3.9	0.009	609	3.8	0.014	399
	Mix 39	3.5	3.3	0.008	363	3.1	0.016	287
	Mix 41	3.4	3.4	0.005	1,074	3.0	0.013	632
	Mix 43	4.0	4.2	0.010	553	3.8	0.018	180
	Mix 45	3.1	4.7	0.008	677	4.6	0.010	515
	Mix 47	3.8	4.2	0.006	829	3.9	0.013	409
	Mix 49	3.1	4.3	0.008	653	4.1	0.014	379
	Mix 65	2.9	4.5	0.006	580	4.1	0.014	282
	Mix 67	3.1	5.6	0.004	1,122	4.9	0.020	253
	Mix 71	3.4	4.7	0.007	734	4.4	0.012	462

Note: *The spacing factors measured based on all chords data suggest desirable performances. However, the first four concrete mixtures were not even air-entrained, and the rest of these mixtures were intentionally dosed with less than 4% air in the fresh state. The S.F. measurements based on chords longer than 30 microns, however, catch this and suggest more reliable and meaningful results. The same applies to the S.S. measurements, where data based on all chords will yield high S.S. values, which does not appear to be reliable. The differences between air content are negligible. S.F. = spacing factor (in.), S.S. = specific surface (in.⁻¹).

Table C-3. Fresh air content and SAM number measurements.

Mix #	Fresh Air Content Measurements					SAM Number Measurements				
	Meter 1 (%)	Meter 2 (%)	Avg. (%)	STD	COV (%)	Meter 1	Meter 2	Avg.	STD	COV (%)
1	3.4	3.0	3.2	0.3	8.8	0.60	0.78	0.69	0.13	18.4
2	7.0	7.1	7.1	0.1	1.0	0.33	0.55	0.44	0.16	35.4
3	2.6	2.8	2.7	0.1	5.2	0.67	0.61	0.64	0.04	6.6
4	5.3	6.1	5.7	0.6	9.9	0.25	0.21	0.23	0.03	12.3
5	3.4	3.7	3.6	0.2	6.0	0.75	0.94	0.85	0.13	15.9
6	6.9	7.5	7.2	0.4	5.9	0.19	0.29	0.24	0.07	29.5
7	3.1	3.2	3.2	0.1	2.2	0.75	0.70	0.73	0.04	4.9
8	6.4	6.8	6.6	0.3	4.3	0.19	0.33	0.26	0.10	38.1
9	3.0	3.0	3.0	0.0	0.0	0.84	0.92	0.88	0.06	6.4
10	4.9	5.1	5.0	0.1	2.8	0.32	0.56	0.44	0.17	38.6
11	2.6	2.9	2.8	0.2	7.7	0.78	0.69	0.74	0.06	8.7
12	6.5	5.9	6.2	0.4	6.8	0.17	0.26	0.22	0.06	29.6
13	3.2	2.9	3.1	0.2	7.0	0.69	0.70	0.70	0.01	1.0
14	6.0	5.5	5.8	0.4	6.1	0.34	0.43	0.39	0.06	16.5
15	2.9	3.0	3.0	0.1	2.4	0.93	0.95	0.94	0.01	1.5
16	7.4	6.9	7.2	0.4	4.9	0.32	0.21	0.27	0.08	29.4
17	4.2	3.8	4.0	0.3	7.1	0.68	0.80	0.74	0.08	11.5
18	7.8	6.5	7.2	0.9	12.9	0.07	0.10	0.09	0.02	25.0
19	4.3	3.7	4.0	0.4	10.6	0.73	0.71	0.72	0.01	2.0
20	7.6	7.6	7.6	0.0	0.0	0.18	0.21	0.20	0.02	10.9
21	3.4	3.2	3.3	0.1	4.3	0.37	0.41	0.39	0.03	7.3
22	7.8	8.1	8.0	0.2	2.7	0.11	0.21	0.16	0.07	44.2
23	3.1	3.3	3.2	0.1	4.4	0.76	0.81	0.79	0.04	4.5
24	5.8	6.0	5.9	0.1	2.4	0.16	0.15	0.16	0.01	4.6
25	3.1	3.8	3.5	0.5	14.3	0.65	0.59	0.62	0.04	6.8
26	7.0	6.2	6.6	0.6	8.6	0.09	0.12	0.11	0.02	20.2
27	3.7	4.0	3.9	0.2	5.5	0.83	0.81	0.82	0.01	1.7
28	5.3	5.5	5.4	0.1	2.6	0.29	0.38	0.34	0.06	19.0
29	3.8	3.7	3.8	0.1	1.9	0.81	0.79	0.80	0.01	1.8
30	6.7	7.1	6.9	0.3	4.1	0.10	0.19	0.15	0.06	43.9
31	3.9	3.7	3.8	0.1	3.7	0.81	0.67	0.74	0.10	13.4
32	6.7	7.2	7.0	0.4	5.2	0.15	0.15	0.15	0.00	0.0
33	3.4	3.3	3.4	0.1	2.1	0.73	0.70	0.72	0.02	3.0
34	7.0	6.2	6.6	0.6	8.6	0.21	0.39	0.30	0.13	42.4
35	3.9	3.7	3.8	0.1	3.7	0.66	0.93	0.80	0.19	24.0
36	5.8	6.4	6.1	0.4	7.0	0.55	0.48	0.52	0.05	9.6
37	3.4	3.3	3.4	0.1	2.1	0.68	0.62	0.65	0.04	6.5
38	5.2	5.4	5.3	0.1	2.7	0.36	0.37	0.37	0.01	1.9
39	3.3	3.6	3.5	0.2	6.1	0.87	0.92	0.90	0.04	4.0
40	5.7	6.0	5.9	0.2	3.6	0.39	0.40	0.40	0.01	1.8

Mix #	Fresh Air Content Measurements					SAM Number Measurements				
	Meter 1 (%)	Meter 2 (%)	Avg. (%)	STD	COV (%)	Meter 1	Meter 2	Avg.	STD	COV (%)
41	3.5	3.2	3.4	0.2	6.3	0.68	0.76	0.72	0.06	7.9
42	6.1	5.8	6.0	0.2	3.6	0.17	0.33	0.25	0.11	45.3
43	4.1	3.8	4.0	0.2	5.4	0.80	0.67	0.74	0.09	12.5
44	6.3	5.8	6.1	0.4	5.8	0.18	0.23	0.21	0.04	17.2
45	2.9	3.3	3.1	0.3	9.1	0.61	0.65	0.63	0.03	4.5
46	7.5	6.7	7.1	0.6	8.0	0.38	0.34	0.36	0.03	7.9
47	3.8	3.7	3.8	0.1	1.9	0.78	0.75	0.77	0.02	2.8
48	5.4	6.2	5.8	0.6	9.8	0.26	0.18	0.22	0.06	25.7
49	3.1	3.1	3.1	0.0	0.0	0.75	0.80	0.78	0.04	4.6
50	7.8	7.2	7.5	0.4	5.7	0.28	0.31	0.30	0.02	7.2
51	3.0	3.0	3.0	0.0	0.0	0.54	0.56	0.55	0.01	2.6
52	5.3	5.5	5.4	0.1	2.6	0.31	0.28	0.30	0.02	7.2
53	3.4	3.3	3.4	0.1	2.1	0.43	0.43	0.43	0.00	0.0
54	4.9	5.2	5.1	0.2	4.2	0.31	0.25	0.28	0.04	15.2
55	3.7	3.5	3.6	0.1	3.9	0.74	0.54	0.64	0.14	22.1
56	4.6	5.3	5.0	0.5	10.0	0.50	0.25	0.38	0.18	47.1
57	4.3	3.3	3.8	0.7	18.6	0.41	0.33	0.37	0.06	15.3
58	5.4	5.1	5.3	0.2	4.0	0.36	0.43	0.40	0.05	12.5
59	3.7	4.0	3.9	0.2	5.5	0.63	0.68	0.66	0.04	5.4
60	5.7	6.4	6.1	0.5	8.2	0.52	0.51	0.52	0.01	1.4
61	2.8	2.9	2.9	0.1	2.5	0.43	0.51	0.47	0.06	12.0
62	7.5	6.6	7.1	0.6	9.0	0.27	0.07	0.17	0.14	83.2
63	3.5	3.4	3.5	0.1	2.0	0.62	0.66	0.64	0.03	4.4
64	5.2	5.3	5.3	0.1	1.3	0.63	0.70	0.67	0.05	7.4
65	2.9	2.8	2.9	0.1	2.5	0.28	0.39	0.34	0.08	23.2
66	7.4	6.8	7.1	0.4	6.0	0.14	0.19	0.17	0.04	21.4
67	3.0	3.1	3.1	0.1	2.3	0.43	0.41	0.42	0.01	3.4
68	7.0	7.1	7.1	0.1	1.0	0.26	0.32	0.29	0.04	14.6
69	4.5	4.1	4.3	0.3	6.6	0.54	0.52	0.53	0.01	2.7
70	5.3	5.1	5.2	0.1	2.7	0.52	0.61	0.57	0.06	11.3
71	3.2	3.6	3.4	0.3	8.3	0.68	0.67	0.68	0.01	1.0
72	7.6	7.5	7.6	0.1	0.9	0.03	0.07	0.05	0.03	56.6
73	4.2	4.3	4.3	0.1	1.7	0.41	0.37	0.39	0.03	7.3
74	7.7	6.1	6.9	1.1	16.4	0.21	0.25	0.23	0.03	12.3
75	3.2	3.6	3.4	0.3	8.3	0.64	0.62	0.63	0.01	2.2
76	7.0	7.1	7.1	0.1	1.0	0.21	0.26	0.24	0.04	15.0
77	3.6	2.9	3.3	0.5	15.2	0.31	0.29	0.30	0.01	4.7
78	6.1	6.3	6.2	0.1	2.3	0.10	0.16	0.13	0.04	32.6
79	3.4	3.8	3.6	0.3	7.9	0.78	0.82	0.80	0.03	3.5
80	5.1	5.5	5.3	0.3	5.3	0.42	0.37	0.40	0.04	9.0
81	2.9	3.1	3.0	0.1	4.7	0.62	0.67	0.65	0.04	5.5
82	7.1	7.3	7.2	0.1	2.0	0.15	0.17	0.16	0.01	8.8

