Investigation of the Long Term Effects of Magnesium Chloride and Other Concentrated Salt Solutions on Pavement and Structural Portland Cement Concrete

PROJECT NUMBER: SD2002-01

Submitted by:

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Quarterly Report 2

Overview

This Quarterly Report is submitted to outline the work accomplished during the reporting period 1-15-03 to 4-15-03, identify problems (current and anticipated), and to describe any deviations from the agreed Work Plan. This Quarterly Report is arranged by the Tasks described in the project Work Plan. In general, for this reporting period, progress has been made on Task 1, 2, 5 and 6.

The following is a summary of results for this reporting period

- Work has progressed on the literature review with currently over 500 papers being reviewed.
- The survey of State DOT's has been conducted and replies from 16 states have been received. These replies are being processed.
- Field samples were received from South Dakota and cataloged.
- Mixture designs for the mortar mixes to be tested have been developed.
- Tests have been conducted to determine the reproducibility of strength determinations for both cube and cylinder geometries.
- Split cylinder tests on 2" x 4" cylinders shave been determined to be the most reproducible method of testing.
- Standard procedures for mixing and testing mortar cylinders have been developed.

<u>Task Report</u>

Task 1: Literature Review

To date over 500 papers on topics related to deicing chemicals and their effect on concrete have been assembled. Current work involves reading these papers and summarizing key points from each that are relevant to this study.

Task 1 Problems and/or Deviations from Work Plan

There are no problems or deviations to report for this Task

Task 1 Completion - 30%

Task 2: Conduct Survey

A survey of States and Canadian Provinces has been conducted to assess the deicer/anti-icing practices and application strategies. The survey included questions regarding known or suspected links between deicer/anti-icing use and concrete degradation. The survey was prepared in two forms with one being an on-line WWW based form and the other a Microsoft Excel spreadsheet. Both were disseminated over the WWW. The survey was announced on the SNOW-ICE mailing list sponsored by the Iowa Institute of Hydraulic Research (IIHR) at the University of Iowa. It was also brought to the attention of the appropriate State and Provincial personnel by notification over various e-mail list servers accessible by DOT personnel. To date the following states have replied with some sending in multiple replies from different divisions: Maryland, Washington, Kansas, Iowa, Kentucky, Wyoming, Montana, Alaska, Indiana, Missouri, Idaho, Maine, Wisconsin, Oregon, Connecticut, and Minnesota. A student was recently hired and assigned the task of collating and summarizing these responses

Task 2 Problems and/or Deviations from Work Plan

There are no problems or deviations to report for this Task. The summary will be completed within the next reporting cycle

Task 2 Completion - 50%

Task 3: Site Selection

Since the last reporting period, no additional field sites have been identified for coring. The research team is still relying on substantiated reports from the participating agencies regarding possible sites that will be done only with demonstrated distress and with adequate documentation of the amount and type of deicer used.

Task 3 Problems and/or Deviations from Work Plan

There were no problems or deviations for Task 3 incurred during the reporting period.

Task 3 Completion -90%

Task 4: Meeting with Technical Panel

Task 4 Completion -100%

Task 5: Characterization of Field Specimens

Work on Task 5 has progressed only slightly as the main focus has been on initiating the laboratory study as part of Task 6. Cores from sites in South Dakota were received and cataloged. Additionally, the principal graduate student on this project has begun the process of learning how to prepare these cores for analysis by practicing with laboratory prepared specimens. The student comes with excellent metallographic and materials characterization skills and simply needs to become aware of the nuances of preparing concrete specimens. He is being trained under the guidance of an ASTM C 856 qualified petrographer, Karl Peterson.

Task 5 Problems and/or Deviations from Work Plan

There were no problems or deviations for Task 5 incurred during the reporting period.

