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

Overview

This Quarterly Report is submitted to outline the work accomplished during the reporting period 7-15-05 to 10-15-06, 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. Tasks not listed have been completed and the details of each can be found in previous reports. The following is a summary of results for this reporting period.

- Chloride profiling of samples from Task 6 have are proceeding.
- Work at the University of Toronto continues on identifying distress mechanisms and determining scaling potential of various deicers, and measuring diffusivity, sorptivity, and permeability of specimens from Task 6

Task Report

Task 5: Characterization of Field Specimens

Billets used for chloride profiling (reported in the previous quarterly report) have been prepared into thin sections and petrographic examination was begun. No specific details of the petrographic examination are available at this time.

Task 5 Problems and/or Deviations from Work Plan

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

Task 5 Completion -80%

Task 6: Laboratory Experiment

Work Conducted at Michigan Tech

Samples removed from the various brines are being prepared and analyzed to determine chloride profiles, and for petrographic analysis. To date, only the specimens immersed in calcium chloride solutions have exhibited expansion and cracking. Given the large number of samples to prepare and analyze, this has been the sole focus for the reporting period for this project.

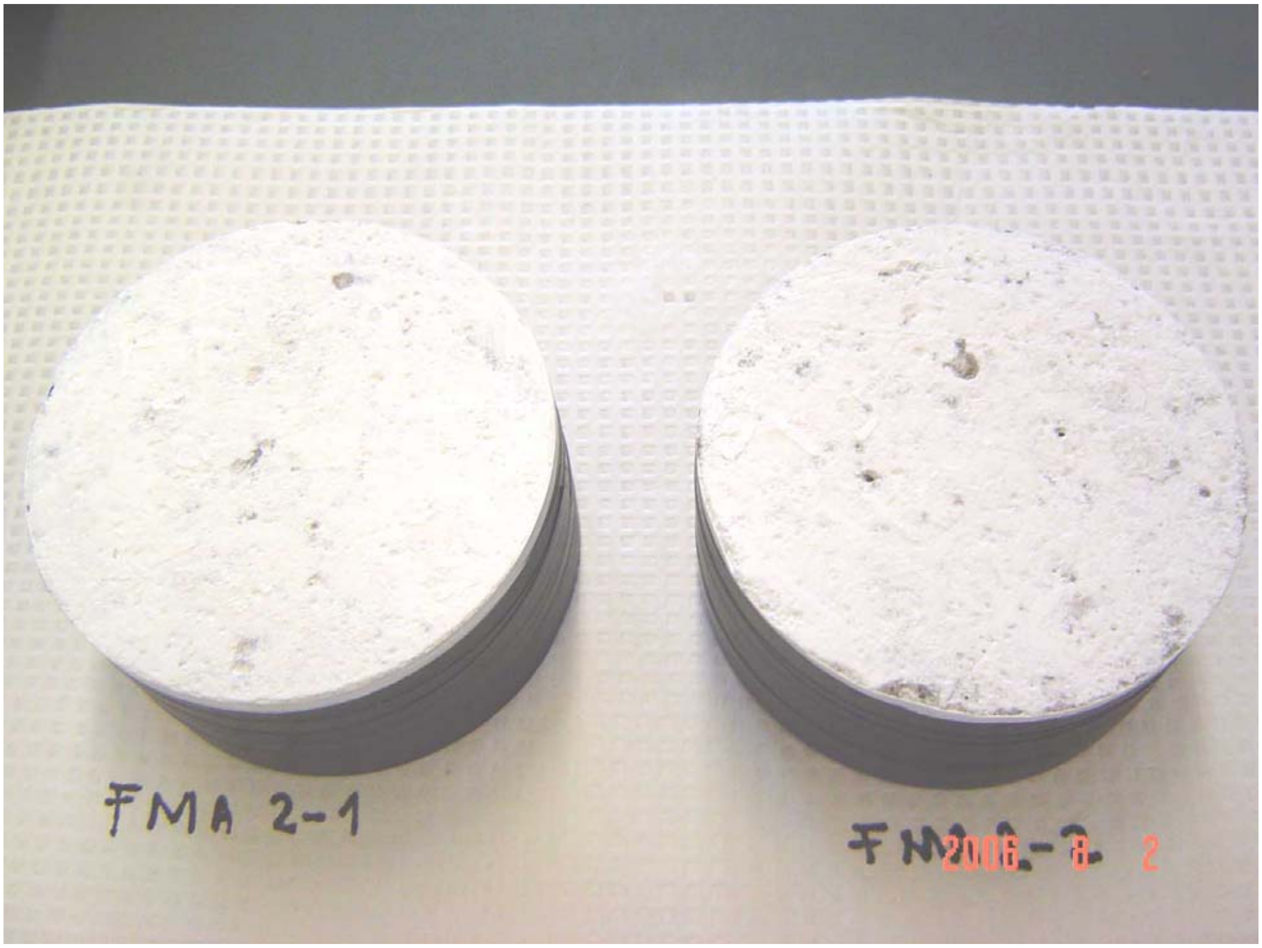
Work Conducted at University of Toronto

Salt scaling Resistance

Concrete slabs continue to be tested for chemical, physical and chemical-physical attack as described in the last quarterly report. No specific details are available at this time. It is expected that the slabs may need to be cycled for more than 300 cycles for signs of distress to appear on the concrete surface.

Diffusion and Permeability assessment

Concrete and mortar specimens cast at Michigan Tech and sent to the University of Toronto for an assessment of their penetrability are being tested. It is worth mentioning that samples tested for sorptivity using 15% $MgCl_2$ as the exposure solution presented a clear development of a white layer of what it is believed to be brucite (see picture below). However, no distress was visible at the tested sample surface during the test. Preliminaries results are shown below.