Mix #	Fresh Air Content Measurements					SAM Number Measurements				
	Meter 1 (%)	Meter 2 (%)	Avg. (%)	STD	COV (%)	Meter 1	Meter 2	Avg.	STD	COV (%)
83	3.7	3.8	3.8	0.1	1.9	0.47	0.45	0.46	0.01	3.1
84	4.9	5.1	5.0	0.1	2.8	0.52	0.61	0.57	0.06	11.3
85	3.5	2.5	3.0	0.7	23.6	0.50	0.41	0.46	0.06	14.0
86	5.4	5.2	5.3	0.1	2.7	0.45	0.54	0.50	0.06	12.9
87	3.3	4.1	3.7	0.6	15.3	0.37	0.41	0.39	0.03	7.3
88	5.3	6.0	5.7	0.5	8.8	0.65	0.66	0.66	0.01	1.1
89	3.5	3.4	3.5	0.1	2.0	0.75	0.62	0.69	0.09	13.4
90	5.0	4.9	5.0	0.1	1.4	0.38	0.42	0.40	0.03	7.1
91	4.1	4.5	4.3	0.3	6.6	0.51	0.66	0.59	0.11	18.1
92	5.9	6.6	6.3	0.5	7.9	0.16	0.20	0.18	0.03	15.7
93	3.1	3.0	3.1	0.1	2.3	0.56	0.57	0.57	0.01	1.3
94	6.1	5.9	6.0	0.1	2.4	0.28	0.17	0.23	0.08	34.6
95	3.4	3.8	3.6	0.3	7.9	0.47	0.54	0.51	0.05	9.8
96	5.8	6.7	6.3	0.6	10.2	0.54	0.52	0.53	0.01	2.7
97	3.4	3.0	3.2	0.3	8.8	0.72	0.77	0.75	0.04	4.7
98	5.8	5.7	5.8	0.1	1.2	0.26	0.30	0.28	0.03	10.1
99	3.8	4.1	4.0	0.2	5.4	0.70	0.83	0.77	0.09	12.0
100	5.2	5.4	5.3	0.1	2.7	0.48	0.57	0.53	0.06	12.1
101	2.5	2.1	2.3	0.3	12.3	0.91	0.90	0.91	0.01	0.8
102	5.2	5.1	5.2	0.1	1.4	0.36	0.34	0.35	0.01	4.0
103	4.5	4.1	4.3	0.3	6.6	0.52	0.73	0.63	0.15	23.8
104	6.9	7.6	7.3	0.5	6.8	0.13	0.26	0.20	0.09	47.1
105	2.9	3.1	3.0	0.1	4.7	0.61	0.85	0.73	0.17	23.2
106	6.0	6.2	6.1	0.1	2.3	0.16	0.24	0.20	0.06	28.3
107	3.5	3.9	3.7	0.3	7.6	0.78	0.89	0.84	0.08	9.3
108	4.7	5.3	5.0	0.4	8.5	0.41	0.40	0.41	0.01	1.7
109	4.1	3.9	4.0	0.1	3.5	0.59	0.52	0.56	0.05	8.9
110	5.9	5.9	5.9	0.0	0.0	0.40	0.35	0.38	0.04	9.4
111	2.7	3.0	2.9	0.2	7.4	0.80	0.98	0.89	0.13	14.3
112	5.2	5.6	5.4	0.3	5.2	0.31	0.30	0.31	0.01	2.3
113	3.8	3.8	3.8	0.0	0.0	0.82	0.70	0.76	0.08	11.2
114	5.8	6.0	5.9	0.1	2.4	0.22	0.26	0.24	0.03	11.8
115	4.2	4.4	4.3	0.1	3.3	0.45	0.39	0.42	0.04	10.1
116	6.1	6.8	6.5	0.5	7.7	0.19	0.15	0.17	0.03	16.6
117	3.9	4.0	4.0	0.1	1.8	0.54	0.50	0.52	0.03	5.4
118	5.5	5.5	5.5	0.0	0.0	0.29	0.35	0.32	0.04	13.3
119	3.5	3.7	3.6	0.1	3.9	0.67	0.72	0.70	0.04	5.1
120	6.0	6.5	6.3	0.4	5.7	0.19	0.26	0.23	0.05	22.0
121	3.9	4.5	4.2	0.4	10.1	0.38	0.41	0.40	0.02	5.4
122	5.1	4.7	4.9	0.3	5.8	0.41	0.47	0.44	0.04	9.6
123	3.3	3.9	3.6	0.4	11.8	0.52	0.69	0.61	0.12	19.9
124	6.5	6.1	6.3	0.3	4.5	0.27	0.29	0.28	0.01	5.1

Mix #	Fresh Air Content Measurements					SAM Number Measurements				
	Meter 1 (%)	Meter 2 (%)	Avg. (%)	STD	COV (%)	Meter 1	Meter 2	Avg.	STD	COV (%)
125	4.3	4.4	4.4	0.1	1.6	0.46	0.39	0.43	0.05	11.6
126	5.2	4.8	5.0	0.3	5.7	0.33	0.27	0.30	0.04	14.1
127	3.3	2.8	3.1	0.4	11.6	0.72	0.77	0.75	0.04	4.7
128	6.9	6.9	6.9	0.0	0.0	0.13	0.23	0.18	0.07	39.3
129	3.6	3.3	3.5	0.2	6.1	0.54	0.52	0.53	0.01	2.7
130	5.3	4.8	5.1	0.4	7.0	0.32	0.34	0.33	0.01	4.3
131	3.5	3.9	3.7	0.3	7.6	0.67	0.76	0.72	0.06	8.9
132	6.0	5.8	5.9	0.1	2.4	0.33	0.40	0.37	0.05	13.6
133	3.4	3.0	3.2	0.3	8.8	0.39	0.41	0.40	0.01	3.5
134	6.1	5.0	5.6	0.8	14.0	0.43	0.40	0.42	0.02	5.1
135	4.1	4.2	4.2	0.1	1.7	0.75	0.75	0.75	0.00	0.0
136	5.7	6.1	5.9	0.3	4.8	0.35	0.29	0.32	0.04	13.3
137	3.5	3.0	3.3	0.4	10.9	0.63	0.45	0.54	0.13	23.6
138	5.1	5.4	5.3	0.2	4.0	0.22	0.24	0.23	0.01	6.1
139	3.5	3.7	3.6	0.1	3.9	0.66	0.69	0.68	0.02	3.1
140	6.9	7.4	7.2	0.4	4.9	0.16	0.18	0.17	0.01	8.3
141	3.0	3.2	3.1	0.1	4.6	0.34	0.41	0.38	0.05	13.2
142	6.2	5.9	6.1	0.2	3.5	0.21	0.24	0.23	0.02	9.4
143	4.5	4.8	4.7	0.2	4.6	0.68	0.68	0.68	0.00	0.0
144	7.0	7.7	7.4	0.5	6.7	0.18	0.34	0.26	0.11	43.5

Note: STD = standard deviation, COV = coefficient of variation.

Table C-4. Average fixed-focus optical microscope measurements.

Mix #	Modified ASTM C457 (Chords longer than 30 microns)						ASTM C457 (All chords)					
	Air (%)		S.F. (in.)		S.S. (in. ⁻¹)		Air (%)		S.F. (in.)		S.S. (in. ⁻¹)	
	Avg.	STD	Avg.	STD	Avg.	STD	Avg.	STD	Avg.	STD	Avg.	STD
1	2.04	0.10	0.022	0.003	325	18	2.27	0.37	0.014	0.004	521	94
2	5.48	0.36	0.009	0.001	521	43	5.77	0.26	0.007	0.000	686	30
3	2.98	0.36	0.019	0.003	323	28	3.09	0.41	0.012	0.003	531	114
4	4.19	NA	0.009	NA	523	NA	4.55	NA	0.005	NA	983	NA
5	2.95	0.37	0.019	0.000	340	20	3.05	0.37	0.012	0.000	536	41
6	3.90	0.41	0.009	0.002	605	66	4.02	0.44	0.006	0.003	757	76
7	2.39	NA	0.013	NA	511	NA	2.46	NA	0.010	NA	668	NA
8	5.36	0.57	0.009	0.001	538	91	5.57	0.59	0.007	0.001	696	140
9	2.54	0.88	0.022	0.010	310	124	2.83	0.67	0.016	0.009	462	244
10	3.07	0.40	0.015	0.002	399	43	3.31	0.37	0.009	0.002	691	127
11	2.59	0.45	0.023	0.009	307	94	2.93	0.68	0.013	0.015	1,059	729
12	3.93	0.85	0.011	0.001	495	23	4.08	0.88	0.008	0.001	699	25
13	2.49	0.78	0.019	0.004	366	58	2.57	0.78	0.012	0.002	554	74
14	4.56	NA	0.007	NA	671	NA	5.01	NA	0.005	NA	864	NA
15	3.16	0.31	0.017	0.005	368	84	3.3	0.37	0.010	0.003	605	145
16	5.30	0.48	0.010	0.001	516	66	5.62	0.54	0.007	0.001	686	61
17	3.78	0.57	0.017	0.005	325	51	3.89	0.61	0.011	0.003	495	69
18	5.04	0.22	0.010	0.003	572	196	5.41	0.45	0.006	0.002	800	160
19	2.91	0.96	0.018	0.004	356	64	2.98	0.99	0.013	0.003	480	66
20	5.45	0.07	0.007	0.001	678	76	5.68	0.04	0.005	0.001	874	107
21	2.36	NA	0.013	NA	483	NA	2.67	NA	0.011	NA	584	NA
22	6.31	0.99	0.008	0.000	584	69	7	0.27	0.004	0.003	754	112
23	3.10	0.74	0.020	0.003	315	43	3.18	0.76	0.014	0.003	450	84
24	5.01	NA	0.009	NA	516	NA	5.21	NA	0.006	NA	726	NA
25	4.03	0.35	0.016	0.004	363	97	4.1	0.35	0.012	0.002	455	99
26	5.76	0.33	0.008	0.000	569	15	6.1	0.29	0.005	0.000	899	84
27	3.81	0.13	0.014	0.003	399	66	3.95	0.2	0.009	0.003	610	137
28	5.76	NA	0.009	NA	462	NA	5.97	NA	0.006	NA	665	NA
29	2.51	0.43	0.022	0.004	325	79	2.54	0.43	0.018	0.004	409	114
30	5.58	NA	0.008	NA	561	NA	6.05	NA	0.006	NA	691	NA
31	2.61	0.35	0.017	0.001	404	48	2.7	0.31	0.011	0.002	625	142
32	5.42	NA	0.007	NA	597	NA	5.61	NA	0.006	NA	772	NA
33	3.56	NA	0.014	NA	376	NA	3.77	NA	0.011	NA	478	NA
34	4.36	0.76	0.010	0.002	549	99	4.61	0.83	0.006	0.002	846	236
35	2.30	1.11	0.019	0.005	371	10	2.42	1.19	0.014	0.001	554	66
36	4.16	1.39	0.010	0.002	556	30	4.89	0.93	0.004	0.002	1,638	777
37	2.39	NA	0.017	NA	401	NA	2.48	NA	0.012	NA	635	NA
38	6.06	0.11	0.014	0.001	335	18	6.17	0.09	0.010	0.001	445	36
39	3.12	NA	0.016	NA	287	NA	3.35	NA	0.008	NA	363	NA