Task 5 Completion -20%

Task 6: Laboratory Experiment

Over this reporting period, the research team has focused on developing the necessary mortar mix designs and finalizing the method of physically testing the mortar specimens after being exposed to deicing solution. As described in the modified work plan, the research team has opted to use a 2" x 4' cylinder for the specimen geometry and physically test those cylinders using ASTM C 496 "*Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens*. The rationale for this decision is that a more reproducible breaking strength can be obtained from a split tension test on a cylinder than can be obtained from mortar cubes. The wide variance in mortar cube strength is commonly thought to be associated with variances in compaction effort used in producing any series of cubes. This problem has been recognized by ASTM and modifications to ASTM C 109 have been proposed to allow for automated compaction methods and vibrating tables to compact cube specimens. The research team, as mentioned in the previous quarterly report, has investigated these new approaches but feels split tensile testing of 2' x 4" cylinders will be a low cost, effective alternative. To substantiate this, 7-day old mortar cubes and cylinders were tested using their respective test methods to assess variability. The cubes were molded and tested in accordance with ASTM C 109 "*Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens)*". The mortar cylinders were molded in accordance with ASTM C 192 "*Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory*" and they were tested in accordance with ASTM C 496 "*Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens"*. The results are presented in Appendix I in Tables A1 - A5. As can be clearly seen, the coefficient of variance for the cylinders is approximately 1/5 the variation seen for the cubes. These tests were performed on 7-day old mortars to more closely mimic the lower strengths expected from exposure to deicers. For both the molding of the cylinders and testing of the cylinders, standard procedures have been developed and these are included in Appendix II and III, respectively. The mortar mixes given in Appendix II may vary slightly as we are no scaling up from a small Hobart type mixer to a larger mixer of the same type. Final mixture designs will be included in the next quarterly report.

Task 6 Problems and/or Deviations from Work Plan

There were no problems or deviations for Task 6 incurred during the reporting period.

Task 6 Completion -5%

APPENDIX I

COMPARISON OF SPLIT TENSILE STRENGTHS AND ASTM C 109 MORTAR CUBE STRENGTHS FOR PREPARED MORTAR MIXTURES

Table A1 Results of compression strength tests for 7-day old mortar cubes.

Specimen Type - Cubes

w/c = 0.4			**w/c = 0.6**		
	Compressive Strength			**Compressive Strength**	
Mix ID	**Max (psi)**	**Max (lbf)**	**Mix ID**	**Max (psi)**	**Max (lbf)**
a	18401.2	4600.3	a	12650.4	3162.6
b	19450.4	4862.6	b	8951.4	2237.9
c	17700.5	4425.1	c	9700.5	2425.1
d	20700.8	5175.2	d	8701.7	2175.4
e	16500.4	4125.1	e	12100.7	3025.2
f	21751.8	5438.0	f	10451.5	2612.9
g	22801.0	5700.3	g	8351.4	2087.8
h	10050.9	2512.7	h	8800.4	2200.1
I	15201.6	3800.4	I	11150.3	2787.6
j	23700.0	5925.0	j	10050.9	2512.7
k	17050.0	4262.5	k	11351.6	2837.9
l	27651.7	6912.9	l	8901.1	2225.3
m	18550.3	4637.6	m	9400.5	2350.1
n	18000.6	4500.2	n	9700.5	2425.1
o	29451.8	7363.0	o	7900.4	1975.1
p	19700.1	4925.0	p	11851.0	2962.8
q	22400.3	5600.1	q	8003.0	2000.7
			r	9100.5	2275.1
	Average	4986.2	s	5951.2	1487.8
	Max	7363.0	t	7850.0	1962.5
	Min	2512.7			
	Std Dev	1145.6		**Average**	2386.5
	C of V	23.0%		**Max**	3162.6
				Min	1487.8
				Std Dev	417.6
				C of V	17.5%

Table A2 Results of compression strength tests for 7-day old mortar cubes.

