

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

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Submitted by:

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Quarterly Report 7

Overview

This Quarterly Report is submitted to outline the work accomplished during the reporting period 4-15-04 to 7-15-04, identify problems (current and anticipated), and to describe any deviations from the agreed Work Plan. This Quarterly Report is presented in three main sections. The first section is a summary of the progress meeting held June 1 in Rapid City South Dakota between the PI's and Project Director, Dan Johnston, South Dakota DOT. The second section is a summary of research progress and results for the reporting period and is arranged by the Tasks described in the project Work Plan. The third section is a presentation of the proposed experimental plan for Phase 2 involving the testing of concrete specimens. The following is a brief summary of this report.

- The project PI's met with the Project Director in Rapid City, South Dakota to present and discuss preliminary results.
- Field cores have been further processed and thin sections of some are completed. Analysis of these specimens will begin after completion of the mortar specimens. Preliminary results indicate calcium hydroxide depletion near the joints for cores extracted from pavement sections in South Dakota.
- Laboratory analyses of the various mortar specimens have continued. Clear signs of chemical attack are seen in the mortar specimens exposed at a constant low temperature (40 °F) to MgCl₂ and CaCl₂ deicing solutions.
- An experimental plan for Phase 2 of this study is proposed where concrete specimens will be tested using the ASTM C 672 scaling resistance test and submersion in deicing solutions at 40 °F.

SECTION I – PROGRESS MEETING REPORT

On June 1, 2004, the project Principal Investigators met with the Project Director, Dan Johnston, of the South Dakota Department of Transportation, in Rapid City, South Dakota. The project Principal Investigators present at the meeting were Drs. Larry Sutter and Tom Van Dam from Michigan Tech and Dr. Doug Hooton from the University of Toronto. The purpose of the meeting was to review and discuss the preliminary results of the mortar experiment, which were presented in the last quarterly report for the reporting period January 15, 2004 through April 15, 2004.

As discussed in the quarterly report, unexpected deterioration occurred in many of the specimens subjected to the various deicer solutions (no damage was observed in the control specimens). Deterioration was not only observed in specimens subjected to the fairly aggressive cyclic temperature experiment (-15 °F to 135 °F), but also in some diffusion specimens conditioned at a constant temperature of 40 °F and 135 °F. The most damaging effects were observed in cyclic temperature specimens subjected to NaCl solution, but the CaCl₂ and MgCl₂ eventually also suffered extensive damage in time. At the constant low temperature of 40 °F, the NaCl and calcium magnesium acetate (CMA) specimens showed little damage, whereas CaCl₂ and MgCl₂ began showing signs of distress at 28 days. Specimens at a constant high temperature of 135 °F were relatively unscathed except those in CMA, which were heavily damaged within 28 days.

To facilitate discussion, the PI's brought example specimens from the various tests for examination. A wide ranging discussion amongst the participants identified a number of possible failure mechanisms for the mortar samples tested including salt crystallization, paste weakening through both calcium hydroxide dissolution and alteration of the calcium silicate hydrate, osmotic pressure, acid attack (in the case of CMA) and thermal shock. It was the consensus that most probably different mechanisms were at work in the three different tests conducted.

For the cyclic temperature experiment, salt crystallization, paste weakening through both calcium hydroxide dissolution and alteration of the calcium silicate hydrate and osmotic pressure were identified as potential distress mechanisms. Although preliminary data indicated the distress originated in the oven cycle, thermal shock was ruled out as the pre-oven and pre-freezer conditioning cycles were thought to be adequate for equilibrating the samples to room temperature before being subjected to either temperature extreme. In large part, this was based upon the performance of the control specimens that went through the same cycles and exhibited no distress. There were no indications in the petrographic analyses performed to date that chemical attack had occurred. Calcium hydroxide dissolution had occurred to a limited extent but was not thought to be prevalent enough to account for the observed distress. Also, the observed distress in the cyclic temperature experiment was more akin to an expansion process, not a dissolution process.

Chemical attack was thought to be the most probable cause of the deterioration that occurred at a constant low temperature (40 °F), as these specimens were not subjected to

extremes in temperature and no opportunity for salt crystallization was possible (note that a condition of supersaturation is required for salt crystallization to occur). Likewise with the constant high temperature experiment where only specimens in the CMA solution experienced distress, a chemical attack was suspected where alteration of the CMA produced a weak acetic acid which attacked the mortar. The observed distress in these specimens was consistent with such a process. However, no pH measurements were made on the solutions used and therefore this hypothesis cannot be proven. For both constant temperature experiments, osmotic pressure was also discussed as a possible mechanism assuming pore solutions of different ionic strength were created as a result of dehydration of the specimens.

To help identify the distress mechanisms at work, two experiments were proposed by the PI's to isolate causes and determine if additional mortar research was required. These experiments are as follows:

Experiment 1 – Repeat the cyclical temperature experiment for NaCl and MgCl₂, eliminating the oven step for half the specimens and the oven step and lime water-conditioning step for the other half. The 20 hours that the specimens would have normally been in the oven would now be at room temperature, with half the specimens equilibrating slowly to room temperature without exposure to limewater. If the distress was associated with drying (i.e. salt crystallization or osmotic pressure) then the distress should disappear with the elimination of the oven. If distress still occurred, chemical attack of the paste constituents is left as the probable cause, and additional mortar tests would be required. The elimination of the limewater conditioning step was also done to isolate osmotic pressure distress that might result from interactions between the limewater and the ionic pore water of the mortars. Given that the distress in the NaCl specimens occurred so quickly, it was thought that 2 weeks would be enough time to identify the effects of eliminating the oven and limewater steps, respectively. However, it was proposed that the specimens be exposed for up to 56 days to ensure that no distress would occur.

Experiment 2 – Continue with the petrographic analysis of the constant low temperature specimens but simultaneously start new constant low temperature MgCl₂ and CaCl₂ samples exposed to the solutions at varying concentrations. For this experiment, solution concentrations were chosen at 3, 7, 10, and 14 percent for each solution. Again, assuming that chemical attack is occurring, this experiment will help bracket the effect of solution concentration on the observed distress.