Mix #	Modified ASTM C457 (Chords longer than 30 microns)						ASTM C457 (All chords)					
	Air (%)		S.F. (in.)		S.S. (in. ⁻¹)		Air (%)		S.F. (in.)		S.S. (in. ⁻¹)	
	Avg.	STD	Avg.	STD	Avg.	STD	Avg.	STD	Avg.	STD	Avg.	STD
40	6.04	NA	0.016	NA	378	NA	6.12	NA	0.013	NA	770	NA
41	3.01	0.21	0.013	0.001	632	56	3.35	0.23	0.005	0.000	1,074	71
42	4.29	0.84	0.009	0.002	513	43	4.66	0.93	0.005	0.001	1,123	43
43	3.80	0.34	0.018	0.006	180	150	4.16	0.7	0.010	0.002	554	56
44	7.15	1.12	0.009	0.003	442	38	7.51	1.05	0.005	0.001	742	102
45	4.59	1.65	0.010	0.000	516	66	4.72	1.65	0.008	0.000	678	124
46	4.78	0.18	0.010	0.003	523	81	5.21	0.15	0.006	0.000	937	8
47	3.89	1.46	0.013	0.007	409	198	4.17	1.6	0.006	0.004	828	234
48	6.20	NA	0.007	NA	607	NA	6.54	NA	0.004	NA	876	NA
49	4.07	0.40	0.014	0.003	378	58	4.28	0.37	0.008	0.001	653	71
50	5.44	NA	0.010	NA	437	NA	5.74	NA	0.006	NA	742	NA
51	2.22	0.21	0.033	0.003	216	23	2.26	0.2	0.024	0.005	310	69
52	5.17	NA	0.006	NA	762	NA	5.86	NA	0.003	NA	1,382	NA
53	2.51	0.41	0.019	0.004	353	117	2.59	0.33	0.010	0.002	559	323
54	3.92	0.30	0.012	0.001	475	33	4.04	0.34	0.009	0.001	617	18
55	4.22	NA	0.019	NA	274	NA	4.39	NA	0.010	NA	541	NA
56	4.48	0.64	0.013	0.002	394	20	4.66	0.61	0.008	0.000	622	56
57	2.34	0.07	0.024	0.005	290	64	2.41	0.11	0.012	0.000	462	145
58	4.38	NA	0.008	NA	579	NA	4.53	NA	0.003	NA	737	NA
59	3.02	0.28	0.024	0.001	257	20	3.08	0.27	0.017	0.001	371	46
60	5.34	1.10	0.009	0.002	538	51	5.61	1.18	0.006	0.002	800	64
61	2.95	NA	0.021	NA	272	NA	3.13	NA	0.015	NA	386	NA
62	4.84	0.36	0.010	0.000	531	28	4.98	0.36	0.007	0.000	704	58
63	2.27	0.32	0.025	0.001	290	23	2.34	0.36	0.016	0.006	472	142
64	4.90	NA	0.010	NA	505	NA	5.19	NA	0.006	NA	818	NA
65	4.13	0.23	0.014	0.001	282	193	4.48	0.33	0.006	0.001	579	48
66	5.38	0.55	0.012	0.001	386	10	5.53	0.51	0.008	0.000	861	119
67	4.93	0.08	0.020	0.000	254	3	5.64	0.15	0.004	0.000	1,123	79
68	6.58	0.12	0.006	0.001	635	28	7.16	0.09	0.004	0.001	1,057	168
69	2.23	0.31	0.020	0.001	358	23	2.27	0.3	0.015	0.001	467	58
70	3.31	0.91	0.016	0.000	389	76	3.43	0.85	0.010	0.003	612	226
71	4.42	NA	0.012	NA	462	NA	4.65	NA	0.007	NA	734	NA
72	5.76	1.20	0.007	0.001	643	84	6.22	1.02	0.004	0.001	1,074	318
73	3.98	0.42	0.011	0.001	511	56	4.13	0.43	0.008	0.001	696	71
74	6.37	1.28	0.006	0.002	688	114	7.01	1.49	0.003	0.001	1,186	211
75	3.61	0.39	0.019	0.003	315	46	3.83	0.46	0.009	0.002	665	137
76	6.51	NA	0.006	NA	592	NA	6.92	NA	0.004	NA	922	NA
77	3.47	0.48	0.017	0.001	353	69	3.55	0.48	0.012	0.001	498	102
78	4.44	0.44	0.014	0.001	373	18	4.58	0.46	0.010	0.002	554	114
79	3.15	0.80	0.012	0.002	503	13	3.41	0.79	0.006	0.000	945	112
80	5.56	NA	0.007	NA	582	NA	5.9	NA	0.004	NA	820	NA

Mix #	Modified ASTM C457 (Chords longer than 30 microns)						ASTM C457 (All chords)					
	Air (%)		S.F. (in.)		S.S. (in. ⁻¹)		Air (%)		S.F. (in.)		S.S. (in. ⁻¹)	
	Avg.	STD	Avg.	STD	Avg.	STD	Avg.	STD	Avg.	STD	Avg.	STD
81	3.59	1.12	0.024	0.001	246	20	3.65	1.14	0.016	0.002	356	33
82	5.62	NA	0.012	NA	401	NA	5.89	NA	0.008	NA	511	NA
83	3.26	0.95	0.015	0.005	394	69	3.51	1.08	0.007	0.003	805	145
84	4.19	1.10	0.015	0.005	358	58	4.36	1.2	0.010	0.004	551	104
85	3.37	0.24	0.018	0.004	315	91	3.45	0.2	0.013	0.004	457	163
86	4.20	0.42	0.020	0.001	262	28	4.44	0.31	0.011	0.005	556	315
87	3.25	NA	0.021	NA	274	NA	3.34	NA	0.013	NA	442	NA
88	3.82	0.97	0.020	0.008	315	99	3.93	1.01	0.012	0.004	475	94
89	2.90	0.55	0.016	0.005	356	23	3.38	0.52	0.009	0.008	445	30
90	5.10	0.18	0.013	0.000	389	99	5.18	0.19	0.011	0.000	973	544
91	4.13	0.61	0.012	0.003	455	81	4.38	0.61	0.007	0.002	798	226
92	6.40	NA	0.008	NA	493	NA	6.63	NA	0.006	NA	673	NA
93	2.03	NA	0.019	NA	363	NA	2.08	NA	0.014	NA	493	NA
94	4.84	0.98	0.010	0.002	511	58	5.12	0.9	0.006	0.000	871	150
95	4.20	0.52	0.013	0.003	429	48	4.47	0.56	0.006	0.001	815	36
96	5.05	0.35	0.012	0.002	394	61	5.35	0.5	0.007	0.002	726	208
97	2.98	0.71	0.017	0.006	409	104	3.09	0.77	0.011	0.004	594	157
98	6.11	0.17	0.007	0.000	693	8	6.55	0.28	0.004	0.001	1,041	97
99	3.32	0.40	0.024	0.002	249	8	3.4	0.48	0.016	0.007	396	150
100	5.45	0.37	0.013	0.004	394	117	5.62	0.37	0.008	0.002	564	112
101	2.47	0.77	0.027	0.003	254	41	2.52	0.73	0.018	0.006	417	203
102	5.23	1.63	0.010	0.005	495	132	5.5	1.86	0.007	0.004	744	279
103	3.75	0.85	0.015	0.003	378	43	3.89	0.85	0.009	0.001	594	8
104	5.49	0.22	0.009	0.001	518	58	5.8	0.02	0.006	0.002	838	226
105	1.95	0.17	0.023	0.006	345	79	2.04	0.19	0.013	0.005	610	218
106	6.04	0.29	0.006	0.002	676	81	6.4	0.29	0.004	0.001	960	81
107	3.85	0.96	0.016	0.005	363	74	3.97	1	0.010	0.002	551	53
108	2.90	NA	0.019	NA	330	NA	3.04	NA	0.010	NA	607	NA
109	3.15	0.41	0.017	0.005	381	135	3.32	0.36	0.011	0.006	711	470
110	3.60	0.17	0.010	0.004	592	170	3.8	0.2	0.006	0.002	892	165
111	2.97	0.14	0.020	0.000	320	8	3.09	0.09	0.012	0.004	577	173
112	4.48	1.41	0.009	0.005	902	NA	4.96	1.84	0.005	0.003	1,593	NA
113	2.37	0.23	0.023	0.005	307	64	2.42	0.24	0.016	0.003	439	56
114	5.40	NA	0.010	NA	480	NA	5.57	NA	0.007	NA	653	NA
115	4.26	0.12	0.013	0.005	409	130	4.38	0.21	0.010	0.004	561	201
116	6.97	NA	0.004	NA	688	NA	7.42	NA	0.003	NA	925	NA
117	2.71	0.99	0.013	0.002	526	79	2.85	0.96	0.007	0.002	681	124
118	3.79	0.39	0.011	0.002	513	147	3.9	0.4	0.008	0.001	902	323
119	1.72	NA	0.017	NA	467	NA	1.82	NA	0.010	NA	803	NA
120	5.33	NA	0.010	NA	478	NA	5.82	NA	0.005	NA	998	NA
121	2.89	0.28	0.019	0.001	323	28	3.01	0.37	0.014	0.000	434	43