Specimen Type - Cubes

w/c = 0.4

	Compressive Strength	
Mix ID	**Max (psi)**	**Max (lbf)**
a	20600.1	5150.0
b	16951.4	4237.9
c	32850.8	8212.7
d	16250.7	4062.7
e	24701.8	6175.5
f	29850.6	7462.7
g	17652.1	4413.0
h	16951.4	4237.9
I	21051.1	5262.8
j	21701.5	5425.4
k	28201.4	7050.4
	Average	5608.2
	Max	8212.7
	Min	4062.7
	Std Dev	1433.9
	C of V	25.6%

w/c = 0.6

	Compressive Strength	
Mix ID	**Max (psi)**	**Max (lbf)**
a	6750.6	1687.6
b	10650.9	2662.7
c	12751.1	3187.8
d	12151.0	3037.8
e	9102.4	2275.6
f	10451.5	2612.9
g	11851.0	2962.8
h	10250.2	2562.6
I	11800.7	2950.2
j	7050.6	1762.7
k	13701.5	3425.4
l	11001.3	2750.3
m	11651.6	2912.9
n	12900.1	3225.0
o	9650.2	2412.5
p	7551.9	1888.0
q	10350.9	2587.7
r	9201.1	2300.3
	Average	2622.5
	Max	3425.4
	Min	1687.6
	Std Dev	500.1
	C of V	19.1%

Table A3 Results of split tension tests for 7-day old mortar cylinders.

Specimen Type - Split Cylinders

w/c = 0.4			w/c = 0.6		
	Split Tensile Strength			Split Tensile Strength	
Mix ID	**Max (psi)**	**Max (lbf)**	**Mix ID**	**Max (psi)**	**Max (lbf)**
a	9301.8	740.2	a	5200.0	413.8
b	10201.8	811.8	b	5500.2	437.7
c	10050.7	799.8	c	5051.1	402.0
d	10801.9	859.6	d	5401.4	429.8
e	10250.2	815.7	e	4950.4	393.9
f	10050.9	799.8	f	5351.1	425.8
g	11001.3	875.5	g	5153.7	410.1
h	11101.9	883.5	h	5300.8	421.8
I	11351.6	903.3	I	5600.8	445.7
j	10201.8	811.8	j	4551.7	362.2
k	11301.3	899.3	k	5250.5	417.8
l	10101.2	803.8	l	5401.4	429.8
m	11350.6	903.3	m	5351.1	425.8
n	10850.3	863.4	n	4801.4	382.1
o	9450.8	752.1	o	5202.1	414.0
p	9750.8	775.9	p	5600.8	445.7
	Average	831.2		**Average**	416.1
	Max	903.3		**Max**	445.7
	Min	740.2		**Min**	362.2
	Std Dev	53.5		**Std Dev**	22.5
	C of V	6.4%		**C of V**	5.4%

Table A4 Results of split tension tests for 7-day old mortar cylinders.

Specimen Type - Split Cylinders

w/c = 0.4			**w/c = 0.6**		
	Split Tensile Strength			**Split Tensile Strength**	
Mix ID	**Max (psi)**	**Max (lbf)**	**Mix ID**	**Max (psi)**	**Max (lbf)**
a	10950.9	871.4	a	5850.5	465.6
b	11951.7	951.1	b	5602.8	445.9
c	11351.6	903.3	c	5051.1	402.0
d	11750.4	935.1	d	5401.4	429.8
e	10451.5	831.7	e	4853.7	386.2
f	10600.6	843.6	f	5751.8	457.7
g	11200.6	891.3	g	5651.1	449.7
h	10600.6	843.6	h	5302.7	422.0
I	12000.1	954.9	I	5151.7	410.0
j	12050.4	958.9	j	5457.7	434.3
k	11601.3	923.2	k	5753.7	457.9
l	11400.0	907.2	l	5651.1	449.7
m	12151.0	966.9	m	5200.1	413.8
n	11150.3	887.3	n	5500.2	437.7
			o	5000.8	397.9
	Average	905.0	p	5701.5	453.7
	Max	966.9	q	5101.4	406.0
	Min	831.7	r	5850.5	465.6
	Std Dev	45.7	s	5250.5	417.8
	C of V	5.1%	t	5300.8	421.8
				Average	431.3
				Max	465.6
				Min	386.2
				Std Dev	24.0
				C of V	5.6%

Table A5 Results of split tension tests for 7-day old mortar cylinders.