Sorptivity test **(ASTM C 1585-04)**

In general, the higher the rate of absorption, the more susceptible the sample is to penetration of the exposure solution. Although the absorption results for all concrete samples gave small changes in magnitude, the results distinguish between concrete samples with water-cementitious ratio of 0.45 and 0.55 respectively (Table 1). Also, the formation of the white layer on the top of the samples exposed to $MgCl_2$ clearly slows down the penetration of the solution compared with the other solutions (Figure 1). The GGBFS blended cement concrete consistently shows lower rate of absorption (Figure 2).

Table 1. Summary of Preliminary Results - Concrete samples

Exposure solution / Code	w/cm=0.45		w/cm=0.55	
	Initial Absorption Si ($mm/s^{½}$) / [r^2]	Secondary Absorption S_s ($mm/s^{½}$) / [r^2]	Initial Absorption Si ($mm/s^{½}$) / [r^2]	Secondary Absorption S_s ($mm/s^{½}$) / [r^2]
Water				
PCW	3.0×10^{-3} [0.99]	1.9×10^{-3} [0.96]	6.2×10^{-3} [0.99]	2.7×10^{-3} [0.92]
FCW	2.7×10^{-3} [0.99]	1.8×10^{-3} [0.99]	6.6×10^{-3} [0.99]	2.1×10^{-3} [0.82]
SGW	1.8×10^{-3} [0.99]	1.1×10^{-3} [0.99]	2.8×10^{-3} [0.99]	1.8×10^{-3} [0.99]
$CaCl_2$				
PCC	1.2×10^{-3} [0.99]	4.9×10^{-4} [0.94]	3.0×10^{-3} [0.99]	1.7×10^{-3} [0.99]
FCC	2.4×10^{-3} [0.98]	8.1×10^{-4} [0.99]	4.3×10^{-3} [0.99]	2.4×10^{-3} [0.99]
SGC	1.1×10^{-3} [0.98]	2.2×10^{-4} [0.99]	1.5×10^{-3} [0.98]	6.1×10^{-4} [0.97]
$MgCl_2$				
PCM	6.6×10^{-4} [0.99]	7.4×10^{-4} [0.99]	1.3×10^{-3} [0.97]	1.2×10^{-3} [0.99]
FCM	4.6×10^{-4} [0.98]	3.3×10^{-4} [0.99]	1.4×10^{-3} [0.99]	1.3×10^{-3} [0.99]
SGM	4.2×10^{-4} [0.96]	1.9×10^{-4} [0.99]	6.7×10^{-4} [0.99]	2.5×10^{-4} [0.99]

PCW: Portland cement concrete - tap water
PCC: Portland cement concrete - calcium chloride
PCM: Portland cement concrete - magnesium chloride
FCW: Portland cement + 15% fly ash concrete - tap water
FCC: Portland cement + 15% fly ash concrete - calcium chloride
FCM: Portland cement + 15% fly ash concrete - magnesium chloride
SGW: GGBFS blended cement concrete - tap water
SGC: GGBFS blended cement concrete - calcium chloride
SGM: GGBFS blended cement concrete - magnesium chloride