Mix #	Modified ASTM C457 (Chords longer than 30 microns)						ASTM C457 (All chords)					
	Air (%)		S.F. (in.)		S.S. (in. ⁻¹)		Air (%)		S.F. (in.)		S.S. (in. ⁻¹)	
	Avg.	STD	Avg.	STD	Avg.	STD	Avg.	STD	Avg.	STD	Avg.	STD
122	3.71	0.37	0.011	0.002	513	79	3.92	0.36	0.007	0.000	818	74
123	3.62	0.08	0.020	0.008	300	102	3.72	0.16	0.013	0.007	472	226
124	5.47	1.00	0.010	0.002	445	5	5.56	0.87	0.006	0.002	678	33
125	2.95	0.61	0.017	0.003	371	56	3.17	0.71	0.010	0.002	615	155
126	4.51	0.07	0.009	0.001	533	10	4.66	0.15	0.007	0.000	693	76
127	3.06	NA	0.021	NA	290	NA	3.14	NA	0.014	NA	442	NA
128	5.27	0.70	0.007	0.001	671	69	5.6	0.71	0.005	0.000	1,011	74
129	2.49	0.37	0.017	0.002	401	97	2.55	0.32	0.012	0.004	556	221
130	3.64	NA	0.010	NA	610	NA	3.92	NA	0.006	NA	1,019	NA
131	2.56	0.70	0.025	0.001	272	18	2.61	0.73	0.017	0.003	399	25
132	6.05	0.14	0.009	0.002	493	13	6.57	0.44	0.005	0.001	775	5
133	3.28	0.72	0.016	0.000	361	33	3.38	0.76	0.011	0.001	521	5
134	4.62	0.89	0.012	0.002	406	71	4.81	0.91	0.010	0.004	549	213
135	3.36	0.04	0.018	0.003	320	43	3.42	0.04	0.013	0.001	439	13
136	4.59	0.83	0.010	0.005	511	112	5.46	1.74	0.005	0.003	851	145
137	3.06	NA	0.014	NA	373	NA	3.55	NA	0.011	NA	505	NA
138	4.94	1.15	0.008	0.004	594	114	5.76	2.06	0.005	0.003	879	196
139	3.76	NA	0.012	NA	457	NA	3.93	NA	0.007	NA	709	NA
140	6.21	0.76	0.008	0.003	584	127	6.52	0.99	0.005	0.003	826	272
141	2.51	NA	0.020	NA	320	NA	2.54	NA	0.016	NA	389	NA
142	4.57	0.42	0.009	0.001	541	48	4.79	0.46	0.006	0.001	790	28
143	4.55	0.25	0.015	0.000	348	18	4.71	0.33	0.009	0.002	556	114
144	6.38	1.68	0.006	0.001	752	36	6.82	1.86	0.004	0.001	1085	18

Note: S.F. = spacing factor, S.S. = specific surface.

Correlation Between SAM Number and Fresh Air Content: General

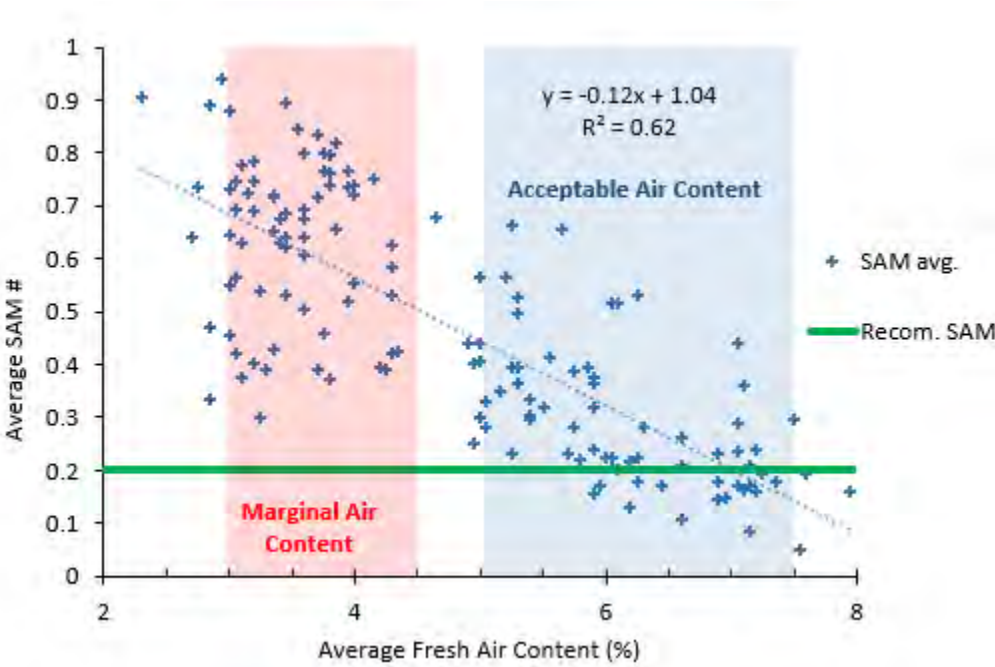
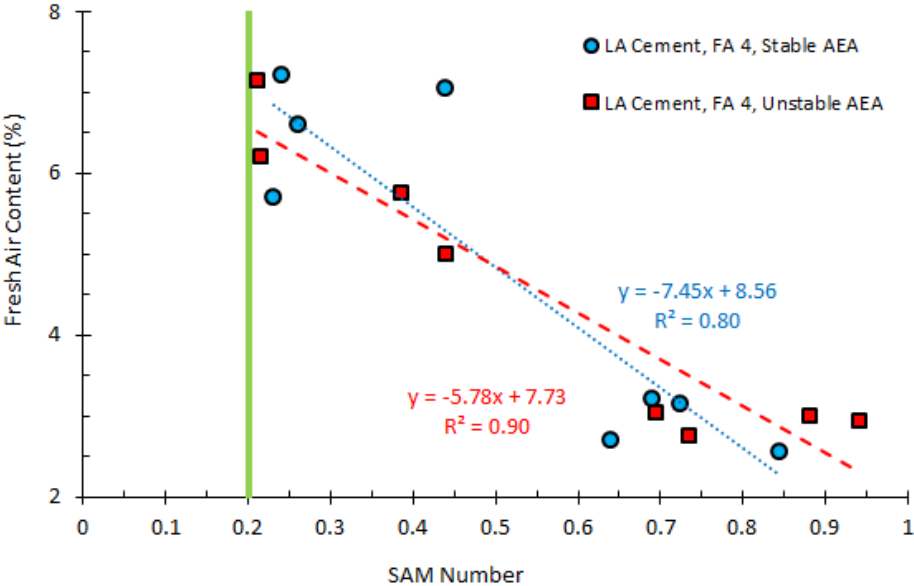


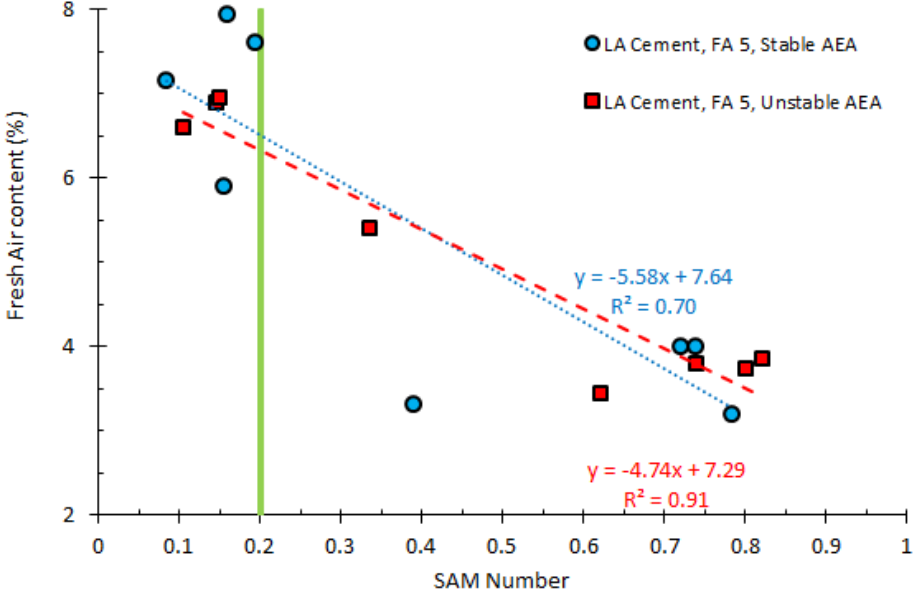
Figure C-1. Correlation between SAM number and fresh air content.

SAM Number vs. Fresh Air Content: Effect of Concrete Mixture Properties



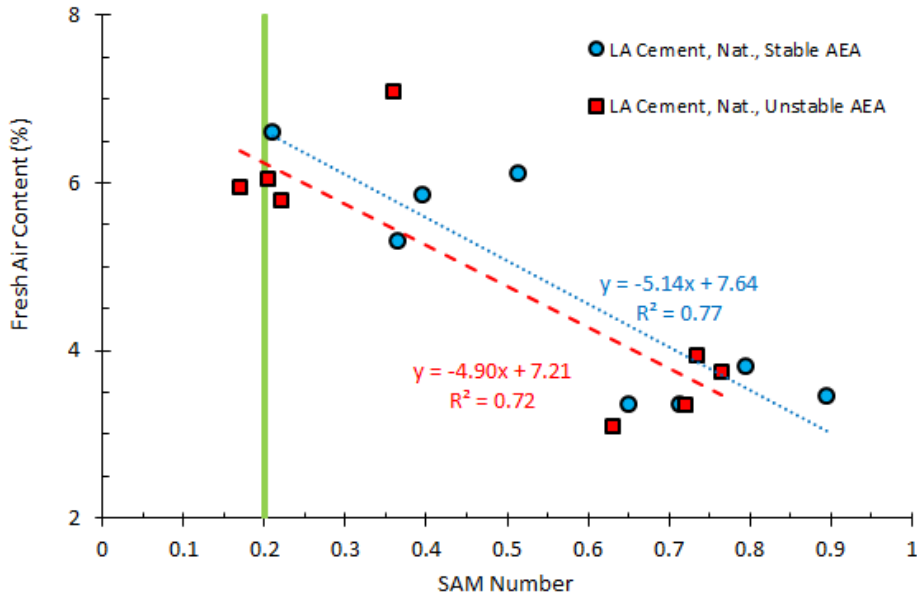
Note: AEA = air-entraining agent, LA = low-alkali.

