Deicer Scaling Resistance of Concrete Mixtures Containing Slag Cement

National Concrete Pavement Technology Center

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16. Abstract

Concern has been expressed about the deicer scaling resistance of concrete containing slag, especially when the dosage of slag exceeds 50% of the total cementitious material in the mixture. Much of the concern appears to be based on the results of laboratory scaling tests based on ASTM C 672, despite indications that such mixtures often perform well in the field.

The initial phase of this study showed that construction-related issues played a bigger role in the observed scaling performance than did the amount of slag in the concrete mixture. The work also indicated that the test method (ASTM C 672) may be more severe than most environments. A second phase developed an alternative laboratory test method to ASTM C 672 that would better represent the field performance of concretes, based on a method from the Canadian Quebec Ministry of Transportation.

The work described in this report was to repeat some tests using similar materials in a second laboratory to evaluate repeatability of the test methods.

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DEICER SCALING RESISTANCE OF CONCRETE MIXTURES CONTAINING SLAG CEMENT

Phase 3 Final Report
January 2014

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Finally, the researchers would also like to acknowledge the companies that supplied the materials used in the experimental work: Lafarge North America Inc. for cement and slag, Holcim (US) Inc. for cement, Holcim (US) Inc. and St Marys Cement for aggregates, and Euclid Chemical Company and BASF for chemical admixtures.

EXECUTIVE SUMMARY

Concrete containing slag cement generally exhibits good long-term strength and durability characteristics. However, concern has been expressed about the deicer scaling resistance of concrete containing slag, especially when the dosage of slag exceeds 50% of the total cementitious material in the mixture. Much of the concern appears to be based on the results of laboratory scaling tests based on ASTM C 672, despite indications that such mixtures often perform well in the field.

The initial phase of this project consisted of field surveys of portland cement concrete pavements and bridge decks containing slag cement. The surveys were conducted to evaluate whether the addition of slag cement to the concrete mixtures increased the surface scaling caused by the routine application of deicer salt. From this study, it appeared that construction-related issues played a bigger role in the observed scaling performance than did the amount of slag in the concrete mixture (Schlorholtz et al. 2008). The work also indicated that the ASTM C 672 test method may be more severe than most environments.

A second phase was undertaken to evaluate alternative test methods, including finishing and curing practices, to develop an alternative laboratory test method to ASTM C 672 that would better represent the field performance of concretes containing slag cement. A test method already in use by the Quebec Ministry of Transportation was evaluated, and several modifications were tested. As a result, a new draft test method has been proposed (Hooton et al. 2012).

The work described in this report was to repeat someof the testing using similar materials in a second laboratory to evaluate repeatability of the test methods.

INTRODUCTION

Background

Concrete containing slag cement generally exhibits good long-term strength and durability characteristics. However, concern has been expressed about the deicer scaling resistance of concrete containing slag, especially when the dosage of slag exceeds 50% of the total cementitious material in the mixture. Much of the concern appears to be based on the results of laboratory scaling tests based on ASTM C 672, despite indications that such mixtures often perform well in the field.

The initial phase of this project consisted of field surveys of portland cement concrete pavements and bridge decks containing slag cement. These surveys were conducted to evaluate whether the addition of slag cement to the concrete mixtures increased the surface scaling caused by the routine application of deicer salt. From this study, it appeared that construction-related issues played a bigger role in the observed scaling performance than did the amount of slag in the concrete mixture (Schlorholtz et al. 2008). The work also indicated that the ASTM C 672 test method may be more severe than most environments.

A second phase was undertaken to evaluate alternative test methods, including finishing and curing practices, to develop an alternative laboratory test method to ASTM C 672 that would better represent the field performance of concretes containing slag cement. A test method already in use by the Quebec Ministry of Transportation was evaluated, and several modifications were tested. As a result, a new draft test method has been proposed (Hooton et al. 2012).

The work described in this report was to repeat some of the testing using similar materials in a second laboratory to evaluate repeatability of the test methods.

Objective

The aim of this project is to recommend a test method that is more representative of field performance for concrete in a salt scaling environment.

WORK CONDUCTED

Materials

Cementitious materials used in this work were similar to those used in the work reported by Hooton et al. (2012). Aggregates used were local Iowa materials.

Cementitious Materials

Two ASTM Type I portland cement types were utilized: low alkali (LA) from Lafarge, Alpena, Michigan, and high alkali (HA) from Holcim, Mississauga, Ontario, Canada. Two slag cements representing ASTM C 989 Grades 100 and 120 were obtained from Lafarge, Chicago, Illinois. Results of x-ray fluorescence (XRF) analyses of the cementitious materials are presented in Table 1.