In addition, the PI's presented some preliminary thoughts on the structure of the next phase of this research where laboratory prepared concrete specimens will be tested. It was determined that a more standard test such as ASTM C 672, "*Standard Test Method for Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals*" should be employed. Basic parameters of the concrete mixtures were discussed. It was decided that a water to cementitious ratio (*w/cm*) of 0.42 would be used for these mixtures along with a durable, non-carbonate aggregate. It was decided that the preliminary experimental design be presented in the next quarterly report.

SECTION II - TASK REPORT

Task 1: Literature Review

The literature review continues as additional information becomes available. There is a lot of interest in this subject, and the body of knowledge continues to grow. There is also little consensus on some key aspects of the study requiring the research team to continue to search for reliable and widely accepted sources of information. Michigan Tech has been working with researchers at the University of Toronto to finalize a draft submittal of the literature review. It is anticipated due to the dynamic nature of this study that relevant literature will continue to become available throughout the duration of this project, requiring incorporation in the final report.

Task 1 Problems and/or Deviations from Work Plan

This Task continues to be behind schedule.

Task 1 Completion - 80%

Task 2: Conduct Survey

A survey of States and Canadian Provinces has been conducted to assess the deicing/anti-icing practices and application strategies used by the various agencies responding.

Task 2 Problems and/or Deviations from Work Plan

This Task is essentially complete.

Task 2 Completion - 95%

Task 3: Site Selection

Over the last reporting period, no additional field sites were identified for coring. Therefore, this Task is considered complete at this time by the research team.

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 -100%

Task 4: Meeting with Technical Panel

Task 4 Completion -100%

Task 5: Characterization of Field Specimens

Work on Task 5 has continued. Preparation of specimens for microstructural investigation has continued, with thin sections being prepared for examination of possible alterations to the cement paste or aggregates, evidence of salt crystallization, and evidence of secondary deposits such as chloroaluminates (Friedel's Salt) indicating deicer/cement paste interaction. Additionally, specimens are being prepared to investigate the degree of chloride ion ingress on the selected cores using the x-ray microscope and the scanning electron microscope.

Thin sections prepared from mid-panel and near-joint from the South Dakota site suggest that the cement paste near the joint is more porous than cement paste from mid-panel. The results of fluorescence measurements can be viewed on the web at the following address: http://www.cee.mtu.edu/~krpeters/sodak_deicer/june/. The cement paste near-joint was found to fluoresce more brightly, indicating that a greater volume of pore space absorbed more of the fluorescent dyed epoxy as compared to the cement paste from mid-panel. Duplicate thin sections are being made from the same cores, as well as another set of mid-panel and near-joint cores to confirm these observations.

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 -50%

Task 6: Laboratory Experiment

The majority of the effort for this reporting period was in analyzing the mortar specimens exposed to various deicer solutions as previously reported. In previous quarterly reports, the occurrence of unexpected deterioration in many of the specimens subjected to the various deicer solutions (no damage was observed in the control specimens) was discussed. Damage was not only observed in specimens subjected to the fairly aggressive cyclic temperature experiment (-15 °F to 135 °F), but also in specimens conditioned at a constant 40 °F and 135 °F that were prepared for use in measuring diffusion. The most damaging effects were observed in cyclic temperature specimens subjected to NaCl solution, but the CaCl₂ and MgCl₂ eventually also suffered extensive damage in time. At the constant low temperature of 40 °F, the NaCl and calcium magnesium acetate (CMA) specimens showed little damage, whereas CaCl₂ and MgCl₂ began showing signs of distress at 28 days. And specimens at a constant high temperature of 135 °F were relatively unscathed except those in CMA, which were heavily damaged within 28 days.

In response to these observations, the two other short duration experiments were started as described in Section I of this report. Preliminary results of Experiment 1 are as follows:

There were four distinct tests run during this experiment. The two most destructive deicing solutions in the last cyclical temperature experiment, NaCl and MgCl₂, were chosen. Specimens were exposed to each of the two deicing solutions and were cycled between the freezer and room temperature with and without a two-hour lime conditioning step.

Four bins of thirty samples were prepared. Each contained ten of the three different water-cement ratios: 0.40, 0.50, and 0.60. These specimens were conditioned with limewater for three days prior to the start of cycling.

Salt solutions of MgCl₂ and NaCl were prepared. The target concentration of the MgCl₂ was 15.0% while the target concentration of the NaCl was 17.8%. These were the same solution strengths previously used for all mortar experiments.

The two-day-cycle used was as follows:

- Step.1 At the start on day one, two of the four bins of specimens are filled with limewater. The other two bins are not filled with limewater.
- Step.2 Two hours later, the limewater bins are drained. All four bins are then filled with the appropriate salt solution and placed in a freezer at -15°F.
- Step.3 Twenty hours later, on day two, all four bins are removed from the freezer and placed in a 135°F oven for two hours to thaw the frozen solution.
- Step.4 Two hours later, the salt solution is drained from the bins. The two bins containing specimens to be exposed to limewater are filled with limewater. The other two bins remain air drying at room temperature.
- Step.5 Two hours later, the limewater containing bins are emptied. All four bins remain at room temperature for twenty hours and the cycle is repeated from Step 1.

Two samples of each *w/c* ratio were removed from each bin at seven and fourteen days for petrographic analysis. This analysis has not yet been completed, but a qualitative analysis of the samples was easily made. There was no visible cracking or damage to the seven or fourteen-day samples for either deicer, nor is there any visible distress of the specimens still cycling at the time of this writing.

Based on these results, it is concluded that the oven step was responsible for the distress observed and therefore, either salt crystallization or osmotic pressure are possible distress mechanisms. It should be noted that petrographic examination of previous specimens has not revealed any evidence of salt crystallization. However, the osmotic pressure theory cannot be proved or disproved by this experiment. It is still a possible mechanism but can only be further investigated through a new set of experiments. It is the thinking of

the PI's that the cyclic temperature test in general is not a good test for evaluating deicer performance and no additional resources should be spent investigating why the distress occurred. The cycling from -15 °F to 135 °F is not realistic and although it was evaluated in this research as an accelerated test method, it appears to be too severe and not suitable for the purposes desired. Cycling from -15 °F to room temperature appears to not put undue stress on the specimens and will be used in Phase 2 of this research as described in Section III of this report.