Figure C-2. Correlation between SAM number and fresh air content for concrete made with low-alkali cement and low-quality fly ash (FA 4).



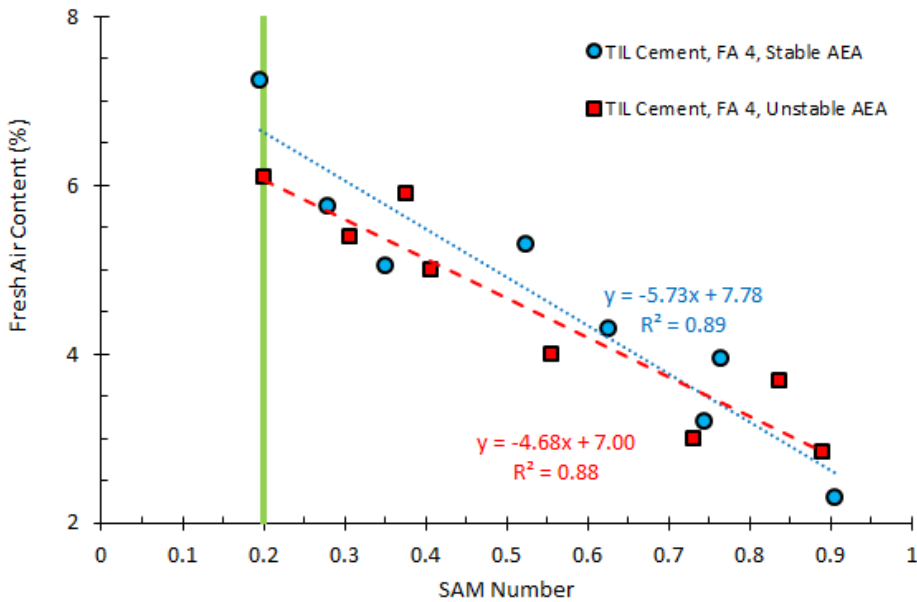
Note: AEA = air-entraining agent, LA = low-alkali.

Figure C-3. Correlation between SAM number and fresh air content for concrete made with low-alkali cement and high-quality fly ash (FA 5).



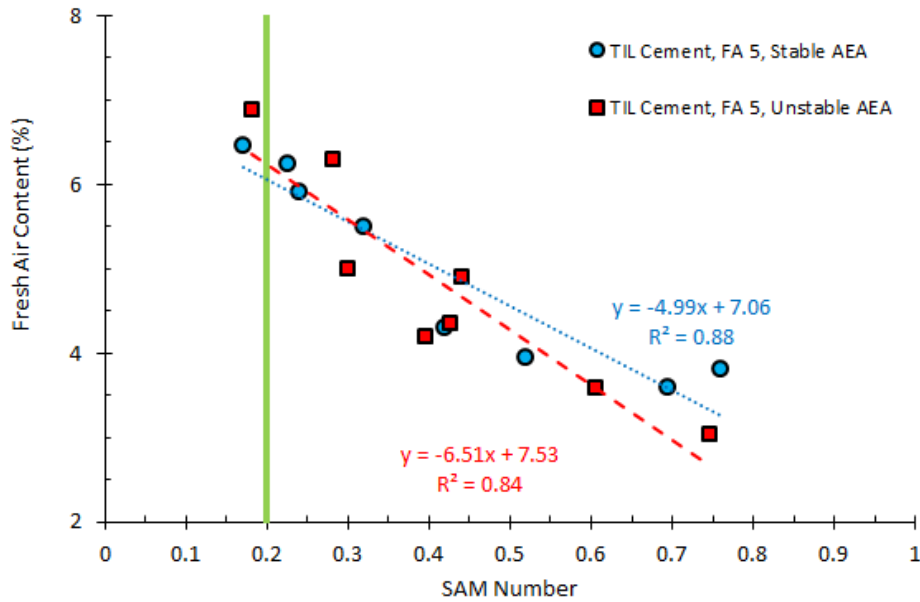
Note: AEA = air-entraining agent, LA = low-alkali, Nat. = natural pozzolan.

Figure C-4. Correlation between SAM number and fresh air content for concrete made with low-alkali cement and natural pozzolan.



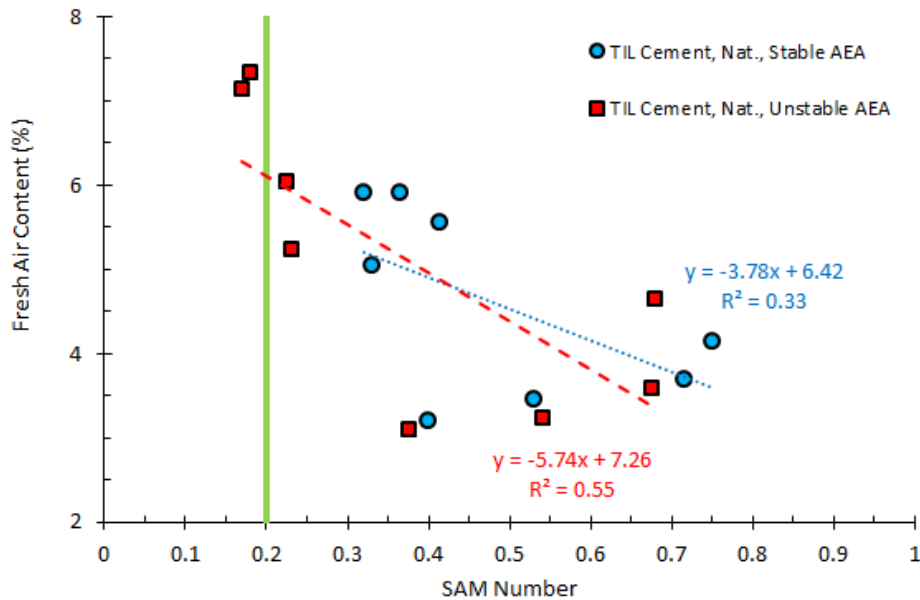
Note: AEA = air-entraining agent, TIL = Type IL portland-limestone.

Figure C-5. Correlation between SAM number and fresh air content for concrete made with TIL cement and low-quality fly ash (FA 4).



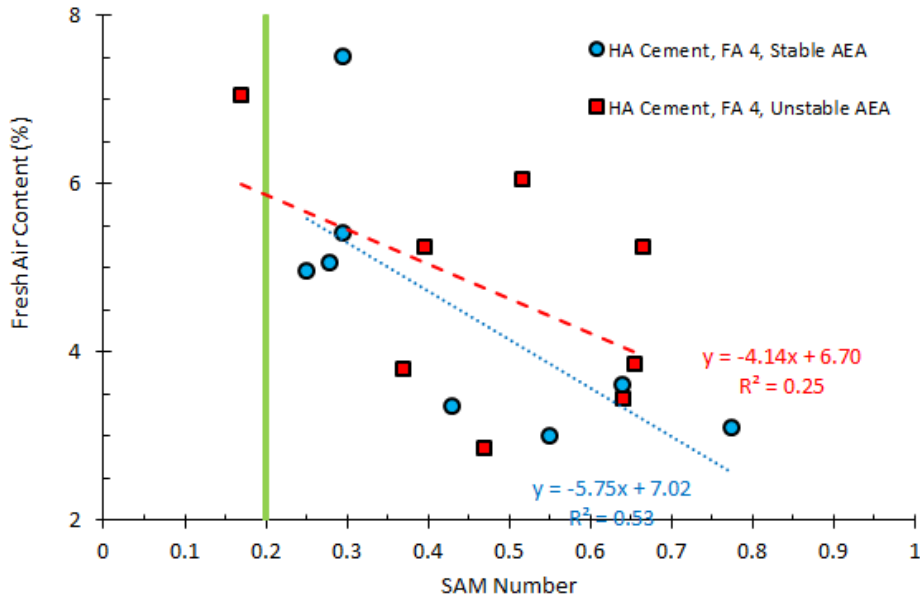
Note: AEA = air-entraining agent, TIL = Type IL portland-limestone.

Figure C-6. Correlation between SAM number and fresh air content for concrete made with TIL cement and high-quality fly ash (FA 5).



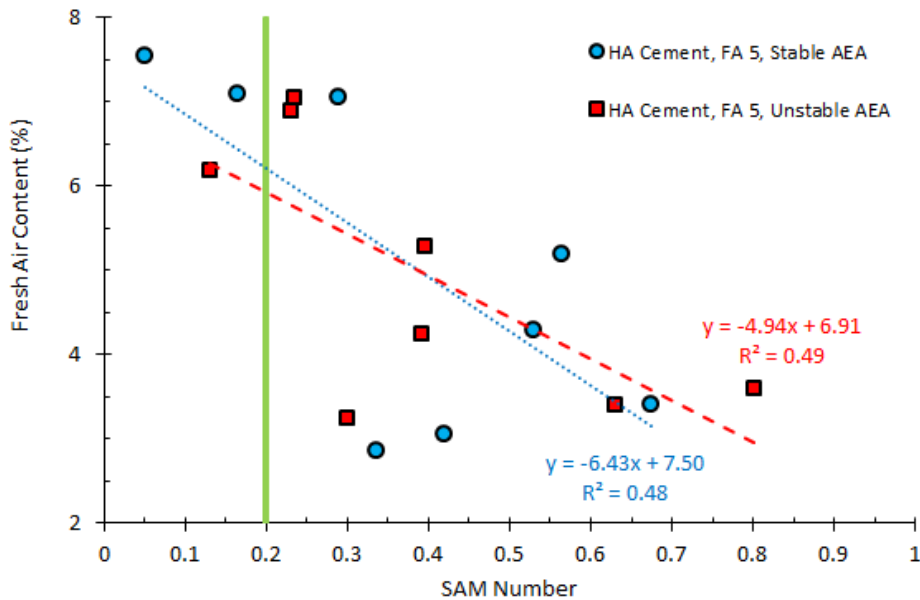
Note: AEA = air-entraining agent, TIL = Type IL portland-limestone.

