TRANSPORTATION POOLED FUND PROGRAM
QUARTERLY PROGRESS REPORT

Lead Agency (FHWA or State DOT): ____IOWA DOT_______________________________________

INSTRUCTIONS:
Project Managers and/or research project investigators should complete a quarterly progress report for each calendar quarter during which the projects are active. Please provide a project schedule status of the research activities tied to each task that is defined in the proposal; a percentage completion of each task; a concise discussion (2 or 3 sentences) of the current status, including accomplishments and problems encountered, if any. List all tasks, even if no work was done during this period.

Transportation Pooled Fund Program Project # *TPF-5(100)*	**Transportation Pooled Fund Program - Report Period:** X Quarter 1 (January 1 – March 31), 2012 ☐ Quarter 2 (April 1 – June 30) ☐ Quarter 3 (July 1 – September 30) ☐ Quarter 4 (October 4 – December 31)

Project Title:
Deicer Scaling Resistance of Concrete Mixtures Containing Slag Cement

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Lead Agency Project ID: RT 0336	**Other Project ID (i.e., contract #):** Addendum 374	**Project Start Date:** 4/15/10
Original Project End Date: 10/14/11	**Current Project End Date:** **7/25/12**	**Number of Extensions:** Pooled fund project; interim funding

Project schedule status:

☐ On schedule X On revised schedule ☐ Ahead of schedule ☐ Behind schedule

Overall Project Statistics:

Total Project Budget	Total Cost to Date for Project	Total Percentage of Work Completed
$74,888	$4,341.11	50%

Quarterly Project Statistics:

Total Project Expenses This Quarter	Total Amount of Funds Expended This Quarter	Percentage of Work Completed This Quarter
$4,341.11	0	25%

Project Description:

Field surveys of portland cement concrete pavements and bridge decks containing slag cement (*13*) have already been conducted. This was done 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. The work also indicated that the test method C672 may be more severe than most environments.

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

Progress this Quarter (includes meetings, work plan status, contract status, significant progress, etc.):

All of the 16 Concrete Mixes have been cast with slumps ranging from 100-150mm.

1. 100% low alkali (LA) cement mix 0.42wc, 6-7% air entrained using Vinsol Admixture
2. 80% LA, 20% slag grade 120 mix 0.42wc, 6-7% air entrained using Vinsol Admixture
3. 65% LA, 35% slag grade 120 mix 0.42wc, 6-7% air entrained using Vinsol Admixture
4. 50% LA, 50% slag grade 120 mix 0.42wc, 6-7% air entrained using Vinsol Admixture
5. 100% high alkali (HA) cement mix 0.42wc, 6-7% air entrained using Vinsol Admixture
6. 80% HA, 20% slag grade 120 mix 0.42wc, 6-7% air entrained using Vinsol Admixture
7. 65% HA, 35% slag grade 120 mix 0.42wc, 6-7% air entrained using Vinsol Admixture
8. 50% HA, 50% slag grade 120 mix 0.42wc, 6-7% air entrained using Vinsol Admixture
9. 80% LA, 20% slag grade 100 mix 0.42wc, 6-7% air entrained using Vinsol Admixture
10. 65% LA, 35% slag grade 100 mix 0.42wc, 6-7% air entrained using Vinsol Admixture
11. 50% LA, 50% slag grade 100 mix 0.42wc, 6-7% air entrained using Vinsol Admixture
12. 80% HA, 20% slag grade 100 mix 0.42wc, 6-7% air entrained using Vinsol Admixture
13. 65% HA, 35% slag grade 100 mix 0.42wc, 6-7% air entrained using Vinsol Admixture
14. 50% HA, 50% slag grade 100 mix 0.42wc, 6-7% air entrained using Vinsol Admixture
15. 65% HA, 35% slag grade 120 mix 0.42wc, 6-7% air entrained using Vinsol Admixture
16. 50% HA, 50% slag grade 120 mix 0.42wc, 6-7% air entrained using Vinsol Admixture

For each mix, 6 slabs were cast for deicer scaling under the ASTM C672, modified BNQ and VaDOT accelerated curing regimes (2 slab specimens for each test).

Tests being conducted on the mixes above include:

- 7, 14, 28 days, and 28 VaDOT accelerated curing (7days moist, then 21days moist at 38°C) and 56 day compression strength tests (2 cylinders cast for each testing period)
- 14, 28, 28 accelerated, 56 day RCPT testing (2 samples per testing period)
- Samples have been prepped and scanned for Air Void analysis for all mixes mentioned above.
- 50 cycles of freeze/thaw cycling has been completed for 16 mixes listed above (scaling mass loss results are shown in Table 1 in Appendix A). For Mix 16, an additional pair of slabs was cast to evaluate the effect of not using a geotextile in the bottom of the forms in the BNQ test.
- Mix #9 was recast and cycling has commenced on slabs to evaluate the impact of a 14 day drying period prior to initiating freezing cycles and after the VaDOT accelerated curing period. Two additional slabs were cast for this mix to evaluate the effects of one-dimensional freezing/thawing (i.e. insulating the sides and bottoms of the slabs)
- A preliminary analysis of the current data is appended to this progress report (Appendix A).
- A slab was instrumented with thermocouples to determine the temperature cycles experienced in the solution and just below the concrete surface (results are shown in figures 1-3 of Appendix A).

- Mixes #15 and #16 were recast to determine the effects of using Micro Air entraining admixture in addition to the Vinsol air entraining admixture used in the prior test mixes. Each mix will also be evaluated for differences in the $CaCL_2$ solution used in ASTM C672 and the NaCl solution used in the BNQ procedure

Anticipated work next quarter:

- Final analysis of all the data obtained including data from the recasting of mixes #15 and 16 to evaluate the effects of Micro-Air entrainment.
- Submission of a MASc thesis and final report
- Iowa State University will continue testing

Significant Results:
See Appendix A attached as pdf.