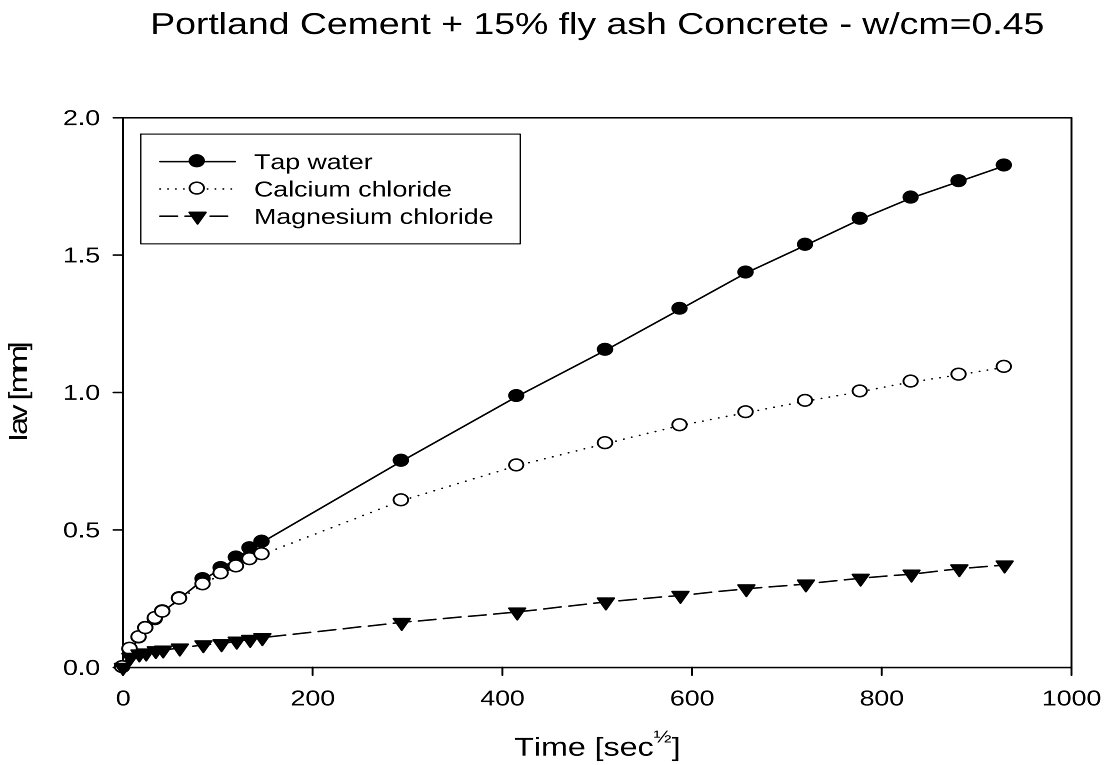


Figure 1. Absorption rate change with time for different exposure solutions.