Figure C-7. Correlation between SAM number and fresh air content for concrete made with TIL cement and natural pozzolan.



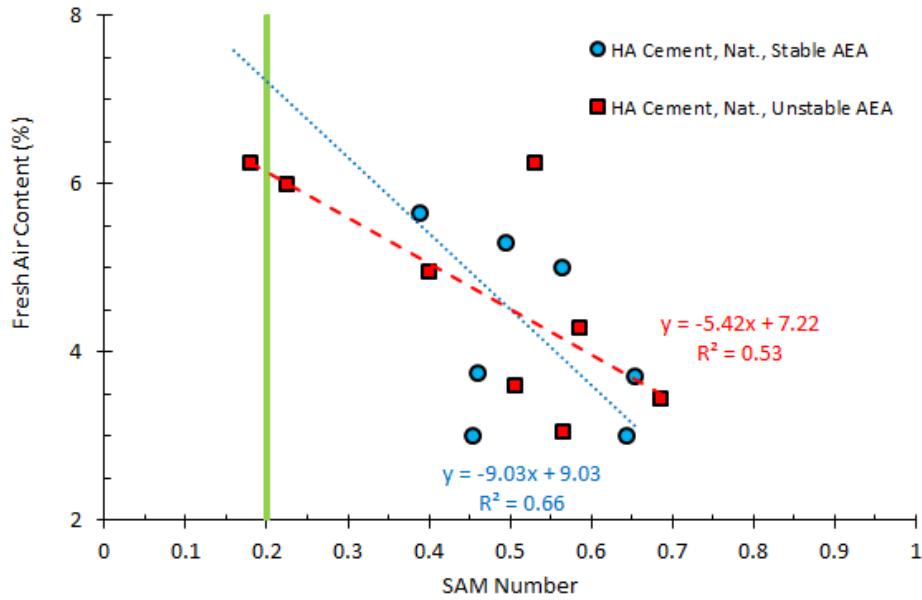
Note: AEA = air-entraining agent, HA = high-alkali.

Figure C-8. Correlation between SAM number and fresh air content for concrete made with high-alkali cement and low-quality fly ash (FA 4).



Note: AEA = air-entraining agent, HA = high-alkali.

Figure C-9. Correlation between SAM number and fresh air content for concrete made with high-alkali cement and high-quality fly ash (FA 5).



Note: AEA = air-entraining agent, HA = high-alkali, Nat. = natural pozzolan.

Figure C-10. Correlation between SAM number and fresh air content for concrete made with high-alkali cement and natural pozzolan.

Fresh vs. Hardened Air Content Measurements: General

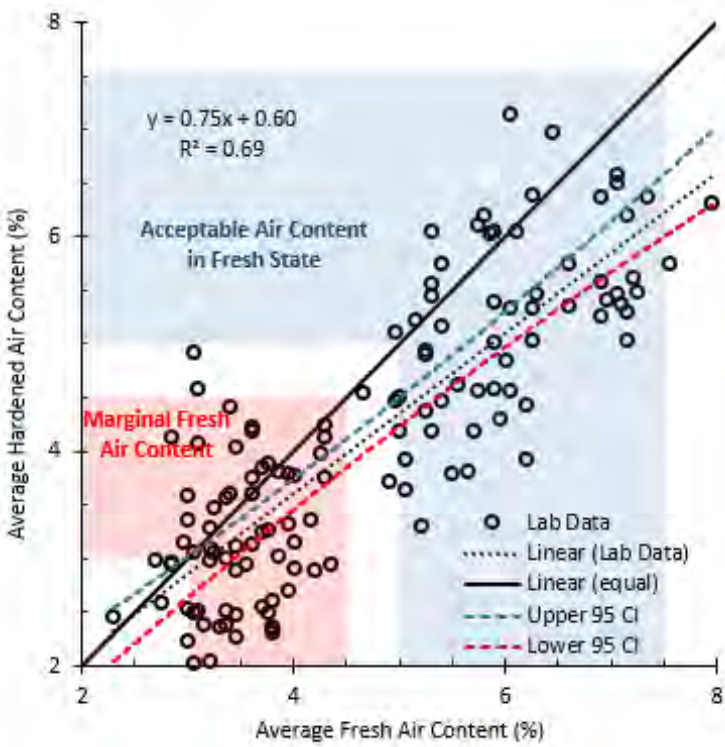


Figure C-11. Correlation between average fresh air content obtained from SAM test and data from testing hardened samples with fixed-focus optical microscope.

Fresh vs. Hardened Air Content Measurements: Effect of Concrete Mixture Properties

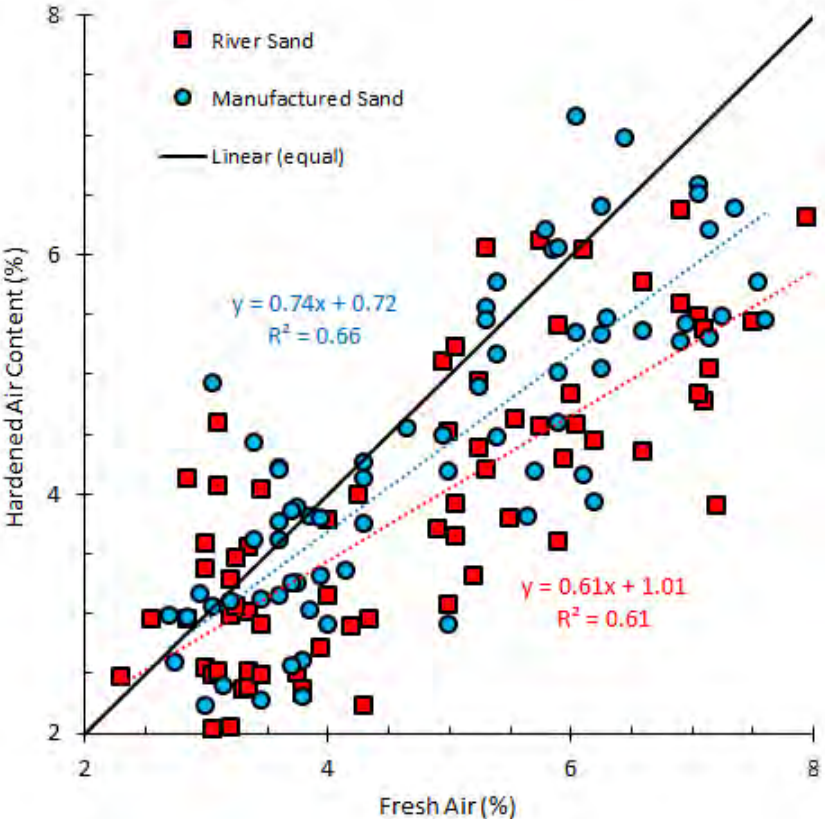
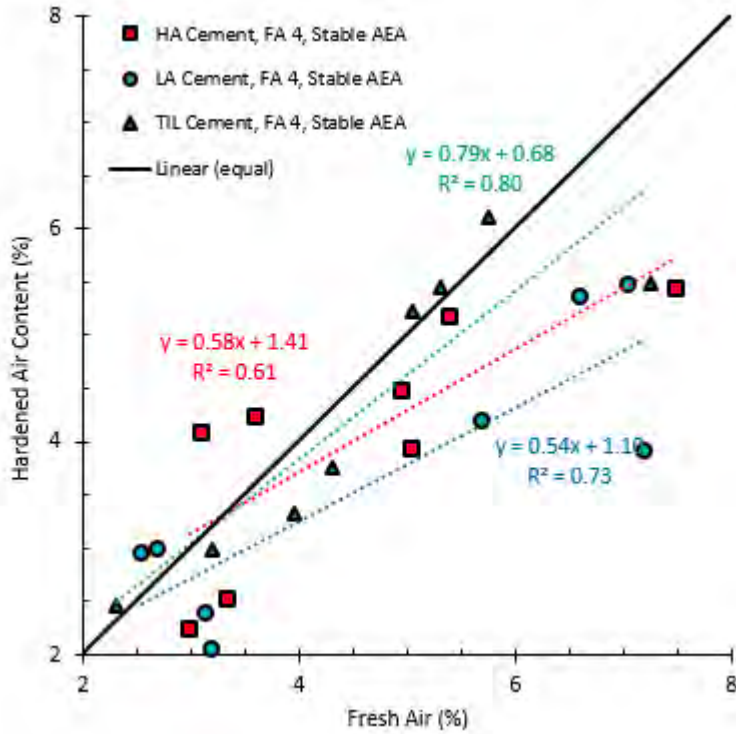
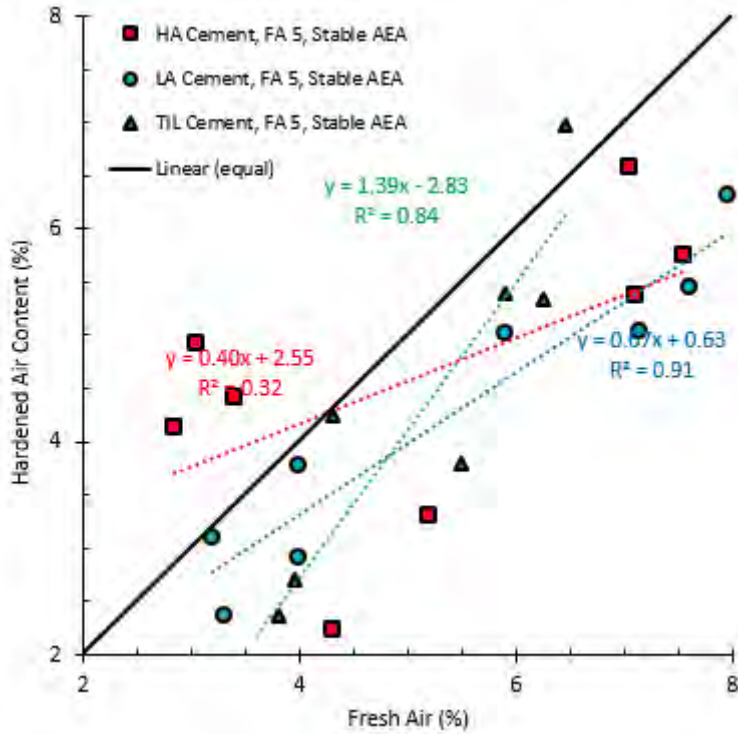


Figure C-12. Correlation between fresh and hardened air content for concrete made with natural or manufactured sand.