Table 1. Chemical analysis of the low and high alkali cements

	High Alkali Cement (%)	Low Alkali Cement (%)	Slag Cement G100 (%)	Slag Cement G120 (%)
SiO_2	20.15	20.39	37.40	36.81
Al_2O_3	5.44	4.71	8.98	9.66
Fe_2O_3	2.35	2.79	0.76	0.61
CaO	62.33	63.55	36.86	36.77
Na_2O	0.21	0.19	0.29	0.31
K_2O	1.2	0.5	0.40	0.35
MgO	2.44	2.6	10.60	10.03
P_2O_5	0.12	0.09	0.02	0.01
SO_3	3.54	2.44	-	-
TiO_2	0.27	0.22	0.38	0.49
SrO	0.08	0.07	0.04	0.05
Mn_2O_3	0.07	0.16	0.73	0.39
LOI	1.94	2.26	-	-

Chemical Admixtures

The air-entraining admixture (AEA) was Micro Air. The water-reducing admixture (WRA) was Glenium 7500, a polycarboxylate-based high-range water reducer.

Aggregates

The aggregates used were 1 in. crushed limestone (Table 2) and a river sand (Table 3).

Table 2. Coarse aggregate properties

Sieve Size	Cumulative percent retained by mass
1"	0.7
3/4"	17.6
1/2"	55.1
3/8"	69.8
No. 4	93.0
Pan	99.9
Relative density	2.66
Absorption %	0.77

Table 3. Fine aggregate properties

Sieve Size	Cumulative percent retained by mass
3/8 in.	0
No.4	2.5
No.8	12.2
No.16	28.6
No.30	62.7
No.50	93.0
No.100	99.7
Pan	-
F.M.	2.98
Relative density	2.68
Absorption %	0.60

Deicing Solutions

Two types of solutions were prepared for deicer scaling:

- 4 wt% $CaCl_2$ for the ASTM C 672 method
- 3 wt% NaCl for the new method

Concrete Mixtures

Matrix

The matrix of mixture variables included the following:

- Cement type, High alkali or low alkali
- Slag cement type, Grade 100 or 120
- Slag cement dosage, 0, 20, 35, and 50%
- Curing, as per ASTM C 672 or Virginia DOT (VDOT)

The fixed parameters were as follows:

- Cement content, 564 pcy (338 kg/m3)
- w/cm, 0.42
- Target air, 6 to 7%
- Target slump, 4 to 6 inches

Mixture proportions are shown in Table 4.

Batching and Mixing

Moisture content of the aggregates was determined according to ASTM C 566 prior to batching and water contents of mixtures were adjusted accordingly.

Mixtures were prepared in accordance with ASTM C 192/C 192M.

Four 11.3 in. x 11.3 in. x 3.1 in. slabs were formed and finished in plastic containers from each mix in accordance with ASTM C 672 or the new method as required. A 4 x 8 in. cylinder was prepared for hardened air void analysis.

Samples were either cured in a standard fog room (ASTM C 192) or in accordance with the VDOT accelerated procedure (7 days at 73ºF followed by 21 days at 100ºF).