Circumstance affecting project or budget (Describe any challenges encountered or anticipated that might affect the completion of the project within the time, scope, and fiscal constraints set forth in the agreement, along with recommended solutions to those problems).
The University of Toronto's work will be completed by the cooperative agreement deadline. However, some of the testing being done by ISU will need to be done after UT's work is completed. An extension will be required.

Appendix A

Short Summary of Test Results as of March 31, 2012

Prepared by D. Vassilev, University of Toronto

1. Analysis of Strength Results (Table 1)

1. The 0.38w/cm mixes with the 50% high-alkali (HA) cement achieved some of the highest compressive strengths to date despite their high slag content of 50%.

2. In general, the accelerated curing did not increase compressive strength significantly at 28 days. Only marginal gains of about 4MPa were experienced due to accelerated curing after 7days moist curing followed by 21days of submerged curing in $Ca(OH)_2$ solution at 38°C (100°F). This is probably because the temperature difference between the moist curing room at 25°C and the 38°C room is small (only 12°C). Additionally, much of the hydration has taken place by the 7^{th} day, which is the point at which accelerated curing begins.

3. Low-alkali (LA) cement mixes performed better than HA mixes in all compression strength cases regardless of slag type and slag content used.

4. On average, LA cement with Grade 100 slag developed 10MPa higher compressive strengths when compared to HA-cement mixes with identical slag contents.

5. On average, LA cement with Grade 120 slag mixes experienced only a 5MPa higher compressive strength when compared to HA-cement mixes with identical slag contents.

6. Overall LA-cement mixes had higher compressive strengths than HA-cement mixes with identical slag contents.

7. By comparing the same cements (LA or HA) but varying slag types it was observed that Grade 100 slag mixes performed better then Grade 120 slag mixes in some cases, but not in others. In each case, the differences in compressive strength were not substantial.

8. Compressive strength increased with curing time except for 3 mixes, which experienced a slight drop in compressive strength at 28days. It is assumed this was due to a defect in the cylinders or grinding process, therefore resulting in slightly lower compressive strengths (the end-grinder was refurbished after these tests).

9. The main factors governing compressive strength results appeared to be the w/cm ratio, cement type, and curing period.

10. Varying the slag type produced inconclusive results.

11. Varying the slag content did not make a significant difference in compressive strength.

12. Increasing the air content reduced compressive strength.

2. Analysis of RCPT Results (Table 2)

1. Reducing the w/cm ratio produced the most significant reduction in charge passed and best results in terms of resistance to current flow.

2. Increasing the slag content also significantly reduced current flow in every case. For example, if 100% cement was used, then the charge passed was >4000 coulombs at 7days and reduced to the low 2000 coulomb range by 56 days, while adding 50% slag reduced the charge passed to <1400coulombs at 7 days and to around 700 coulombs at 56 days.

3. At 56 days and in general, HA cements performed better in the RCPT test than LA cements, but the difference was not great and on average was less than 500 coulombs.

4. In general the Grade 120 slag performed better than the Grade 100 slag, however, the differences were small (<500 coulombs).

5. Length of curing had a large influence on the RCPT results. As curing age increased, the charge passed decreased significantly. This is as expected, due to the higher degree of hydration, resulting in the development of a more tortuous cement microstructure.

6. Accelerated curing had a marginal, but positive effect on the RCPT results (unlike the large reductions found for fly ash concretes by VaDOT). This is likely because the temperature difference between the moist curing room at 25°C and the 38°C room is small (only 12°C). Additionally, unlike fly ash, some of the slag hydration has taken place by the 7th day, which is the point at which accelerated curing begins.

7. The main factors influencing the RCPT test appear to be w/cm ratio, curing time, and slag content. Using HA cement vs LA cement, Grade 120 vs Grade 100 slag and an accelerated curing regime produced positive results, but of lower significance.

3. Analysis of Scaling Results (Table 3)

1. Reducing the w/cm ratio from 0.42 to 0.38 produced the most significant reduction in scaling even with 50% slag content regardless of test method and slag grade used (See Table 3, all tests are not complete). All specimens with w/cm of 0.38 appear to pass the scaling mass loss requirements.

2. Scaling performance after exposure to the VaDOT accelerated curing was much worse than with the ASTM and BNQ curing methods for the **100% Portland cement mixes**. The ASTM method passed the 100% LA-cement mix, however, scaling slightly exceeded the limits for the 100% HA-cement mix. It is possible that the 100% HA cement mix failed using the ASTM method because the hardened air content was found to be 4.8%, which is below the specified range of 6-7% air entrainment. The hardened air content of the LA cement mix was found to be very low at 3.4%, while the fresh concrete air content as measured by the air meter was 6.1%. This large discrepancy is believed to have occurred because of a longer than expected casting time, since only one technician was available for the preparation of this particular mix. This resulted in a very low slump, which made it difficult to finish and consolidate the concrete. However, these results also indicate the strong resistance of the LA cement mix to scaling even at low air entrainment contents. The BNQ method gave the best performance with very limited scaling, which was below both the ASTM <0.8 kg/m^2 and BNQ <0.5 kg/m^2 mass loss scaling limits.