Petrographic Examination of Mortar Cylinders

Fifteen additional mortar specimens have been selected and prepared in thin section. Twelve mortar specimens are from the cyclic temperature experiment, two are from the constant low temperature experiment, and one cylinder from the constant high temperature experiment. The cylinders from the cyclic temperature experiment represent the condition of the mortar at three different stages: after the thaw, after the limewater soak, and after the oven cycle. The cylinders were pulled during the early onset of deterioration. Three of the cylinders were selected from 0.60 w/c ratio mortars exposed to food grade NaCl at eight days, and three more of the cylinders were selected from 0.40 w/c mortars exposed to food grade NaCl at ten days. The other six cylinders were selected from 0.50 w/c mortars exposed to MgCl₂ and CaCl₂ at twenty days. For the constant cold temperature experiment, one cylinder was selected from the 0.50 w/c mortars exposed to CaCl₂ at fifty-six days, and the other cylinder was selected from the 0.50 w/c mortars exposed to MgCl₂ at eighty-four days. For the constant high temperature experiment, one cylinder was selected from the 0.40 w/c mortars exposed to calcium magnesium acetate, (CMA). Large-scale elemental mapping has been performed on eight of the fifteen samples. The maps collected can be viewed on the web at the following address: <http://www.cee.mtu.edu/~jmcargo/Maps.htm/>.

Cyclic Temperature Experiment

Thin sections have been prepared to represent the cylinders after the thaw, (after-thaw), after the lime-soak, (after-lime-soak) and after the oven, (after-oven). However, to date only the thin sections from after-thaw and after-oven have been closely examined. Petrographic microscope images of the CaCl₂ exposed mortar cylinders after-thaw and after-oven can be viewed on the web at the following address: http://www.cee.mtu.edu/~krpeters/cyclic_cacl2/.

After the thaw, many of the cracks and air voids are filled or lined with an amorphous brown translucent material rich in calcium and chlorine. After the oven, the amorphous brown material is gone, appearing to be replaced by secondary calcium hydroxide crystals. A comparison of the cross-polarized images best illustrates the secondary deposition of the Ca(OH)₂ crystals. In the after-thaw sample, there is an absence of crystalline material in the voids and cracks, while in the after-oven sample, the secondary Ca(OH)₂ crystals are readily visible as bright points lining the voids and cracks.

Constant Low Temperature Experiment

The deterioration of the MgCl_2 and CaCl_2 exposed mortars in the constant low temperature experiment was dramatic. The external appearance of the cylinders was similar in both cases, with obvious cracking and expansion, but the onset of distress occurred earlier for the CaCl_2 exposed mortars. In thin section, the deterioration appears similar, with the exception of a magnesium-rich zone near the outer crust of the cylinders exposed to MgCl_2 . Figures 1 through 15 consist of petrographic microscope and electron microscope images from the MgCl_2 exposed mortars, illustrating successive zones of deterioration. The thin section represents a cross-section in a plane perpendicular to the finished top surface of the cylinders, including the top surface of the cylinder. The distinction between the deteriorated and intact zones is best shown in the epifluorescent image in Figure 1. In the deteriorated upper portion of Figure 1, abundant dark cracks run horizontally across the field of view. In the intact bottom portion of Figure 1, there are less cracks, and the cement paste is denser, as evidenced by the light-colored appearance compared to the cement paste of the deteriorated zone. It should be noted here that the epifluorescent images have been inverted to facilitate printing, so dark-gray regions represent high porosity while light-gray regions represent low porosity.

Figure 2, a cross-polarized image, best illustrates a subdivision in the deteriorated zone between the carbonated exterior and an inner region of $\text{Ca}(\text{OH})_2$ depletion. The cement paste of the top half of the deteriorated zone has a uniform light brown appearance under crossed-polars, typical of carbonated cement. The cement paste of the bottom half of the deteriorated zone appears dark due to a lack of $\text{Ca}(\text{OH})_2$ crystals, while the cement paste of the intact zone contains numerous small bright patches of $\text{Ca}(\text{OH})_2$. A more subtle feature of Figure 2 is the light brown crystals of calcium chloride hydrate in the air voids and cracks in the $\text{Ca}(\text{OH})_2$ depleted zone. Even harder to discern in Figure 2 are the long thin plates of secondary $\text{Ca}(\text{OH})_2$ crystals intermixed with calcium chloride hydrate crystals in the air voids just at the interface between the intact and deteriorated zones. Figure 3 shows the same area as Figures 1 and 2, but in transmitted plane-polarized light. In Figure 3, two seams of clear $\text{Mg}(\text{OH})_2$ crystals are indicated with arrows. The $\text{Mg}(\text{OH})_2$ crystals reside in cracks just beneath two sand grains near the top finished surface. Figure 4 consists of a back-scattered electron image. In the back-scattered electron image, the cracks of the deteriorated zone are readily visible.

Figures 5 through 15 consist of characteristic x-ray elemental maps. To facilitate printing, regions containing higher count rates for characteristic x-ray radiation appear darker, and regions containing lower count rates for characteristic x-ray radiation appear lighter. Probably most striking is Figure 8, which shows the high magnesium concentration at the top surface of the cylinder. A more subtle feature is visible in Figure 14; specifically the contrast in calcium count rates in the intact zone versus the neighboring region of $\text{Ca}(\text{OH})_2$ depletion. In the cement paste of the intact zone, there are abundant small dark patches that correspond to high calcium count rates. In the region of $\text{Ca}(\text{OH})_2$ depletion, the cement paste has a similar background of calcium count rates, but the small dark patches are more dispersed.

X-ray diffraction was performed on a crushed 0.50 w/c control cylinder, as well as 0.50 w/c cylinders from the constant low temperature experiment exposed to MgCl₂ and CaCl₂ solutions after 84 days. The exterior portions of the deicer exposed cylinders were scraped away, sieved to remove as much Ottawa sand as possible, and pulverized by mortar and pestle. The control cylinder was crushed, sieved to remove sand, and pulverized. The most notable difference between the control and the deicer exposed cylinders was the presence of strong reflection lines for Ca(OH)₂ in the control, and the absence of these lines in the deicer exposed cylinders.