Table 4. Concrete mixture proportions

Mix	Cement	Slag	Slag Dose (%)	Curing	Cement (pcy)	Slag (pcy)	Water (pcy)	Coarse (pcy)	Fine (pcy)	AEA (oz/cwt)	WRA (oz/cwt)
1	High Alkali	-	0	Standard	564	0	236	1471	1661	1.08	8.96
2	High Alkali	G100	20	Standard	451	113	236	1464	1654	1.08	8.96
3	High Alkali	G100	35	Standard	367	197	236	1460	1649	1.08	8.96
4	High Alkali	G100	50	Standard	282	282	236	1455	1644	1.08	8.96
5	High Alkali	G120	20	Standard	451	113	236	1464	1654	1.08	8.96
6	High Alkali	G120	35	Standard	367	197	236	1460	1649	1.08	8.96
7	High Alkali	G120	50	Standard	282	282	236	1455	1644	1.08	8.96
8	High-Alkali	-	0	VDOT	564	0	236	1471	1661	1.08	8.96
9	High-Alkali	G100	20	VDOT	451	113	236	1464	1654	1.08	8.96
10	High-Alkali	G100	35	VDOT	367	197	236	1460	1649	1.08	8.96
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12	High-Alkali	G120	20	VDOT	451	113	236	1464	1654	1.08	8.96
13	High-Alkali	G120	35	VDOT	367	197	236	1460	1649	1.08	8.96
14	High-Alkali	G120	50	VDOT	282	282	236	1455	1644	1.08	8.96
15	Low Alkali	-	0	Standard	564	0	236	1471	1661	1.08	8.96
16	Low Alkali	G100	20	Standard	451	113	236	1464	1654	1.08	8.96
17	Low Alkali	G100	35	Standard	367	197	236	1460	1649	1.08	8.96
18	Low Alkali	G100	50	Standard	282	282	236	1455	1644	1.08	8.96
19	Low Alkali	G120	20	Standard	451	113	236	1464	1654	1.08	8.96
20	Low Alkali	G120	35	Standard	367	197	236	1460	1649	1.08	8.96
21	Low Alkali	G120	50	Standard	282	282	236	1455	1644	1.08	8.96
22	Low Alkali	-	0	VDOT	564	0	236	1471	1661	1.08	8.96
23	Low Alkali	G100	20	VDOT	451	113	236	1464	1654	1.08	8.96
24	Low Alkali	G100	35	VDOT	367	197	236	1460	1649	1.08	8.96
25	Low Alkali	G100	50	VDOT	282	282	236	1455	1644	1.08	8.96
26	Low Alkali	G120	20	VDOT	451	113	236	1464	1654	1.08	8.96
27	Low Alkali	G120	35	VDOT	367	197	236	1460	1649	1.08	8.96
28	Low Alkali	G120	50	VDOT	282	282	236	1455	1644	1.08	8.96

Tests

The following fresh properties were determined at the time of batching:

- Air content, ASTM C 231 and using the air void analyzer (AVA)
- Slump, ASTM C 143

Hardened concrete air void analysis was conducted in accordance with ASTM C 457 on one sample from each mixture.

For each mixture, four slabs were tested according to ASTM C 672, and the other slabs were tested according to the new test method in Hooton et al. (2012). Two slabs were cured and dried in accordance with the method, while another two were cured in accordance with the VDOT accelerated method. The differences between the ASTM C 672 and new methods are shown in Table 5.

Table 5. Comparison of the scaling test methods

	ASTM C 672	**New Method**
Specimens	Surface area 72 in.^{2} Depth 3 in. 2 specimens/mix	Unchanged
Finishing	Finishing after the concrete has stopped bleeding and then brush with a medium-stiff brush	Strike off after consolidation
Curing	14 days at 100% RH + 14 days at 50% ± 5% RH	A) Plain: 14 days at 100% RH+14 days at 50% ± 5% RH B) SCM 28 days at 100% RH+14 days at 50% ± 5% RH C) 7 days at 100 RH+ 21 days at 38°C 100% RH + 14 days at 50% ± 5% RH Saturated in solution for 7 days before temperature cycling
Solution	4% $CaCl_2$	3% NaCl
Freezing and thawing cycles	50 cycles Freezing at -18 ± 3°C for 16 ± 1h Thawing at 23°C ± 2°C for 8 ± 1h	Unchanged
Evaluation of Surface quality	Every 5 cycles Visual assessment	Every 5 cycles Visual assessment as per ASTM C 672 Mass loss

RESULTS

Measured fresh properties of the 28 mixtures are shown in Table 6.