Specimen Type - Split Cylinders

w/c = 0.4		
	Split Tensile Strength	
Mix ID	**Max (psi)**	**Max (lbf)**
a	9400.5	748.1
b	10850.3	863.4
c	11305.2	899.6
d	9551.5	760.1
e	11150.3	887.3
f	10050.9	799.8
g	10401.2	827.7
h	10453.5	831.9
I	10300.6	819.7
j	10751.6	855.6
k	10300.6	819.7
l	10751.6	855.6
m	10701.2	851.6
n	9050.1	720.2
o	10600.6	843.6
	Average	825.6
	Max	899.6
	Min	720.2
	Std Dev	50.5
	C of V	6.1%

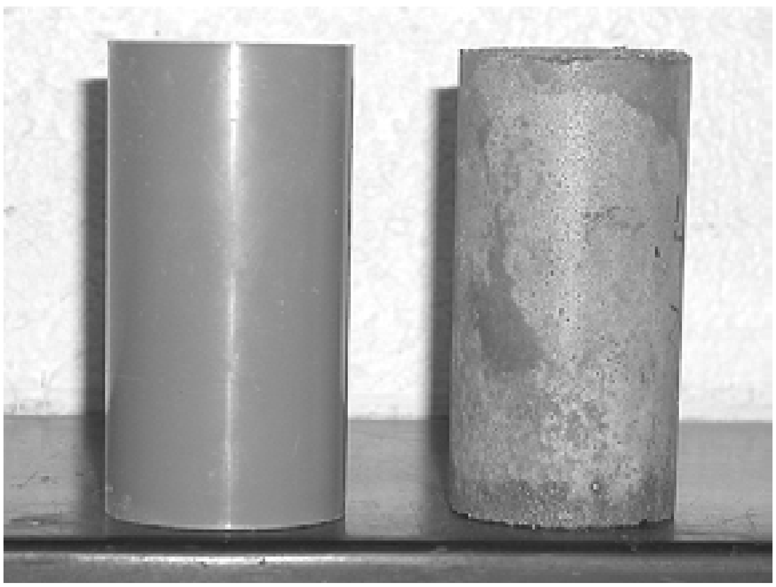
w/c = 0.6		
	Split Tensile Strength	
Mix ID	**Max (psi)**	**Max (lbf)**
a	5951.2	473.6
b	6500.9	517.3
c	5951.2	473.6
d	5951.2	473.6
e	6051.8	481.6
f	6251.2	497.5
g	6100.2	485.4
	Average	486.1
	Max	517.3
	Min	473.6
	Std Dev	16.3
	C of V	3.4%

APPENDIX II

PROCEDURE FOR MAKING 0.40, 0.50, AND 0.60 MORTAR CYLINDERS

Introduction

The objective is to produce 50mm diameter by 100mm mortar cylinders with three different *w/c* ratios as follows: 0.40, 0.50, and 0.60. The volumes of air, sand, and paste are to be kept constant across the range of *w/c* with the mix design volumes of 18.0%, 49.7%, and 32.3% respectively.



Materials

Oven dry U.S. Silica ASTM 20-30 sand
LaFarge Type I regular portland cement
Tap water
ADZ-AIR vinsol resin air entrainer

Batches

0.40 *w/c*	Bulk SG.	% Abs.	mix design (g)	batch (g)
cement	3.15		500.0	500.0
sand	2.65	0.12	1462.5	1462.5
water	1.00		200.0	201.4

air entrainer 0.28 ml

0.50 *w/c*	Bulk SG.	% Abs.	mix design (g)	batch (g)
cement	3.15		500.0	500.0
sand	2.65	0.12	1666.4	1666.4
water	1.00		250.0	251.7
air entrainer	0.28 ml			

0.60 *w/c*	Bulk SG.	% Abs.	mix design (g)	batch (g)
cement	3.15		500.0	500.0
sand	2.65	0.12	1870.2	1870.2
water	1.00		300.0	301.9
air entrainer	0.28 ml			

Mixing

Batches are mixed according to ASTM C 305 - 99 "Standard Practice for Mechanical Mixing of Hydraulic Cement Pastes and Mortars of Plastic Consistency." ASTM C 305 does not cover the addition of air entrainers, so it is noted here that the air entrainer is added to the mixing bowl after the water and prior to the addition of the cement.