Constant High Temperature Experiment

Thin sections were prepared from 0.40 w/c mortars exposed to CMA at high temperature for 28 days. Figures 16 through 18 illustrate the severe deterioration. Elemental maps from the same thin section can be viewed on the web at the following address: <http://www.cee.mtu.edu/~jmcarloso/Maps.htm/>. X-ray diffraction was performed on the fibrous crystals scraped from the exterior of the cylinders, and identified as calcium acetate.

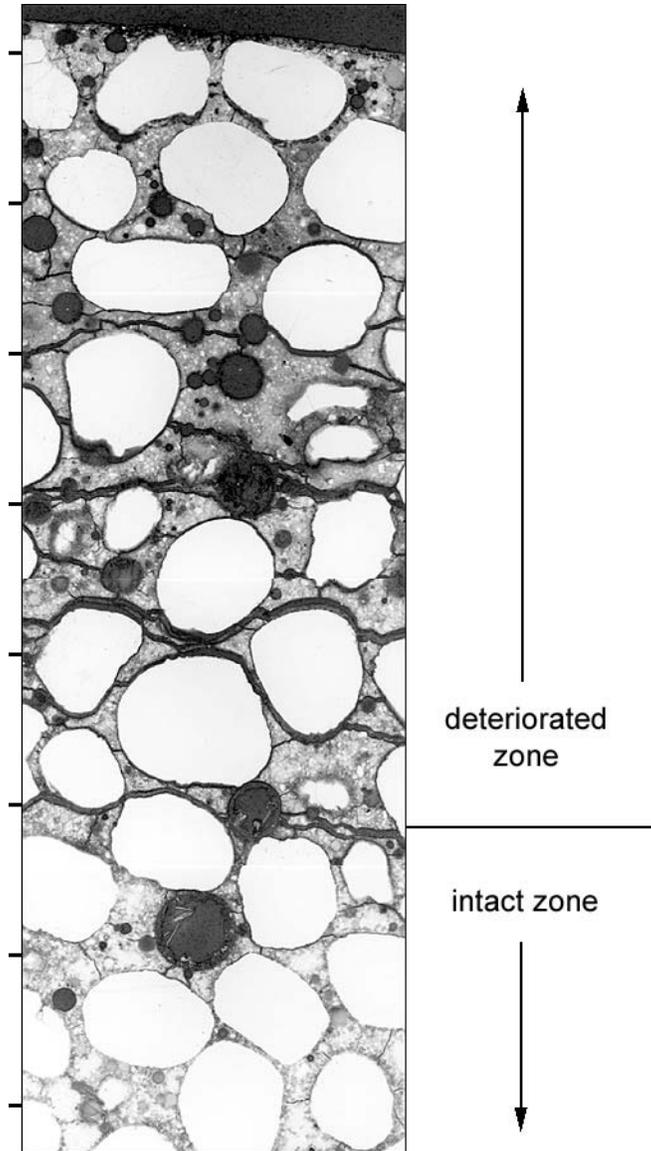


Figure 1: Petrographic microscope image, epifluorescent mode, MgCl_2 constant cold temperature experiment, distance between tic marks is 1.0 mm.

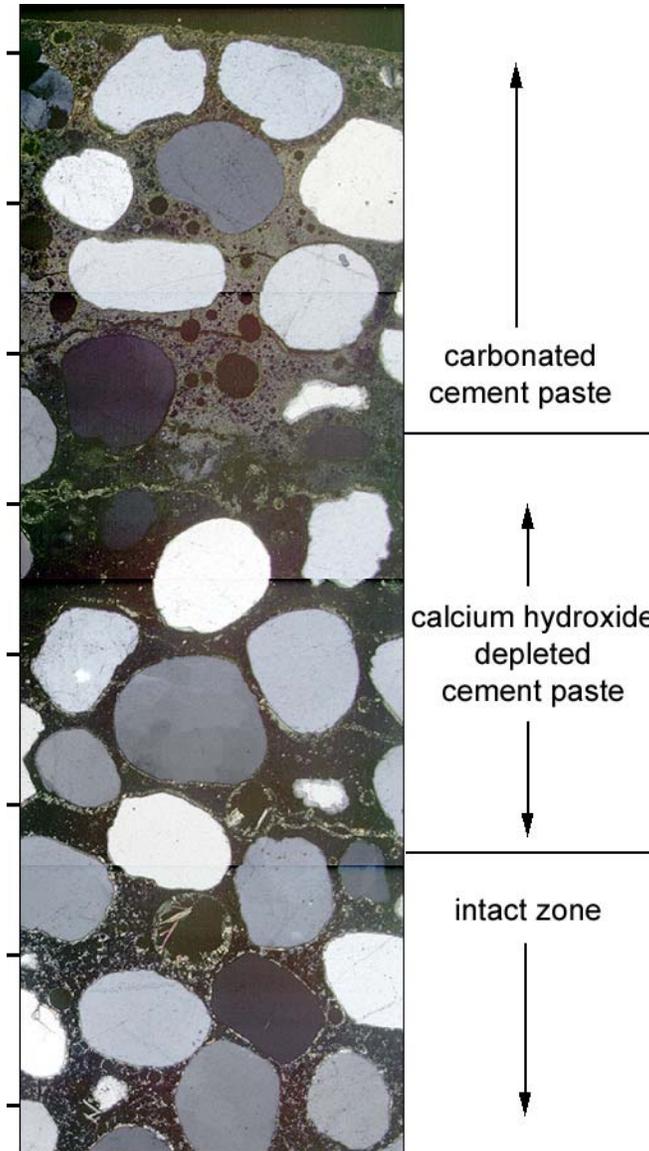


Figure 2: Petrographic microscope image, crossed-polars, MgCl_2 constant cold temperature experiment, distance between tic marks is 1.0 mm.