Table 6. Fresh properties of mixtures including air analyses

Mix		Slump (in.)	Unit Weight (pcf)	Air Content (%)	Spacing Factor AVA (mm^{-1})	Spacing Factor C 457 (mm^{-1})
1	Hi-0--Std	4.5	142.9	6.5	0.305	0.164
2	Hi-20-100-Std	5.5	148.0	4.0	0.444	0.225
3	Hi-35-100-Std	4.0	143.5	4.0	0.326	0.403
4	Hi-50-100-Std	5.5	148.8	7.0	0.644	0.324
5	Hi-20-120-Std	3.0	147.0	6.0	0.357	0.445
6	Hi-35-120-Std	3.5	148.4	5.5	0.391	0.341
7	Hi-50-120-Std	4.0	132.1	6.0	0.443	0.243
8	Hi-0--VA	3.0	152.4	6.5	0.235	0.150
9	Hi-20-100-VA	6.0	139.0	7.0	0.165	0.136
10	Hi-35-100-VA	7.0	139.2	6.0	0.395	0.109
11	Hi-50-100-VA	6.5	144.3	6.5	0.249	0.160
12	Hi-20-120-VA	6.0	144.5	6.5	0.290	0.166
13	Hi-35-120-VA	8.0	141.9	7.5	0.351	0.120
14	Hi-50-120-VA	9.0	145.7	5.0	0.495	0.132
15	Lo-0--Std	4.0	149.0	6.0	0.579	0.086
16	Lo-20-100-Std	7.0	147.8	6.0	0.432	0.071
17	Lo-35-100-Std	5.5	145.7	6.0	0.392	0.169
18	Lo-50-100-Std	6.5	144.3	7.0	0.351	0.110
19	Lo-20-120-Std	3.0	145.5	6.0	0.472	0.151
20	Lo-35-120-Std	5.5	144.3	7.0	0.321	0.118
21	Lo-50-120-Std	6.0	145.7	6.5	0.609	0.142
22	Lo-0--VA	6.0	142.9	7.0	0.564	0.070
23	Lo-20-100-VA	7.0	143.1	6.0	0.530	0.084
24	Lo-35-100-VA	5.0	151.2	6.0	0.650	0.052
25	Lo-50-100-VA	3.0	147.4	7.0	0.652	
26	Lo-20-120-VA	4.0	147.3	6.0	0.274	0.091
27	Lo-35-120-VA	2.5	146.8	5.0	0.480	0.154
28	Lo-50-120-VA	3.5	147.2	5.5	0.656	0.171

Results of the scaling tests are shown in Table 7. For comparison, the results reported by Hooton et al. (2012) are included for comparable mixtures.

The procedure followed in this work was based on the recommendations developed by Hooton et.al. after they completed their lab work. This means there are differences between the procedures. For the standard curing set, the mixtures containing supplementary cementitious materials (SCMs) were wet-cured by Hooton et al. for 14 days while, in this work, they were wet-cured for 28 days. For the VDOT accelerated curing set, Hooton et.al. did not dry samples between the end of the accelerated curing and the start of soaking, but omitting this step reportedly made scaling worse (Hooton, 2012).

Table 7. Scaling test results

		This report				Hooton et al. 2012	
		C 672		New		C 672	New
Mix		Mass (kg/m^2)	Visual Rating	Mass (kg/m^2)	Visual Rating	Mass (kg/m^2)	Mass (kg/m^2)
1	Hi-0--Std	391	5.0	629	5.0	1064	95
2	Hi-20-100-Std	574	5.0	636	4.0	944	986
3	Hi-35-100-Std	192	4.5	517	4.0	290	958
4	Hi-50-100-Std	317	4.5	638	4.0	2568	2662
5	Hi-20-120-Std	263	4.0	481	4.5	777	236
6	Hi-35-120-Std	517	3.0	445	2.5	546	1661
7	Hi-50-120-Std	1118	4.5	1861	5.0	637	1661
8	Hi-0--VA	286	2.5	779	2.0		3692
9	Hi-20-100-VA	351	2.0	437	3.0		934
10	Hi-35-100-VA	323	3.0	460	3.0		1013
11	Hi-50-100-VA	450	5.0	1019	5.0		1698
12	Hi-20-120-VA	155	4.0	138	4.0		761
13	Hi-35-120-VA	366	3.0	875	3.5		1018
14	Hi-50-120-VA	645	3.5	1147	4.0		1683
15	Lo-0--Std	1467	4.0	1149	4.0	170	163
16	Lo-20-100-Std	1886	5.0	1863	5.0	205	79
17	Lo-35-100-Std	815	5.0	896	5.0	527	241
18	Lo-50-100-Std	1233	4.0	2063	5.0	580	1529
19	Lo-20-120-Std	1396	5.0	2475	5.0	399	478
20	Lo-35-120-Std	1650	4.5	1822	5.0	730	1342
21	Lo-50-120-Std	1122	3.5	1761	4.0	1574	2576
22	Lo-0--VA	927	3.0	2725	5.0		487
23	Lo-20-100-VA	2671	4.0	2475	5.0		116
24	Lo-35-100-VA	1090	5.0	1719	5.0		197
25	Lo-50-100-VA	1943	5.0	1594	5.0		1221
26	Lo-20-120-VA	1213	5.0	1824	5.0		545
27	Lo-35-120-VA	870	3.0	811	3.0		1563
28	Lo-50-120-VA	1517	5.0	1956	5.0		2042

1 kg/m^2 = 0.208 lb/ft^2

DISCUSSION

Air Contents

Comparison of the air void measurements indicate the following:

- Air contents of Mixtures 2 and 3 were low, while spacing factors of Mixtures 2 through 7 were greater than 0.2 mm measured using ASTM C 457.
- There was poor correlation between AVA and C 457 spacing factor measurements.