3. When comparing the **20% slag mixes,** the LA-cement mixes performed better than the HA-cement mixes regardless of slag type used. All the 20% slag mixes passed the ASTM scaling limit except for Mix #8 (80% HA 20% SG100 0.42w/c). Mix #8 failed all three scaling tests marginally (refer to Table 3), which could be explained by its lower hardened air entrained content of 4.5% compared to an air content greater than 5% for the remaining 20% slag mixes. The BNQ method gave the best performance, meeting both the ASTM <0.8kg/m^2 and BNQ <0.5kg/m^2 scaling mass loss requirements. The Grade 120 slag performed better than the Grade 100 slag in the HA cement mixes, but the Grade 100 performed better in the LA-cement mixes.

4. When comparing the **35% slag mixes,** the slabs exposed to the ASTM method performed the best and passed the MTO limit of 800 g/m^2. It is important to note that Mix #9 (65%HA 35% SG100 0.42w/cm) initially just failed the ASTM test at 4.9% hardened air entrainment, but when recast with a higher hardened air entrained content of 5.8% it passed well below the specified MTO scaling limit. The results appear to be inconclusive for the BNQ and VaDOT methods as they performed very well for Mix #6 (65%LA 35% SG100 0.42w/cm), but performed quite poorly in all the other 65% cement mixes.

Mix #9 (65%HA 35% SG100 0.42w/cm) was recast to determine reproducibility, compare 1-Dimensional freezing cycles (using insulated bottom and sides of the slabs), and add a 14d drying cycle after the VaDOT 28day curing. Slabs subjected to 1-Dimensional freezing experienced significantly less scaling than all other slabs at 50cycles. Extremely little scaling was observed and thawing cycles were longer by about 2hrs. By applying hand pressure to the frozen surface it was observed that the surface was harder and stiffer than other slabs cast to date. It is likely that the insulation provides lower temperature gradients reducing thermal shock and therefore reducing scaling. 1-Dimensional freezing could also reduce hydraulic pressures as the concrete's pores below the surface may remain frozen and not be subjected to the continuous freeze/thaw cycling.

Additionally, a 14 day drying cycle was added to the VaDOT curing regime before saturating with solution for 7 days prior to initiating freezing cycles. It was hypothesized that during curing, slabs subjected to VaDOT accelerated curing regime become more saturated, since they are submerged in $Ca(OH)_2$ solution and cured for 21days at 38C (100F). This saturation increases scaling when cycling commences, therefore a 14 day drying cycle was added to mimic the BNQ and ASTM conditioning procedures. The slabs exposed to VaDOT accelerated curing and then to a 14 day drying period experienced less scaling than those without a drying cycle by about 50% and met the MTO scaling limits. Part of the improvement in scaling can also be attributed to the better air entrainment obtained in the recasting of Mix #9.

5. When comparing the **50% slag tests,** the slabs exposed to the ASTM preconditioning cycle performed the best and in some cases met MTO mass loss scaling requirements as in Mix #7 and 16, but not the lower BNQ scaling mass loss limit. It was observed that in general, the slabs exposed to the BNQ and VaDOT curing/conditioning methods experienced low levels of scaling during the initial 15 cycles at which point the slab surfaces deteriorated rapidly until termination of testing. It is possible that the 4% $CaCl_2$ solution used in the ASTM test is not as detrimental to the concrete surface at high levels of slag content, compared to the 3% NaCl solution used in the BNQ and VaDOT testing. This is confirmed by Valenza II and Scherer (2005) who suggested that a pessimum concentration exists at ~3%, independent of the solute used. Through the application of hand pressure it was observed that the frozen surfaces of slabs with $CaCl_2$ solution were less stiff than those ponded with NaCl solution. Therefore, it is possible that the ice bond with the concrete surface when $CaCl_2$ solution is used is weaker than the bond formed using NaCl and as the ice cracks, a lower stress is transferred to the surface resulting in less scaling. This theory may be supported by the differential in scaling observed by the VaDOT and BNQ methods where large quantities of small flakes <0.5cm in diameter were collected as residue and smaller quantities of larger flakes ~1.5cm diameter were collected form slabs exposed to the ASTM procedure. This phenomenon was consistent for all mixes tested and may be observed in the scaled surfaces of the slabs in Figures 1 and 2 where the former was exposed to ASTM and the latter to the VaDOT test procedure.

Figure 1: ASTM exposure for Mix #13 50%LA 50%SG120 0.42w/c at 25cycles where coarser scaling is observed

Figure 2: VaDOT exposure for Mix #13 50%LA 50%SG120 0.42w/c at 25cycles where finer scaling is observed

Additionally, 8 instead of 6 slabs were cast for Mix #16 (50%HA 50SG120 0.42w/cm) to test the adequacy of adding a geotextile layer to the lower side of the BNQ slabs. Based on the data collected, it appears that the presence or absence of the geotextile in the forms (to allow some bleed water to be removed) did not make a difference in the scaling of the slabs as the scaling curves were almost identical. It is important to note that none of the 16 mixes cast experienced significant bleeding, probably due to their low w/cm ratio. Therefore, it would be premature to dismiss the effectiveness of a geotextile as a bleeding inhibitor especially in concretes with higher w/cm ratios.

6. After the 15th freezing cycle, the BNQ and VaDOT slabs experienced an increased rate of scaling. It is possible this occurred as the cement pores become more saturated after part of the concrete surface is damaged and flakes off. Repeated freeze/thaw cycling could also damage the finer capillary pore structure typically associated with slag mixes, inducing micro cracking and allowing deeper salt penetration.

4. Analysis of Air Entrainment (A/E) (Table 4)

1. All the original 16 mixes were air entrained with a Vinsol resin admixture. The fresh and hardened air content properties of each mix were determined and recorded in Table 4. A cylinder was cut longitudinally in half and then two sections 75mm x 100mm (3”x4”) were polished and analyzed for A/E content. The average air content and spacing factor of the two sections was recorded in Table 4.