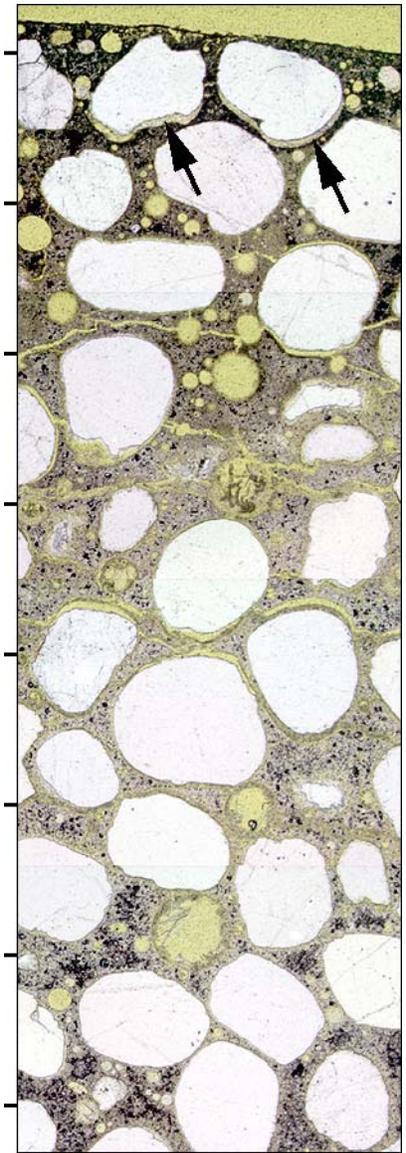


Figure 3: Petrographic microscope image, epifluorescent mode, MgCl_2 constant cold temperature experiment, distance between tic marks is 1.0 mm. Arrows indicate deposits of brucite in cracks beneath sand grains.

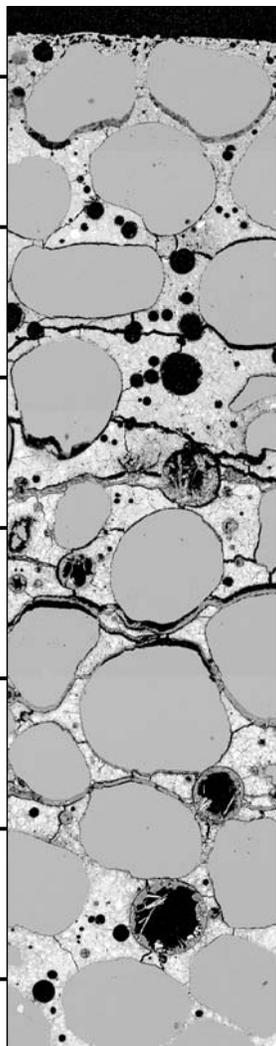


Figure 4: Back-scattered electron image, MgCl_2 constant cold temperature experiment, distance between tic marks is 1.0 mm.

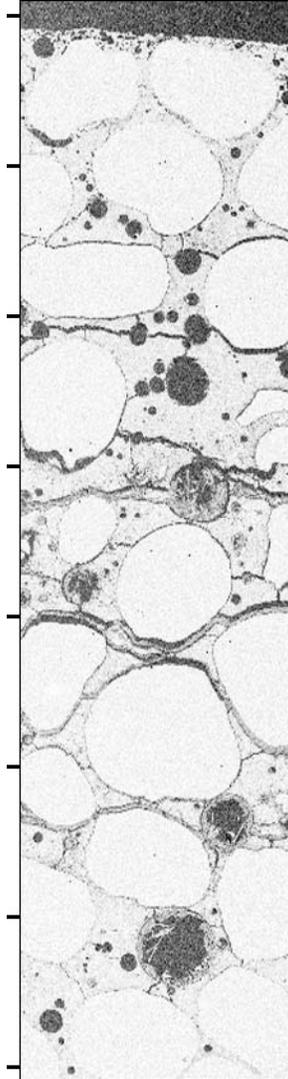


Figure 5: Characteristic x-ray map for carbon, MgCl_2 constant cold temperature experiment, distance between tic marks is 1.0 mm.

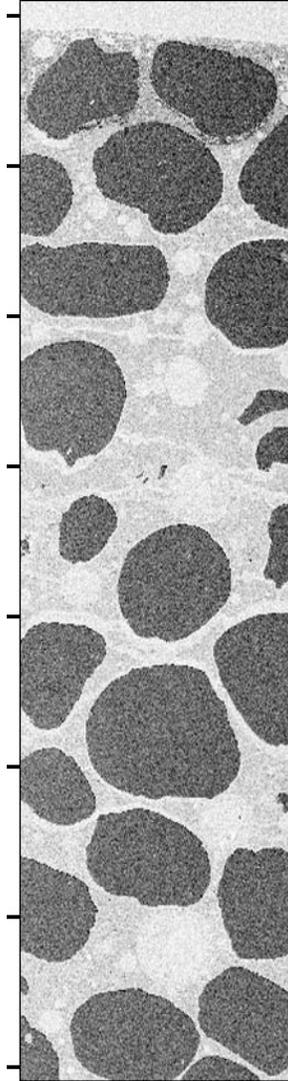


Figure 6: Characteristic x-ray map for oxygen, MgCl_2 constant cold temperature experiment, distance between tic marks is 1.0 mm.

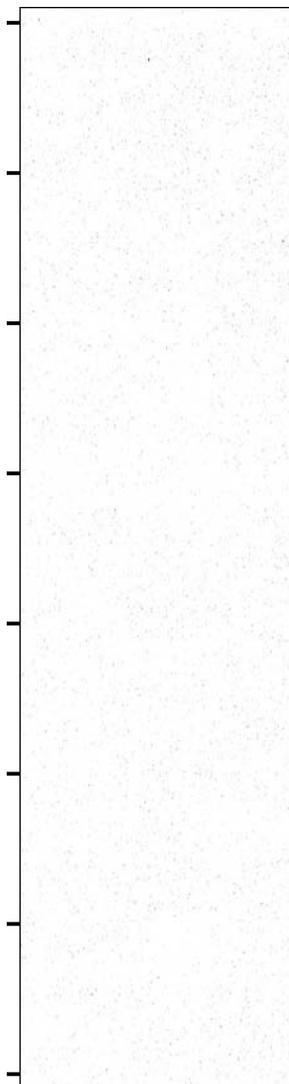


Figure 7: Characteristic x-ray map for sodium, MgCl_2 constant cold temperature experiment, distance between tic marks is 1.0 mm.