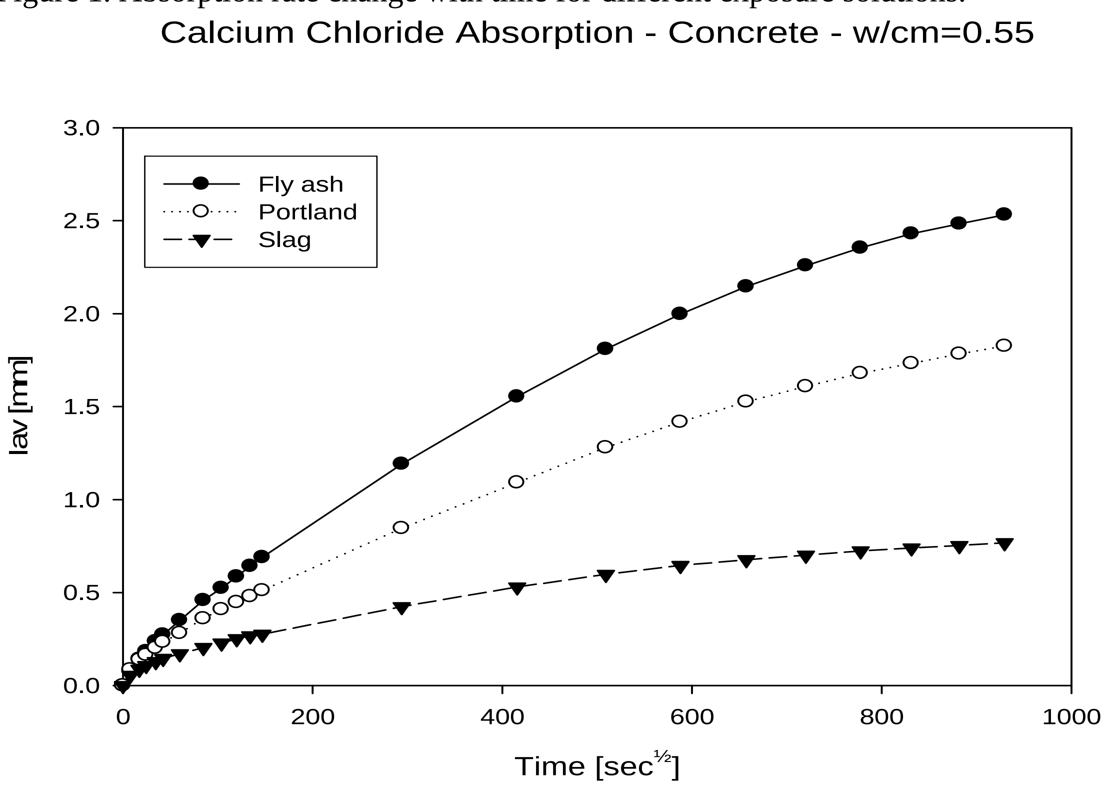


Figure 2. Absorption rate change with time for different type of concrete.

Rapid chloride permeability test **(ASTM C1202-97)**

This accelerated test gives a rapid indication of the samples resistance to the penetration of chloride ions. Table 2 presents the qualitative chloride ion penetration based on charge passed. A typical curve of the charge passed versus time is shown in Figure 3.

Table 2. Summary of Results - Concrete and Mortar samples

Code	w/cm=0.45		w/cm=0.55	
	Charge (coulombs)	Chloride ion penetrability	Charge (coulombs)	Chloride ion penetrability
Concrete Samples				
PCC	4413	High	5236	High
FCC	3397	Moderate	4446	High
SGC	2787	Moderate	3103	Moderate
Mortar Samples				
PCM	5380	High	6151	High
FCM	5219	High	5871	High
SGM	3309	Moderate	4208	High

PCC: Portland cement concrete
FCC: Portland cement + 15% fly ash concrete
SGC: GGBFS blended cement concrete
PCM: Portland cement mortar
FCM: Portland cement + 15% fly ash mortar
SGM: GGBFS blended cement mortar