2. It was observed that the use of 100% LA cement reduced the required air entrainment dosage by about 20% compared to the HA cement.

3. Increasing Grade 100 slag contents with the LA cement progressively reduced the Vinsol A/E demand.

4. Increasing Grade 100 slag contents with HA cement progressively increased the Vinsol A/E demand.

5. Increasing Grade 120 slag contents with LA cement progressively reduced the Vinsol A/E demand.

6. Increasing Grade 120 slag contents with HA cement progressively increased the Vinsol A/E demand.

7. In general an improvement in the hardened air content of a mix improved the scaling resistance regardless of the scaling procedure used to test the concrete surface. The greatest improvement was observed in the VaDOT regime. This supports the previous hypothesis, which suggested that during curing, the slabs subjected to VaDOT accelerated curing regime become more saturated , since they are submerged in $Ca(OH)_2$ solution and cured for 21days at 38C (100F). This saturation increases scaling when cycling commences. However, with improved air content and spacing factor, the hydraulic and crystallization pressures will be reduced resulting in less scaling.

8. While comparing fresh air contents to hardened air contents it was observed that in most cases the hardened air content was under predicted by the pressure air meter test. In several cases this discrepancy was more than 1%, which indicates that additional Vinsol admixture may need to be added to achieve an adequate air content and spacing factor.

9. Comparing this project's polished samples with other existing samples obtained from MTO (for other research) it was visually observed that the Vinsol resin admixture used produced larger air bubbles. Three air entrained samples are presented in the appendix to this report to indicate air contents of 4-5% (Figure 3), 5-6% (Figure 4) and 6-7% (Figure 5). Samples obtained from MTO had much smaller A/E bubbles, which also appear to be more closely spaced. Over 300 samples have been received for air analysis, but only a select few are presented in this report to provide a visual of a 4-5% (Figure 6), 5-6% (Figure 7) and 6-7% (Figure 8) air-entrained concrete. Additional mixtures with Micro Air AEA admixture have been cast to verify this phenomenon. Unfortunately, at this time the composition of the mix designs and type of AE admixture used in the MTO samples is unknown, but a request has been made for this information.

5. Temperature in Slabs during Freezing and Thawing

1. A slab was instrumented with three separate thermocouples to measure the freeze/thaw rate, (a) just above the slab surface and submerged in NaCl solution (Figure 3), (b) 3mm below the slab surface (Figure 4) and, (c) at the slab's center of mass 42mm below the surface (Figure 5).

2. The 1st cycle was performed at the top of the freezer, the 2nd cycle took place in the middle portion, and the 3rd cycle was at the bottom of the freezer.

3. Results were somewhat surprising as all three thermocouples appear to register almost identical temperatures during cycling. It was expected that there would be a significant delay in the rate of freezing and thawing of the slab interior. This is not the case as temperature variations are quite minimal. The observed results may be explained due to concrete's low R-value (thermal resistance). In addition, freezing was not 1-dimensional as all sides of the slab were exposed to freezing, however, the thermocouples were centred in the 300 x 200 mm slab. Unlike a massive concrete structure, which can retain and radiate heat for extended periods of time, the slab subjected to testing was quite small 300mm x 200mm x 85mm (12 x 8 x 3.5 in.).

4. There was no major significance noted in the freeze/thaw rates regardless of top, middle or bottom location of the slab in the freezer. This eliminates the concern with variability in scaling results as all slabs would be subject to nearly identical freeze/thaw cycles, regardless of position in the upright freezer.

5. From the figures, it can be observed that the freezing/thawing point of the NaCl solution takes place at around -3°C (26.5°F). This point is marked by the slower rate of freezing and thawing as water transitions from a solid to liquid state, indicating the change in enthalpy.

6. From the data, it can be observed that the thawing rate is faster than the freezing rate. The sequential freeze/thaw cycles appear to be consistent.

7. Temperatures during cycling are within the thawing limits and peak at about 12°C (53.5°F), however, the freezing limit is slightly exceeded and drops to about -21.5°C (-6.5°F). This is not anticipated to have a significant impact on scaling as the limit is only exceeded by 1.5°C (2.5°F).

Appendix A

Table 1 Compressive Strength Results

Compressive Strength (MPa)					
Mix #: % Cement w/cm	**7 days**	**14 days**	**28 days**	**56 days**	**VaDOT Accelerated Cure 28 days**
Mix #1: 100HA 0.42wc	34.3	39.2	43.0	48.1	48.6
Mix #2: 0.5HA 0.5SG100 0.38wc	40.7	44.0	48.0	60.7	51.0
Mix #3: 0.5HA 0.5SG120 0.38wc	44.6	49.9	50.8	60.1	54.3
Mix #4: 100LA 0.42wc	43.8	45.7	47.0	54.1	51.9
Mix #5: 0.8LA 0.2SG100 0.42wc	37.8	43.2	45.8	50.5	48.3
Mix #6: 0.65LA 0.35SG100 0.42wc	38.4	45.2	49.2	50.2	48.8
Mix #7: 0.5LA 0.5SG100 0.42wc	35.4	41.5	45.7	48.7	49.8
Mix #8: 0.8HA 0.2SG100 0.42wc	29.8	37.8	34.3	46.0	39.2
Mix #9: 0.65HA 0.35SG100 0.42wc	30.3	33.0	35.7	43.1	39.6
Mix #10: 0.5HA 0.5SG100 0.42wc	23.4	28.2	29.1	33.0	32.5
Mix #11: 0.8LA 0.2SG120 0.42wc	38.2	37.5	42.0	44.8	49.6
Mix #12: 0.65LA 0.35SG120 0.42wc	37.3	41.4	48.3	48.7	51.2
Mix #13: 0.5LA 0.5SG120 0.42wc	42.5	43.0	44.3	49.4	50.4
Mix #14: 0.8HA 0.2SG120 0.42wc	32.2	38.9	37.5	42.7	37.2
Mix #15: 0.65HA 0.35SG120 0.42wc	35,2	36.5	38.5	45.0	41.8
Mix #16: 0.5HA 0.5SG120 0.42wc	36.7	39.4	38.5	45.9	42.4