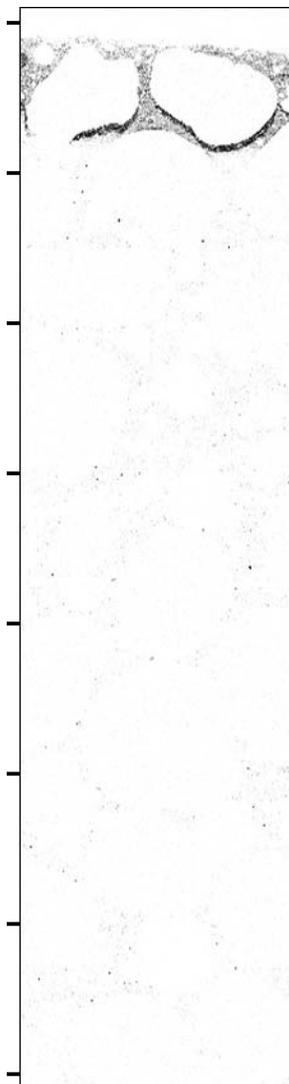


Figure 8: Characteristic x-ray map for magnesium, MgCl_2 constant cold temperature experiment, distance between tic marks is 1.0 mm.

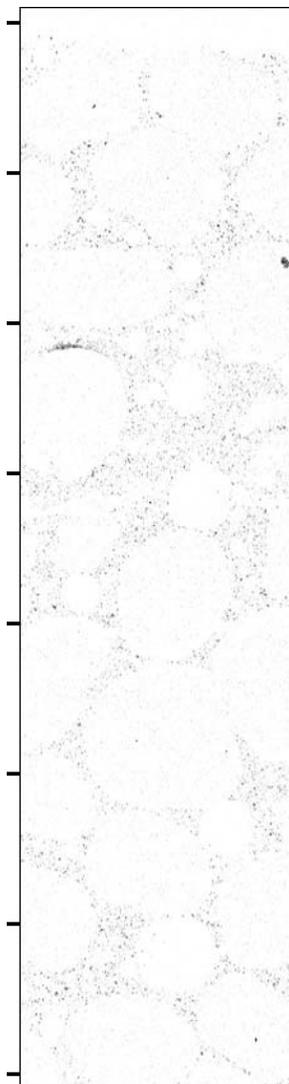


Figure 9: Characteristic x-ray map for aluminum, MgCl_2 constant cold temperature experiment, distance between tic marks is 1.0 mm.

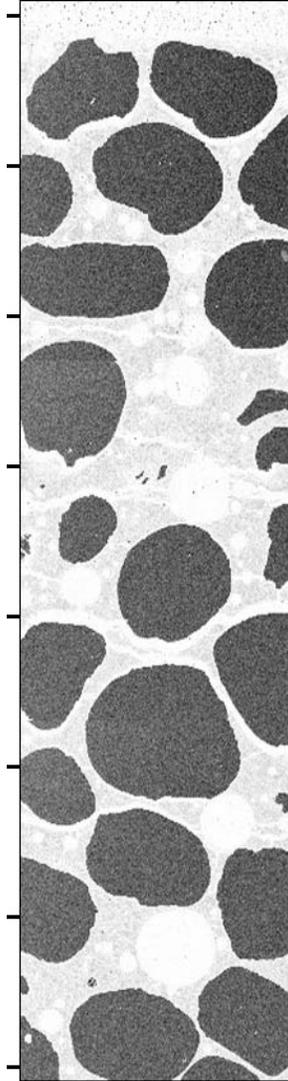


Figure 10: Characteristic x-ray map for silicon, MgCl_2 constant cold temperature experiment, distance between tic marks is 1.0 mm.

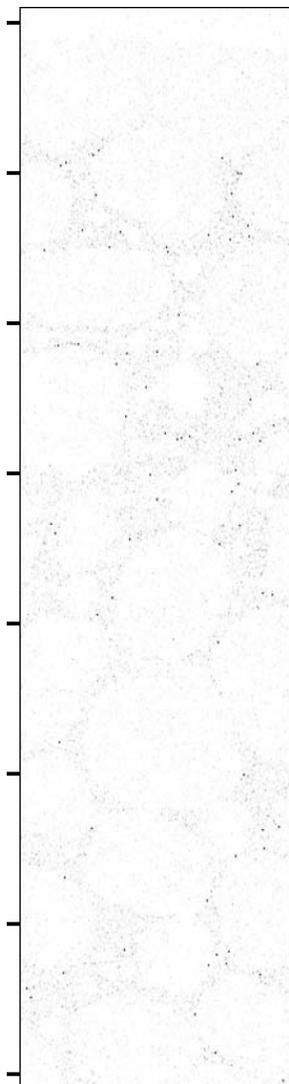


Figure 11: Characteristic x-ray map for sulfur, MgCl_2 constant cold temperature experiment, distance between tic marks is 1.0 mm.

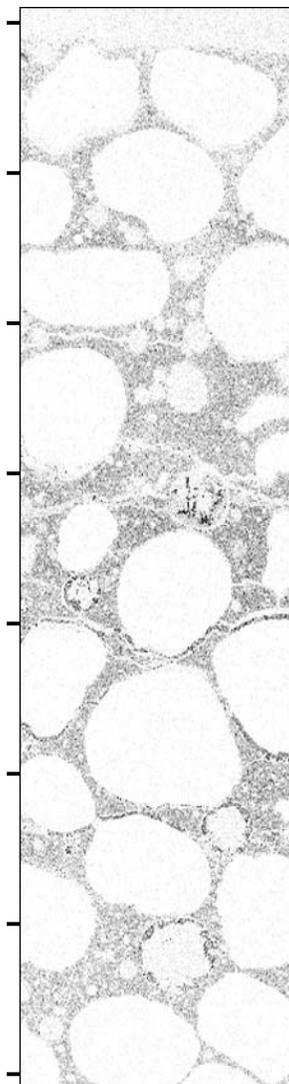


Figure 12: Characteristic x-ray map for chlorine, MgCl_2 constant cold temperature experiment, distance between tic marks is 1.0 mm.