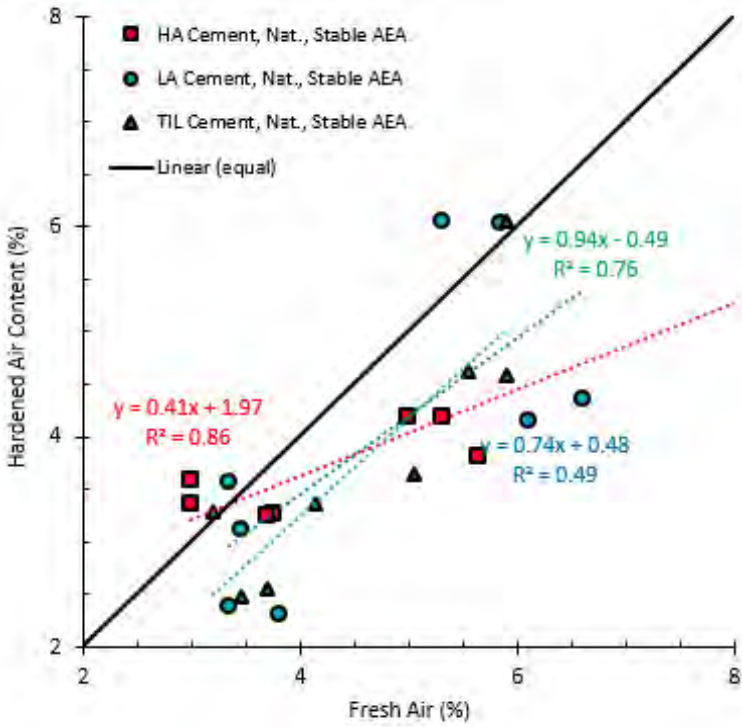
Note: AEA = air-entraining admixture; HA, LA, and TIL = high-alkali, low-alkali, and Type IL portland-limestone, respectively.

Figure C-13. Correlation between fresh and hardened air content for concrete made with stable AEA and low-quality fly ash (FA 4).



Note: AEA = air-entraining admixture; HA, LA, and TIL = high-alkali, low-alkali, and Type IL portland-limestone, respectively.

Figure C-14. Correlation between fresh and hardened air content for concrete made with stable AEA and high-quality fly ash (FA 5).



Note: AEA = air-entraining admixture; HA, LA, and TIL = high-alkali, low-alkali, and Type IL portland-limestone, respectively.

Figure C-15. Correlation between fresh and hardened air content for concrete made with stable AEA and natural pozzolan.

SAM Number vs. Spacing Factor Measurements: General

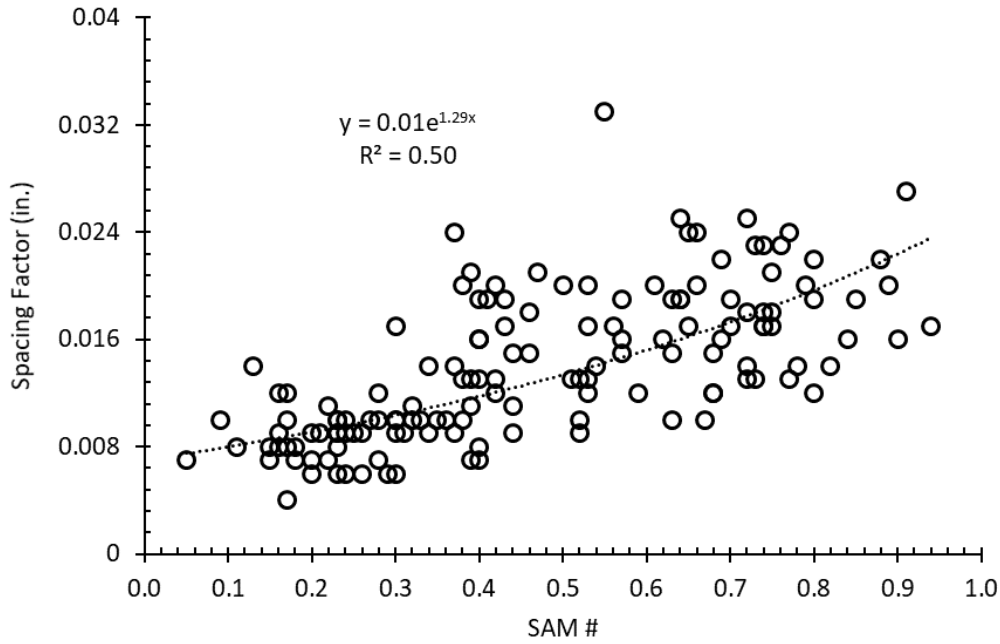


Figure C-16. Correlation between SAM number and spacing factor.

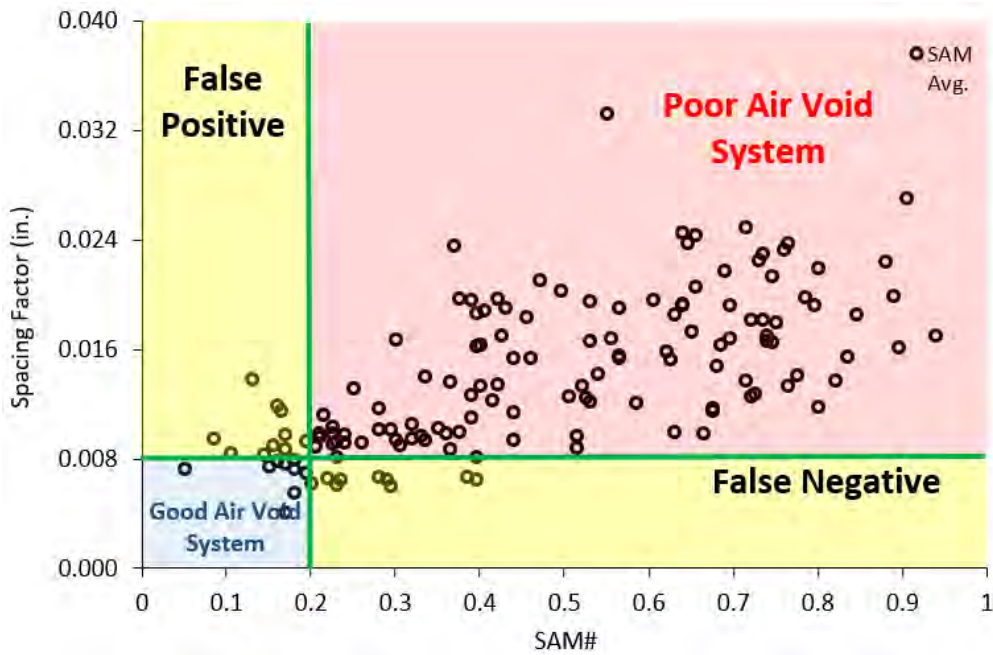


Figure C-17. Distribution of SAM number with cut-off limit of 0.20 and spacing factor with cut-off limit of 0.008 in.