Table 2 ASTM C1202 Data

ASTM C1202 Resistance to Chloride Penetration (coulombs)				
Mix #: % Cement w/cm	**14 days**	**28 days**	**56 days**	**VaDOT Accelerated Cure 28 days**
Mix #1: 100HA 0.42wc	4514	3552	2393	1959
Mix #2: 0.5HA 0.5SG100 0.38wc	821	674	592	522
Mix #3: 0.5HA 0.5SG120 0.38wc	773	560	518	511
Mix #4: 100LA 0.42wc	4920	3664	2057	3283
Mix #5: 0.8LA 0.2SG100 0.42wc	2568	2399	1565	2044
Mix #6: 0.65LA 0.35SG100 0.42wc	1430	1203	1002	898
Mix #7: 0.5LA 0.5SG100 0.42wc	1260	1020	764	778
Mix #8: 0.8HA 0.2SG100 0.42wc	2971	1772	1341	1299
Mix #9: 0.65HA 0.35SG100 0.42wc	1412	1258	832	930
Mix #10: 0.5HA 0.5SG100 0.42wc	1238	1019	763	658
Mix #11: 0.8LA 0.2SG120 0.42wc	2743	2018	1254	1415
Mix #12: 0.65LA 0.35SG120 0.42wc	2019	1243	1147	909
Mix #13: 0.5LA 0.5SG120 0.42wc	1332	992	648	744
Mix #14: 0.8HA 0.2SG120 0.42wc	2207	1734	1209	1386
Mix #15: 0.65HA 0.35SG120 0.42wc	1463	1164	762	950
Mix #16: 0.5HA 0.5SG120 0.42wc	993	826	703	688

Table 3 Scaling Mass Loss Data

Mix	Average Scaling Mass Loss after 50 cycles (g/m^2)						Average Air Content	Spacing Factor	Slump
Test Method	ASTM C672	BNQ	VADOT	VADOT + 14days drying	BNQ 1D Freezing	BNQ no geotextile			
Salt Solution	4% CaCl2	3% NaCl	3% NaCl	3% NaCl	3% NaCl	3% NaCl			
Preconditioning of Slabs	14dmoist/ 14d dry	14dmoist/ 14d dry/7d solution	7d moist-23C/21-d wet-38C	7d moist-23C/ 21d wet-38C/14d dry	14dmoist/ 14d dry/7d solution	14dmoist/ 14d dry/7d solution			
Age when Freezing started	28 days	35 days	28 days	42 days	35 days	35 days			
Mix #1: 100HA 0.42wc	1064	95	3692				4.84	0.247	100
Mix #2: 0.5HA 0.5SG100 0.38wc	248	486	277				5.97	0.196	140
Mix #3: 0.5HA 0.5SG120 0.38wc	101	163	487				6.97	0.178	130
Mix #4: 100LA 0.42wc	409	104	3966				2.93	0.252	100
Mix #4 Recast: 100LA 0.42wc	170	163	487				10	0.122	100
Mix #5: 0.8LA 0.2SG100 0.42wc	268	75	78				7.77	0.165	130
Mix #5 Recast: 0.8LA 0.2SG100 0.42wc	205	79	116				5.09	0.275	120
Mix #6: 0.65LA 0.35SG100 0.42wc	527	241	197				6.7	0.253	135
Mix #7: 0.5LA 0.5SG100 0.42wc	580	1529	1221				4.95	0.252	140
Mix #8: 0.8HA 0.2SG100 0.42wc	944	986	934				4.5	0.239	120
Mix #9: 0.65HA 0.35SG100	897	958	1101				4.91	0.283	140
Mix #9 Recast: 0.65HA 0.35SG100	290	N/A	1013	553	137		5.82	0.248	145
Mix #10: 0.5HA 0.5SG100 0.42wc	2568	2662	1698				6.8	0.155	150
Mix #11: 0.8LA 0.2SG120 0.42wc	399	478	545				5.92	0.181	100
Mix #12: 0.65LA 0.35SG120 0.42wc	730	1342	1563				5.05	0.264	130
Mix #13: 0.5LA 0.5SG120 0.42wc	1574	2576	2042				5.63	0.228	115
Mix #14: 0.8HA 0.2SG120 0.42wc	777	236	761				5.83	0.214	125
Mix #15: 0.65HA 0.35SG120 0.42wc	546	1661	1018				3.22	0.358	140
Mix #16: 0.5HA 0.5SG120 0.42wc	637	1797	1683			1658	4.52	0.23	140