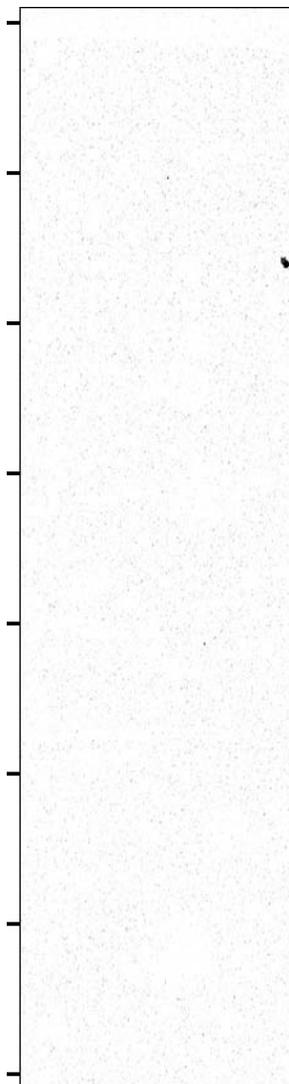


Figure 13: Characteristic x-ray map for potassium, MgCl_2 constant cold temperature experiment, distance between tic marks is 1.0 mm.

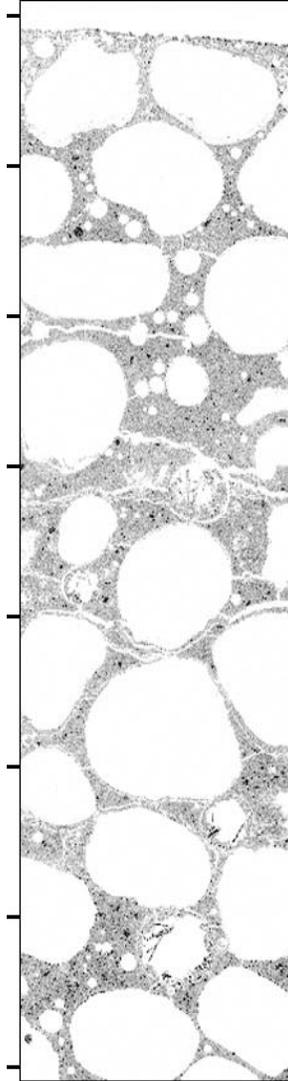


Figure 14: Characteristic x-ray map for calcium, MgCl_2 constant cold temperature experiment, distance between tic marks is 1.0 mm.

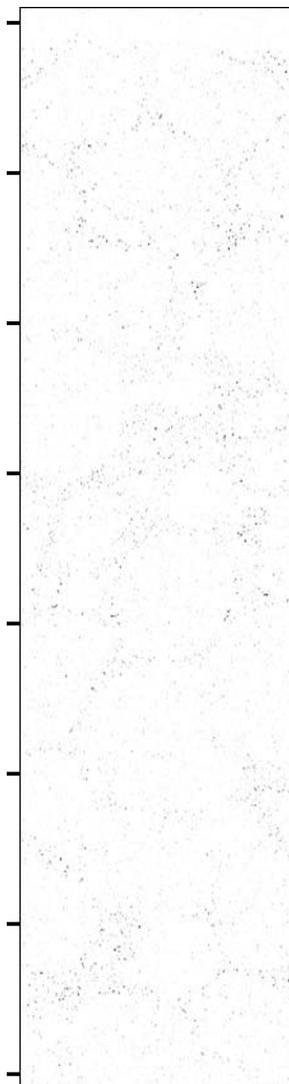


Figure 15: Characteristic x-ray map for iron, MgCl_2 constant cold temperature experiment, distance between tic marks is 1.0 mm.

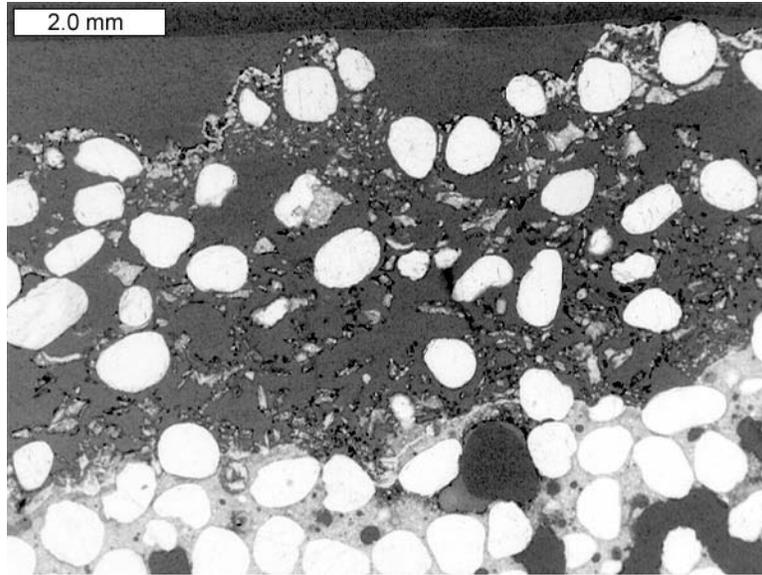


Figure 16: Petrographic microscope image, epifluorescent mode, calcium magnesium acetate constant hot temperature experiment.

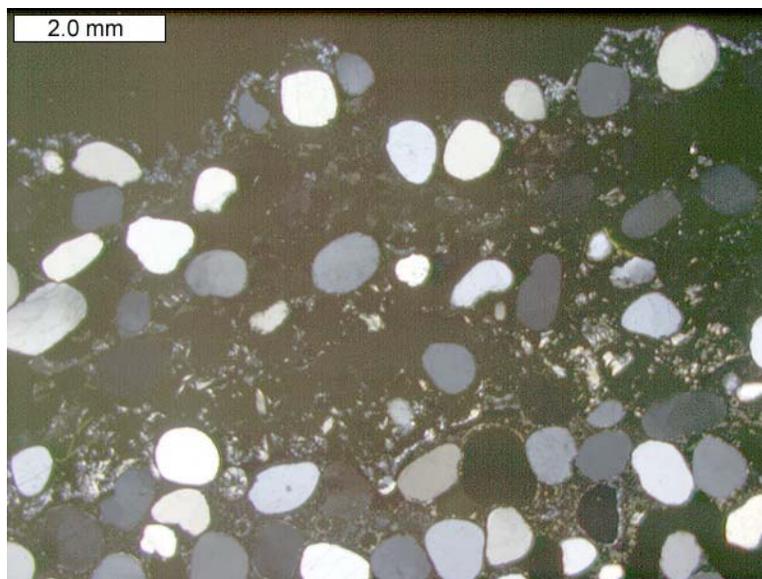


Figure 17: Petrographic microscope image, crossed polars, calcium magnesium acetate constant hot temperature experiment.