SAM Number vs. Spacing Factor Measurements: Effect of Mixture Properties

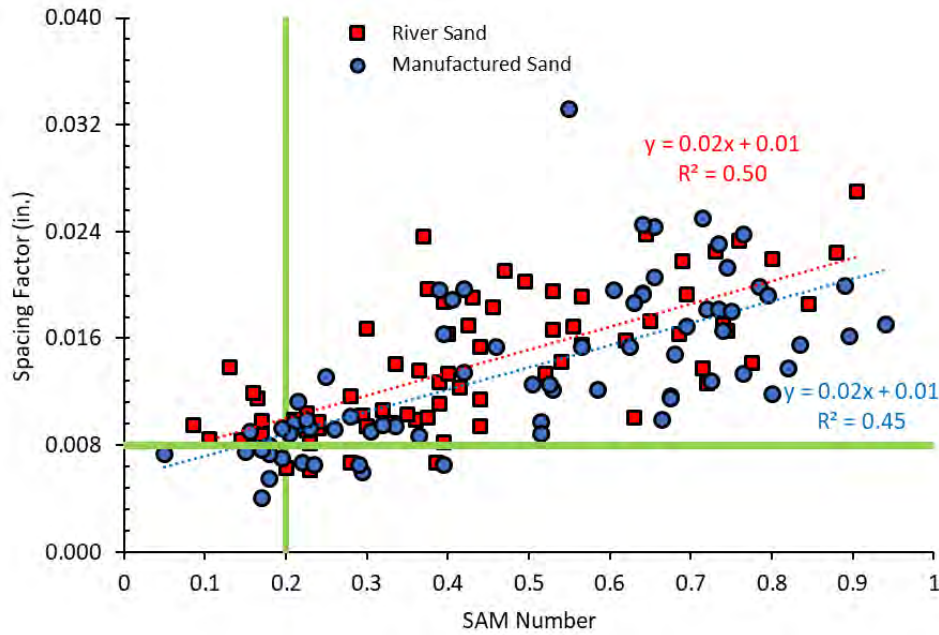
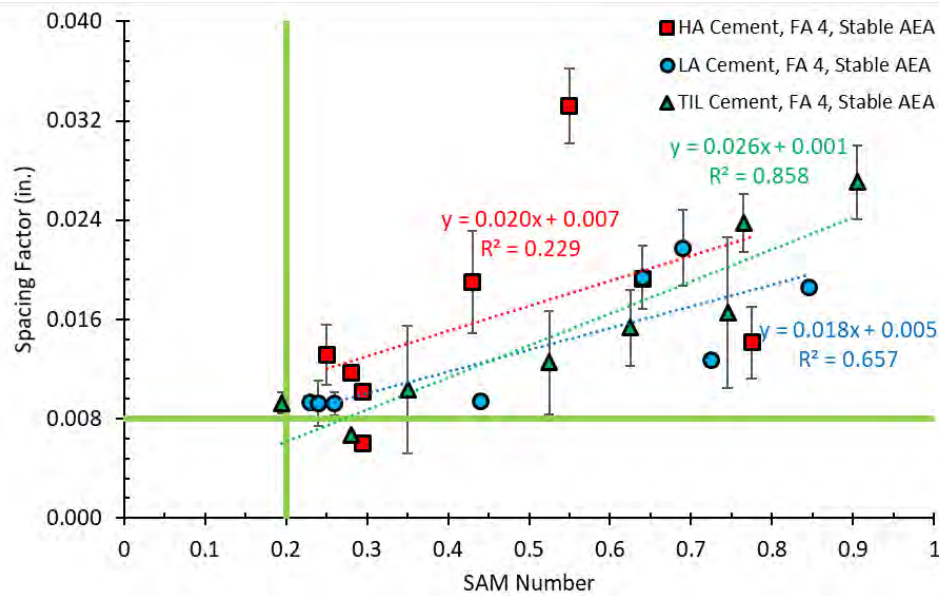
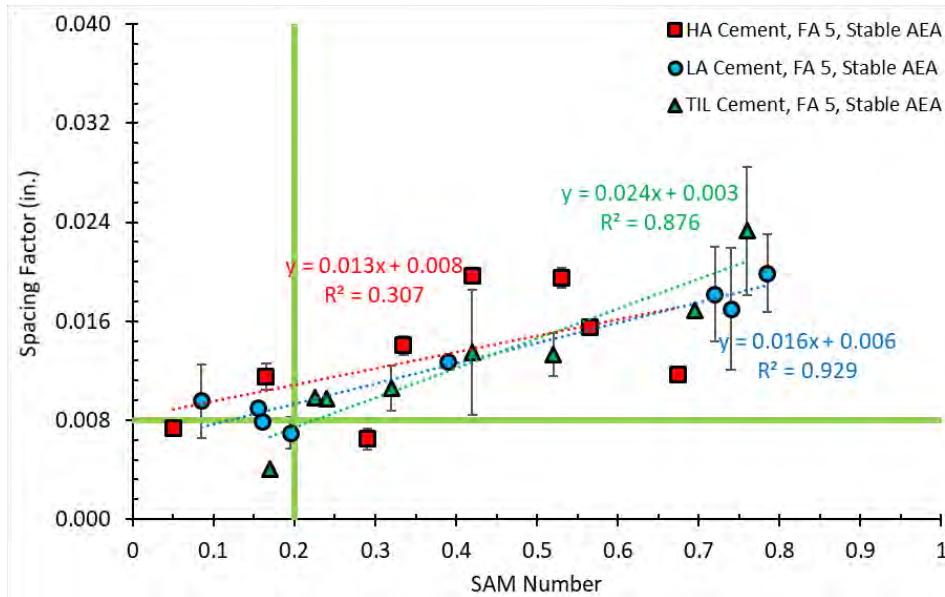


Figure C-18. Correlation between SAM number and spacing factor data for concrete made with natural or manufactured sand.



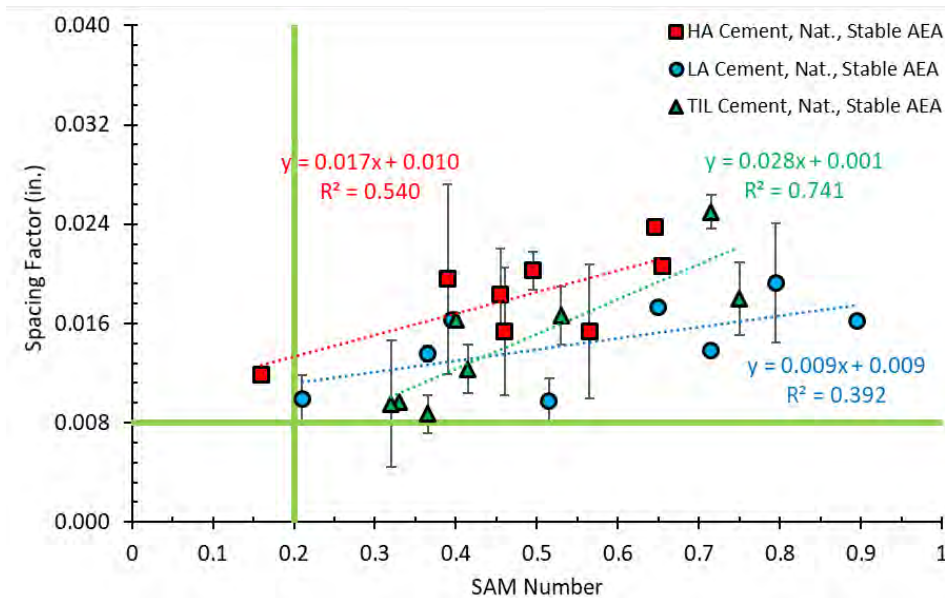
Note. AEA = air-entraining admixture; HA, LA, and TIL = high-alkali, low-alkali, and Type IL portland-limestone, respectively.

Figure C-19. Correlation between SAM number and spacing factor data for concrete made with stable AEA and low-quality fly ash (FA 4).



Note: AEA = air-entraining admixture; HA, LA, and TIL = high-alkali, low-alkali, and Type IL portland-limestone, respectively.

Figure C-20. Correlation between SAM number and spacing factor data for concrete made with stable AEA and high-quality fly ash (FA 5).



Note: AEA = air-entraining admixture; HA, LA, and TIL = high-alkali, low-alkali, and Type IL portland-limestone, respectively; Nat. = natural pozzolan.

Figure C-21. Correlation between SAM number and spacing factor data for concrete made with stable AEA and natural pozzolan.

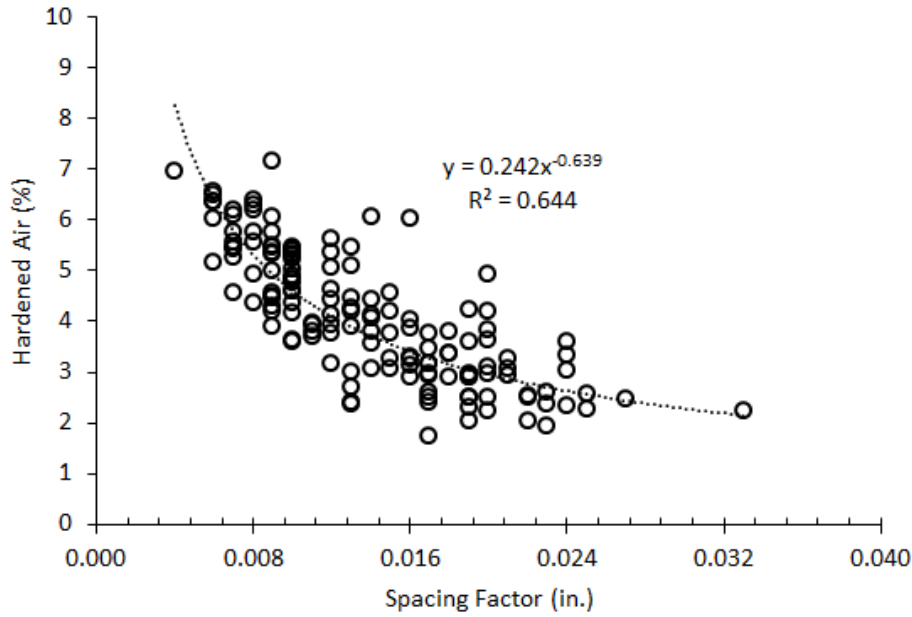


Figure C-22. Correlation between average hardened air content and spacing factors obtained using the fixed-focus optical microscope.

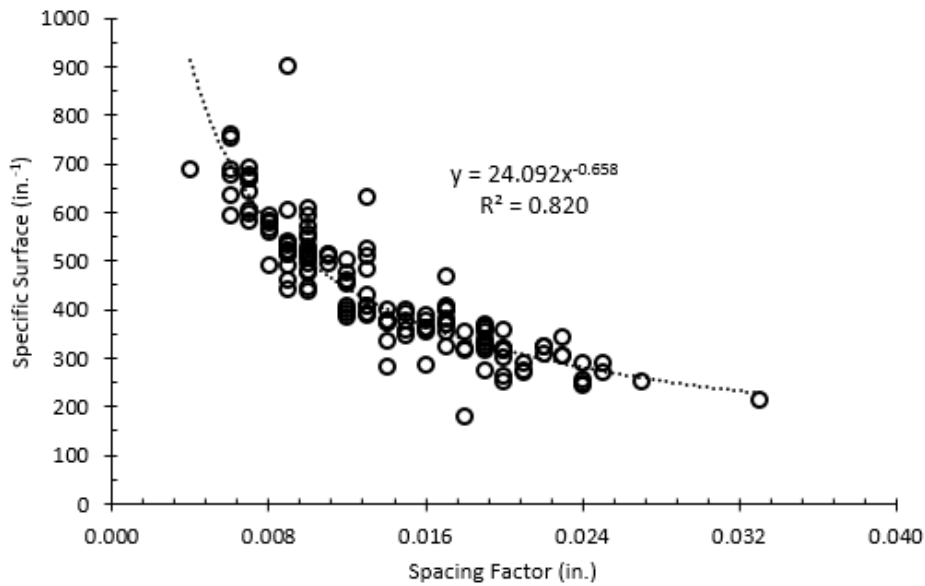


Figure C-23. Correlation between spacing factor and specific surface obtained using the fixed-focus optical microscope.