Table 4 Air Entrainment Properties

Mix	Vinsol Admixture (mL/m3)	Fresh Air Content (%)	Average Hardened Air Content (%)	Spacing Factor (mm)	Slump (mm)
Mix #1: 100HA 0.42wc	135.7	6.0	4.84	0.247	100
Mix #2: 0.5HA 0.5SG100 0.38wc	78.6	6.2	5.97	0.196	140
Mix #3: 0.5HA 0.5SG120 0.38wc	128.6	6.4	6.97	0.178	130
Mix #4: 100LA 0.42wc	107.7	6.1	3.36	0.278	100
Mix #4 Recast: 100LA 0.42wc	105.7	9.4	10	0.122	100
Mix #5: 0.8LA 0.2SG100 0.42wc	85.7	7.5	7.77	0.165	130
Mix #5 Recast: 0.8LA 0.2SG100 0.42wc	75.7	6.8	5.09	0.275	120
Mix #6: 0.65LA 0.35SG100 0.42wc	75.7	7.0	6.7	0.253	135
Mix #7: 0.5LA 0.5SG100 0.42wc	92.9	6.1	4.95	0.252	140
Mix #8: 0.8HA 0.2SG100 0.42wc	107.1	6.2	4.5	0.239	120
Mix #9: 0.65HA 0.35SG100	128.6	7.0	4.91	0.283	140
Mix #9 Recast: 0.65HA 0.35SG100	126.7	6.4	5.82	0.248	145
Mix #10: 0.5HA 0.5SG100 0.42wc	85.7	7.0	6.8	0.155	150
Mix #11: 0.8LA 0.2SG120 0.42wc	100.0	7.0	5.92	0.181	100
Mix #12: 0.65LA 0.35SG120 0.42wc	92.9	6.5	5.05	0.264	130
Mix #13: 0.5LA 0.5SG120 0.42wc	90.0	6.4	5.63	0.228	115
Mix #14: 0.8HA 0.2SG120 0.42wc	113.3	6.2	5.83	0.214	125
Mix #15: 0.65HA 0.35SG120 0.42wc	114.3	6.0	3.22	0.358	140
Mix #16: 0.5HA 0.5SG120 0.42wc	126.7	6.0	4.52	0.23	140

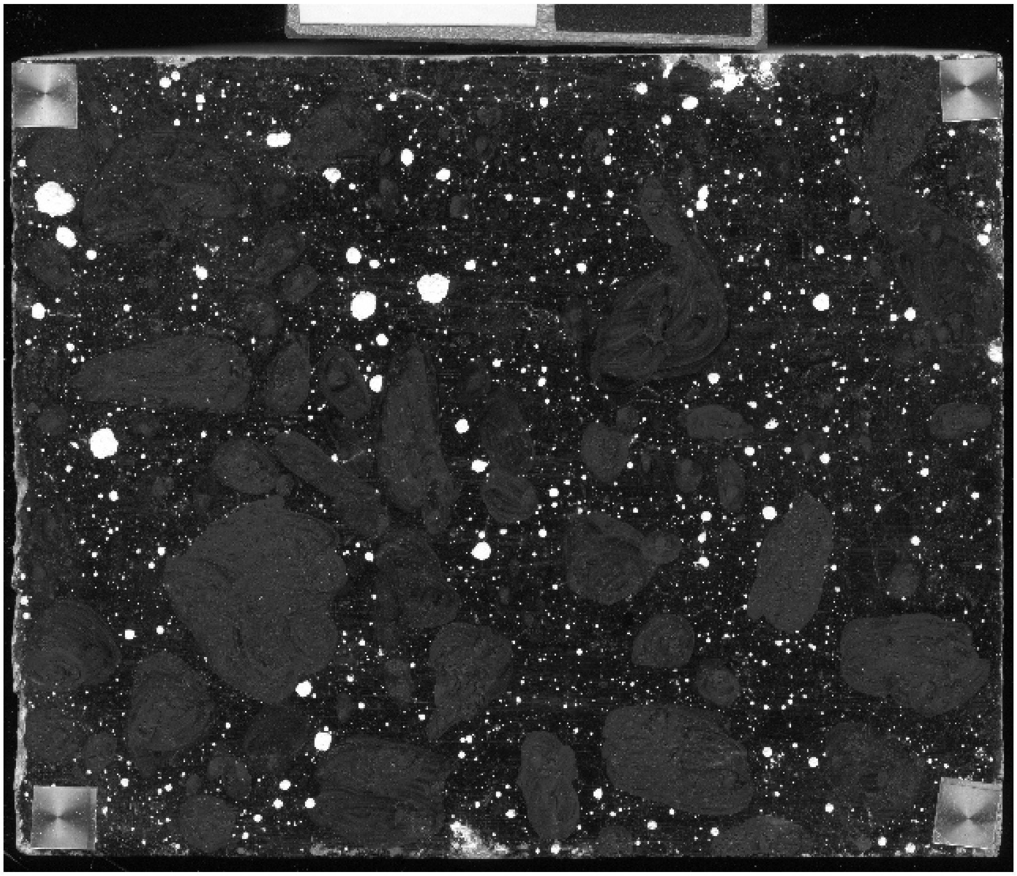

Figure 3: Scanned sample of Mix #8: 0.8HA 0.2SG100 0.42wc for 4-5% air content and 0.239mm spacing factor