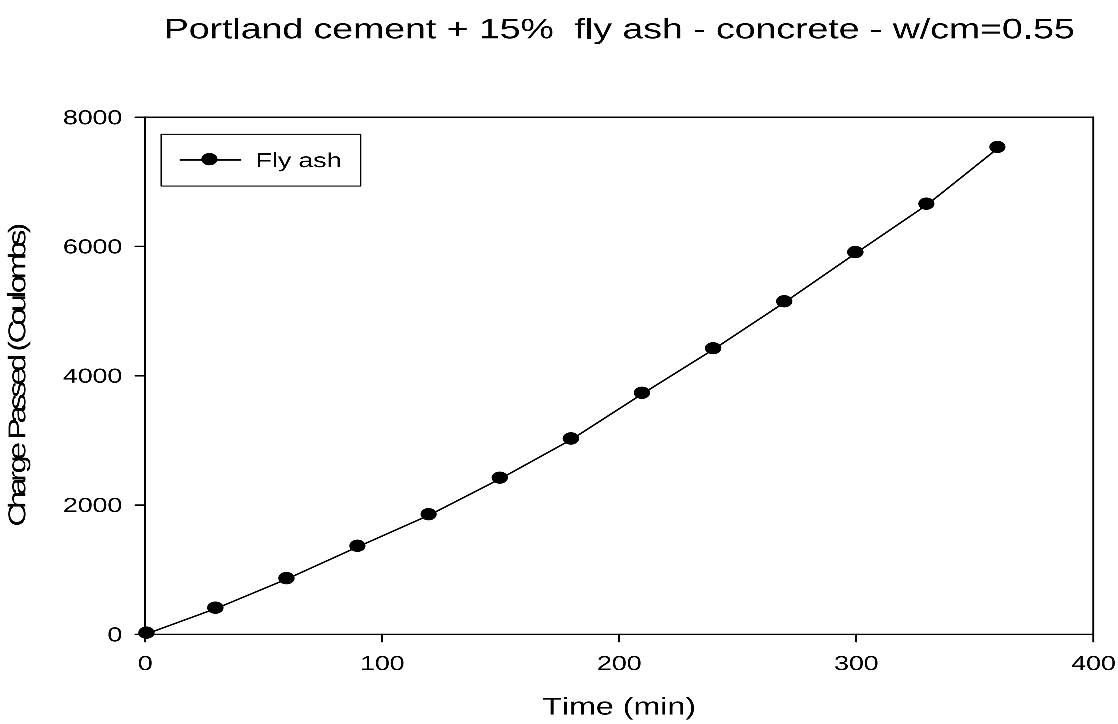


Figure 3. Example of the plot charge passed with time.

Bulk diffusion test **(ASTM C 1556-03)**

The determination of the apparent diffusion coefficient provides an indication of the rate of penetration of chloride into the material. Thus, the higher the apparent diffusion coefficient, the easier for chloride to penetrate into the sample. The depth of penetration for a chloride concentration of 0.1% is presented in Table 3 and 4 to help visualize how the diffusion coefficient correlates with the penetration of chloride, which is related to the initiation of corrosion depending on the location of the reinforcement.

Exposure Conditions: 17% Calcium Chloride at 5^{o}C for 35 days (Table 3)
15 % Magnesium Chloride at 5^{o}C for 35 days (Table 4)

Table 3. Summary of Results - Mortar samples

	w/cm=0.45			w/cm=0.55		
Code	PCM	FCM	SGM	PCM	FCM	SGM
Mortar Samples						
Da (m^2/s)	4.44e-12	2.30e-12	2.00e-12	1.00e-11	7.50e-12	2.50e-12
Cs (%)	1.82	2.38	2.86	1.20	1.76	2.24
P [0.1%] (mm)	10.82	7.74	7.45	13.83	13.12	7.97
r^2	0.9871	0.9981	0.9925	0.9911	0.9882	0.9988

Table 4. Summary of Results - Mortar samples

	w/cm=0.45			w/cm=0.55		
Code	PCM	FCM	SGM	PCM	FCM	SGM
Mortar Samples						
Da (m^2/s)	4.40e-12	2.31e-12	2.51e-12	7.88e-12	6.23e-12	2.75e-11
Cs (%)	1.67	2.91	1.20	1.30	1.19	1.20
P [0.1%] (mm)	9.93	8.06	6.92	12.52	10.87	13.83
r^2	0.9969	0.9839	0.9994	0.9909	0.9921	0.9911

Da: Apparent Diffusion Coefficient
Cs: Surface Concentration
P (0.1%): Penetration depth for 0.1% chloride concentration
r^2: r-squared from fitting Fick's 2nd law equation to experimental data
PCM: Portland cement mortar
FCM: Portland cement + 15% fly ash mortar
SGM: GGBFS blended cement mortar

Task 6 Problems and/or Deviations from Work Plan

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

Task 6 Completion -75%

Task 7: Assessing and Minimizing the Impact of Deicing/Anti-Icing Chemicals

Task 7 Problems and/or Deviations from Work Plan

None

Task 7 Completion -0%

Task 8: Effects of Various Deicing/Anti-Icing Chemicals

No additional work has been conducted on Task 8. Further work will continue once specimens from the Phase II experiments are ready for analysis.

Task 8 Completion -25%

Task 9: Life Cycle Cost Analysis

Task 9 Problems and/or Deviations from Work Plan

None

Task 9 Completion -0%

Task 10: Development of Guidelines

Task 10 Problems and/or Deviations from Work Plan

None

Task 10 Completion -0%

Task 13: Final report

Task 13 Problems and/or Deviations from Work Plan

None

Task 13 Completion -0%

Task 14: Present to Panel

Task 14 Problems and/or Deviations from Work Plan

None

Task 14 Completion -0%

Task 15: Present to Review Board

Task 15 Problems and/or Deviations from Work Plan

None

Task 15 Completion -0%