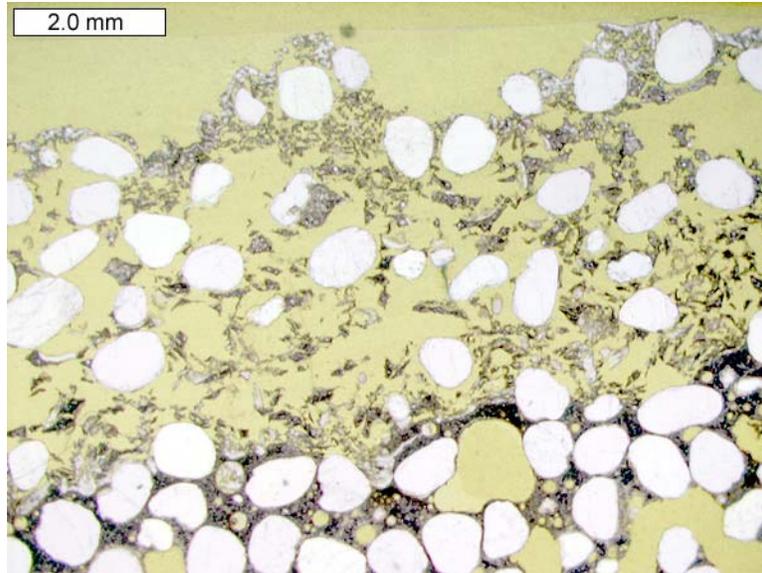


Figure 18: Petrographic microscope image, transmitted plane polarized light, calcium magnesium acetate constant hot temperature experiment.

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 -40%

SECTION III – PROPOSED PHASE II EXPERIMENTAL PLAN

The next phase of this study will investigate the effect various deicers have on concrete. Based on the results of the Phase I mortar experiment, it has been determined that the best approach is to use ASTM C 672, “*Standard Test Method for Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals*” as the basis for the testing. Both unsealed and sealed specimens will be tested. In addition, constant low temperature testing (at 40 °F) will also be conducted along with diffusion and permeability testing.

A single concrete mixture will be used in this testing, made with a high quality, partially crushed gravel coarse aggregate (maximum aggregate size of 1 in), natural sand, 564 lb/yd³ type I/II cement, a vinsol resin air entraining agent (air content of 6 ± 1 percent), and a water-to-cement ratio of 0.42. The slump will be 3 ± 0.5 in.

Scaling Resistance Testing

Table 1 presents the experimental design for the ASTM C 672 testing to be conducted on unsealed concrete specimens. It was decided to use three replicates (versus the two recommended in the test procedure), resulting in a total of 66 specimens being tested. In this test, concrete specimens having a minimum surface area of 72 in² and a depth of 3 in will be made and subjected to freezing and thawing cycles with the various deicers ponded on the surface. In addition to control specimens that will be ponded with limewater, two levels of concentration for each deicer (as listed in table 2) will be used. A total of six specimens will be tested for each deicer/concentration combination, three of which will be tested to 50 cycles and three of which will be tested for 100 cycles. In addition to rating the surface in accordance with ASTM C 672 at 5, 10, 15, 25, and every 25 cycles thereafter, mass loss will also be determined.

Table 1. Experimental design for unsealed ASTM C 672 testing.

<i>Concentration</i>	None		Low		High	
Cycles	50	100	50	100	50	100
Deicer						
None (limewater)	3	3				
NaCl			3	3	3	3
CaCl ₂			3	3	3	3
MgCl ₂			3	3	3	3
CMA			3	3	3	3
Proprietary			3	3	3	3
Total	3	3	15	15	15	15

Table 2. Deicer concentrations to be used in the Phase II testing.

Deicer	Concentration (%)	
	Low	High
NaCl	4.4	17.8
CaCl ₂	4.2	17.0
MgCl ₂	3.6	15.0
CMA	6.4	25.0
Proprietary	TBD	TBD

Similar testing will also be conducted on concrete that has had the surface sealed with one of two silane-based sealants under study. Table 3 summarizes the experimental design for the sealant testing. Once again, three replicates will be used, resulting in a total of 36 specimens being tested. Only the higher concentration of deicer will be used in this investigation. It is anticipated that these specimens will be subjected to 100 freeze-thaw cycles.

Table 3. Experimental design for sealed ASTM C 672 testing.

Deicer	Sealant 1	Sealant 2
None (limewater)	3	3
NaCl	3	3
CaCl ₂	3	3
MgCl ₂	3	3
CMA	3	3
Proprietary	3	3
Total	18	18

In addition to the scaling ratings and mass loss, upon completion of testing, petrography will be conducted on the various specimens. From this analysis, a measure of deicer penetration will be obtained and any alteration to the concrete microstructure will be assessed. This will allow for direct comparisons to be made regarding the effect of deicer concentration, deicer type, and the impact of sealants.

Low Temperature Testing

The constant low temperature testing conducted in Phase I revealed some interesting results, particularly with respect to the observations of chemical degradation observed in the specimens submerged in CaCl₂ and MgCl₂. To more fully understand these observations, 4-in diameter by 2-in high cylindrical concrete specimens will be made and submerged in deicer solutions at the same concentrations listed in table 2. Each week, the solution will be replaced, with the specimens being analyzed visually after 7, 28, 56 and 84 days of submersion. As indicated in table 4, specimens will be pulled at 56 and 84 days for petrographic evaluation.

Table 4. Experimental design for cylindrical specimens tested at 40 °F.

<i>Concentration</i>	None		Low		High	
Days	56	84	56	84	56	84
Deicer						
None (limewater)	3	3				
NaCl			3	3	3	3
CaCl ₂			3	3	3	3
MgCl ₂			3	3	3	3
CMA			3	3	3	3
Proprietary			3	3	3	3
Total	3	3	15	15	15	15

Diffusion and Permeability Assessment

Additional cylindrical specimens will also be cast for diffusion and permeability testing. Two specimens for each deicer/concentration combination will be prepared and submerged in solution to determine the diffusion coefficient at 28 and 56 days. Rapid chloride permeability testing (in accordance with ASTM C 1202) and sorptivity testing will also be conducted to provide an assessment of permeability.