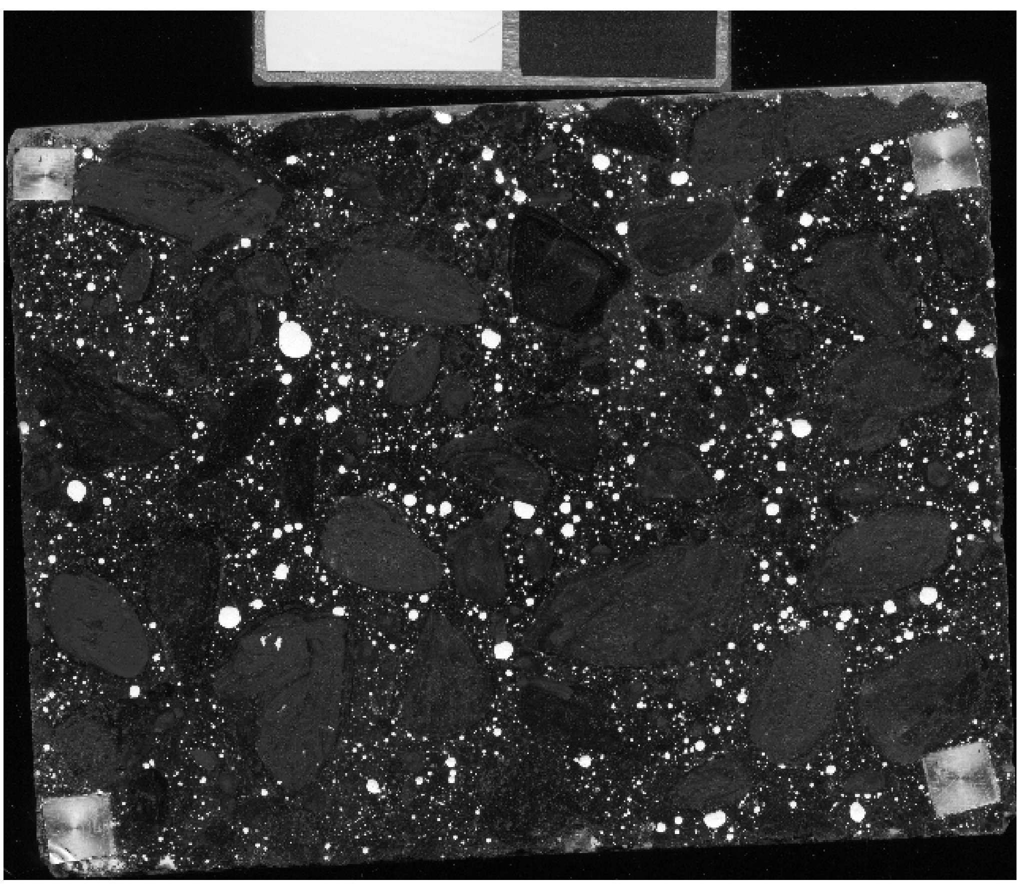

Figure 4: Scanned sample of Mix #14: 0.8HA 0.2SG120 0.42wc for 5-6% air content and 0.214mm spacing factor

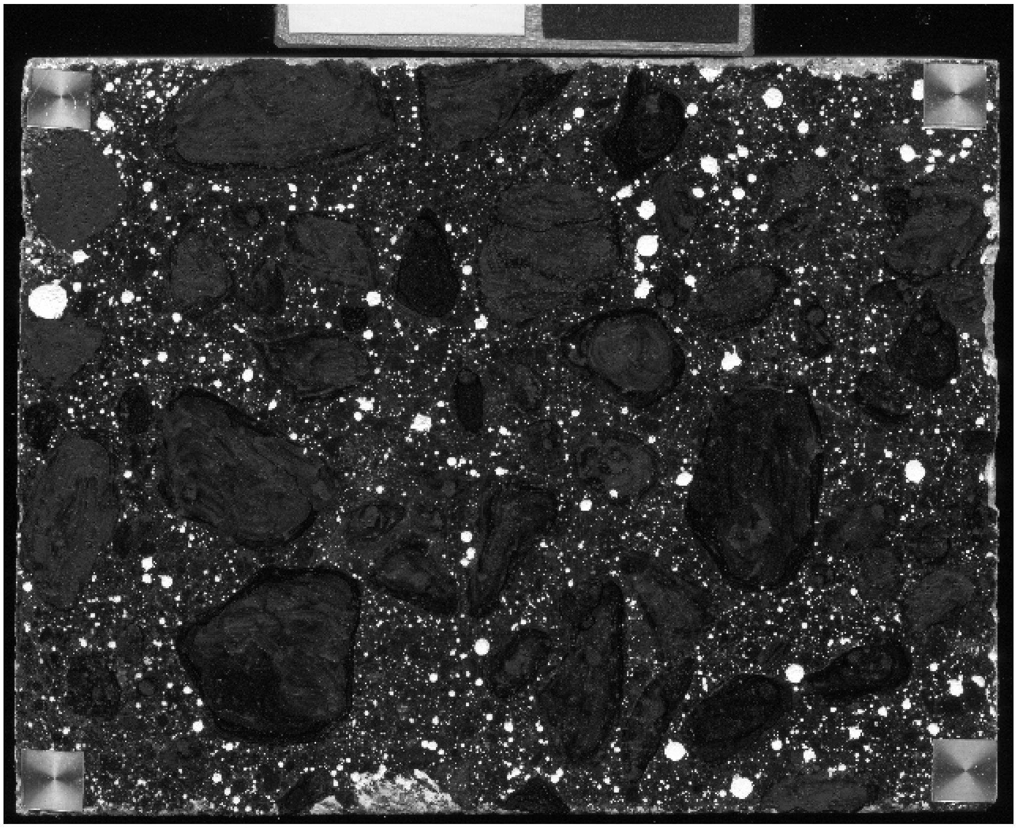

Figure 5: Scanned sample of Mix #10: 0.5HA 0.5SG100 0.42wc for 6-7% air contentand 0.155mm spacing factor