Scaling Tests

The following observations can be made from the scaling tests:

- There is some correlation between data collected in this work using old (C 672) and the new methods for both standard and accelerated curing (Figure 1).
- There is a poor correlation between standard and accelerated curing in this work using the new method.
- Comparison between data collected in this work and that reported by Hooton et al. (2012) using either method on similar mixtures is poor (Figure 2), while the procedures used were slightly different.
- Correlation between mass loss and visual rating was generally poor.

The following is observed when comparing scaling performance with mixture parameters:

- Correlation between slag cement content and scaling performance in this work was less marked than that reported by Hooton et al. (2012).
- Increasing the spacing factor did reflect better scaling performance in both tests, although correlation was better for data from the old method.
- Correlation between air content and scaling performance was poor in all cases.

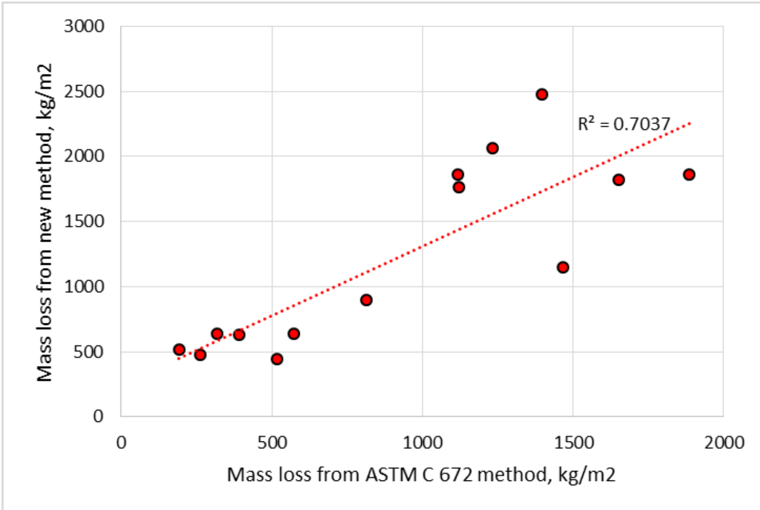

Figure 1. Comparison between data from ASTM C 672 and new test methods for standard curing

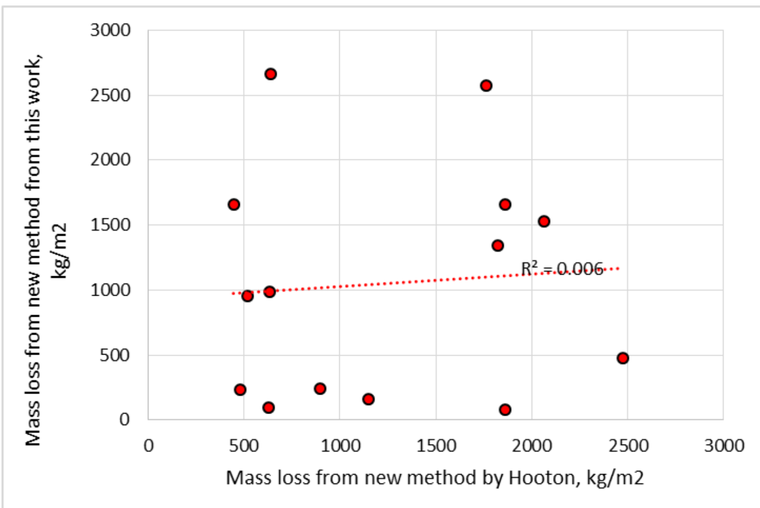

Figure 2. Comparison between data from new test method conducted in two labs for standard curing

RECOMMENDATIONS

The aim of the project, of which this work is a part, is to recommend a test method that is more representative of field performance for concrete in a salt-scaling environment.

The work described in this report was to repeat scaling tests using ASTM C 672 and a new method based on work reported by Hooton et al. (2012) to evaluate repeatability of the test methods.

The data indicate that similar trends are observed in both laboratories but correlation between them is not as good as desired.

It is recommended that the proposed test method be submitted to ASTM for acceptance as a new test method. A round-robin exercise will be needed to develop precision and bias statements. Training may be required to ensure that laboratory staff are conducting the tests as intended.

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