Physical Tests

Air content and flow are measured according to ASTM C 185 - 01 "Standard Test Method for Air Content of Hydraulic Cement Mortar" with the following exceptions:

- The batch listed in Section 9.1 "Batch" is replaced by the previously mentioned 0.40, 0.50, and 0.60 batches.

- The flow determination procedure listed in Section 9.3 "Flow Determination" is replaced by the flow determination procedure in Section 10.3 "Determination of Flow" from ASTM C 109 / C 109M - 99 "Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens."

The volume percent air is to be kept at 18% +/- 2.5%, and the percent flow is to be kept at 85% +/- 5%, 115 +/- 5%, and 125 +/- 5% for the 0.40 *w/c*, 0.50 *w/c*, and 0.60 *w/c* mortars respectively.

Molding of Cylinders

The cylinders are molded using ASTM C 192/ 192M - 00 "Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory" as a guide, with the obvious exception that mortar is used in place of concrete. The mixing and physical tests described previously supercede the mixing and physical tests outlined in ASTM C 192. Furthermore, the following exceptions are made for the consolidation: A 13 mm by 25 mm by 150 mm Teflon prism is used to consolidate the mortar, with 2 equal lifts, rodding 25 times, with 5 taps to the side of the mold after the rodding of the second lift.

APPENDIX III

SPLITTING TENSILE STRENGTH OF CYLINDRICAL SPECIMENS

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INTRODUCTION

The referenced documents for performing this test are ASTM C496, "*Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens*".

This test method determines the split tensile strength of 2”x4” molded cylinders. This is done by applying a diametral compressive load along the complete length of the cylinder at a rate that is within a prescribed range until failure occurs.

As always, remember to use any safety equipment deemed necessary to conduct the test. Safety glasses should always be worn.

SOFTWARE SET-UP

Open Widows Explorer to the C-drive and open the “S Dakota” folder and then click on the “Split Tensile Strength of Concrete Cylinders” folder. Scroll down the menu and open the “ASTM C496.TCC” file, this is the TestStar II program. You’ll then be prompted for a name and password that can be obtained from the lab manager.

After TestStar has opened, go back to Windows Explorer and open “ASTM C496 for 2 by 4 cylinders.000”, this is the TestWare SX program. Select and open the “ASTM C496 Default Procedure.” TestWare SX was programmed to apply a continuos load as per paragraph 7.5 of ASTM C496.

The Data menu automatically opens, enter the sample identification number. Then open the Control Menu and select “reset.”

You are now ready to load samples for testing.

LOAD SPECIMEN

Place the concrete cylinder on the center of the platen with bearing strips placed between the specimen and the upper and lower platens. **Never place or remove a specimen from between the platens while the HPS and HSM are energized.**

Energize the hydraulic power supply (HPS) and hydraulic service manifold (HSM) located on the lower third of the Load Unit Control (LUC).

Figure 1. Load Unit Control

To energize the HPS, first press the “Low” button, wait 5 seconds and then press the “High” button. To energize the HSM, depress the “Low” button, wait 5 seconds and then press the “High” button.

Once the system is energized you will be able to control the actuator by the controls at the bottom of the LUC. The button on the left, “actuator positioning control (APC)”, energizes the actuator and the actuator is controlled by the dial to the right of the APC, **turn the dial counter-clock-wise to raise the platen and clock-wise to lower the platen.**

Slowly raise the actuator until a load of 250 lb is applied to the concrete cylinder. Once this is done, turn off the APC by pressing the button.

TEST SPECIMENS

Now that the sample is loaded, go back to TestWare SX to begin the test and click on "Run." Once the test is complete, click on "Stop," lower the actuator by energizing the APC and turning the dial clock-wise.

Prior to placing a new specimen or removing an old specimen, de-energize the HSM and HPS. This is done by starting with the HSM and pressing the high button then the low button. Then do the same with the HPS, press the high button and then the low button to de-energize.

Never place or remove a specimen from between the platens while the HPS and HSM are energized.

To run another specimen, change the sample name in the data file, select reset in the control menu, load specimen, and run test.