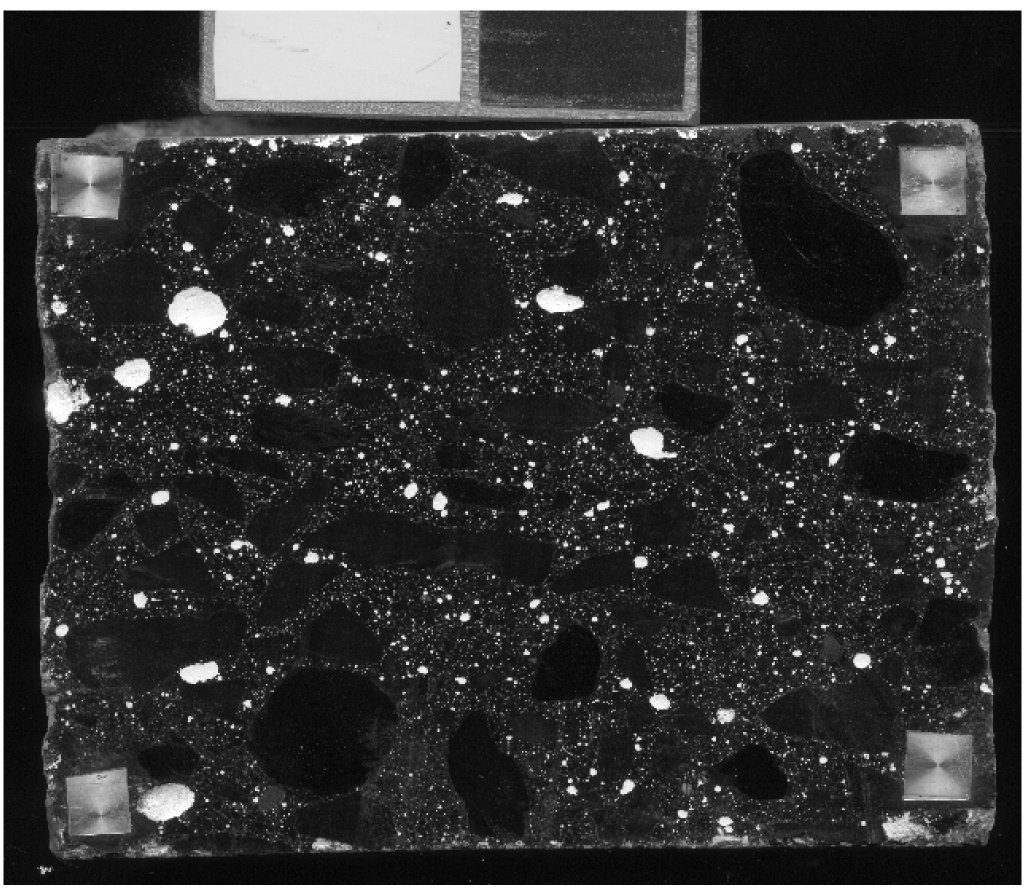

Figure 6: MTO Scanned sample of 4-5% air content

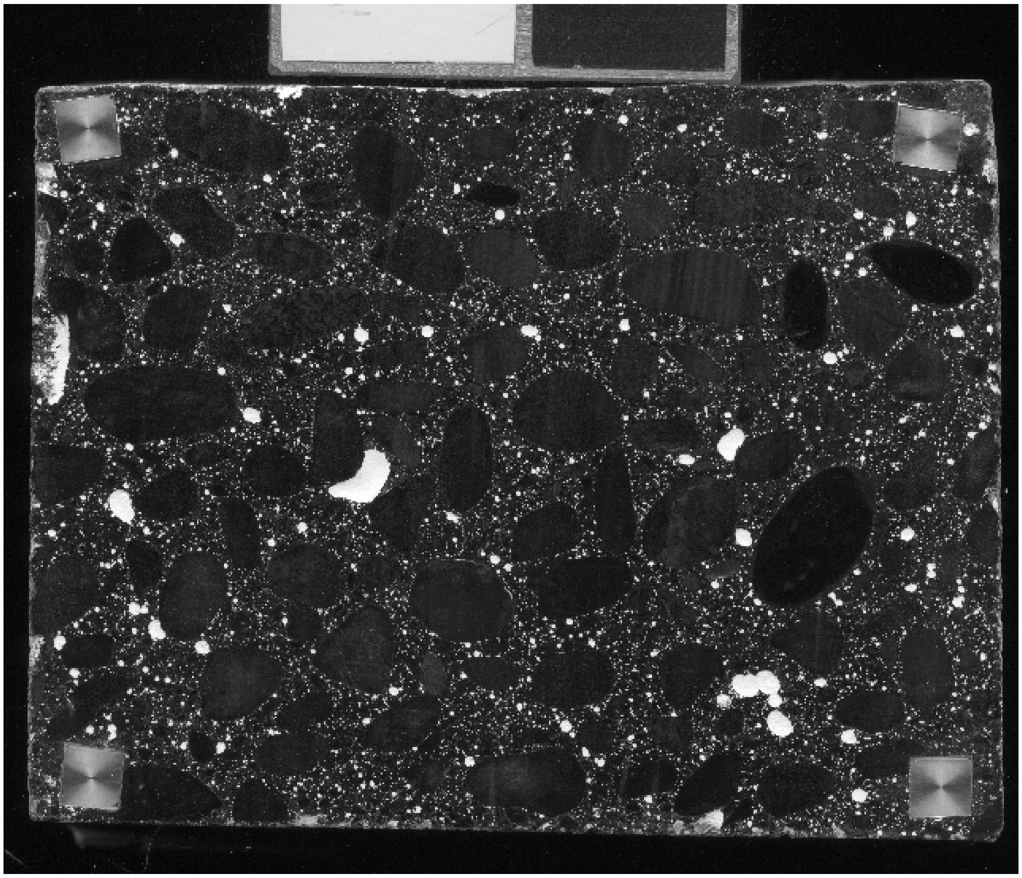

Figure 7: MTO Scanned sample of 5-6% air content

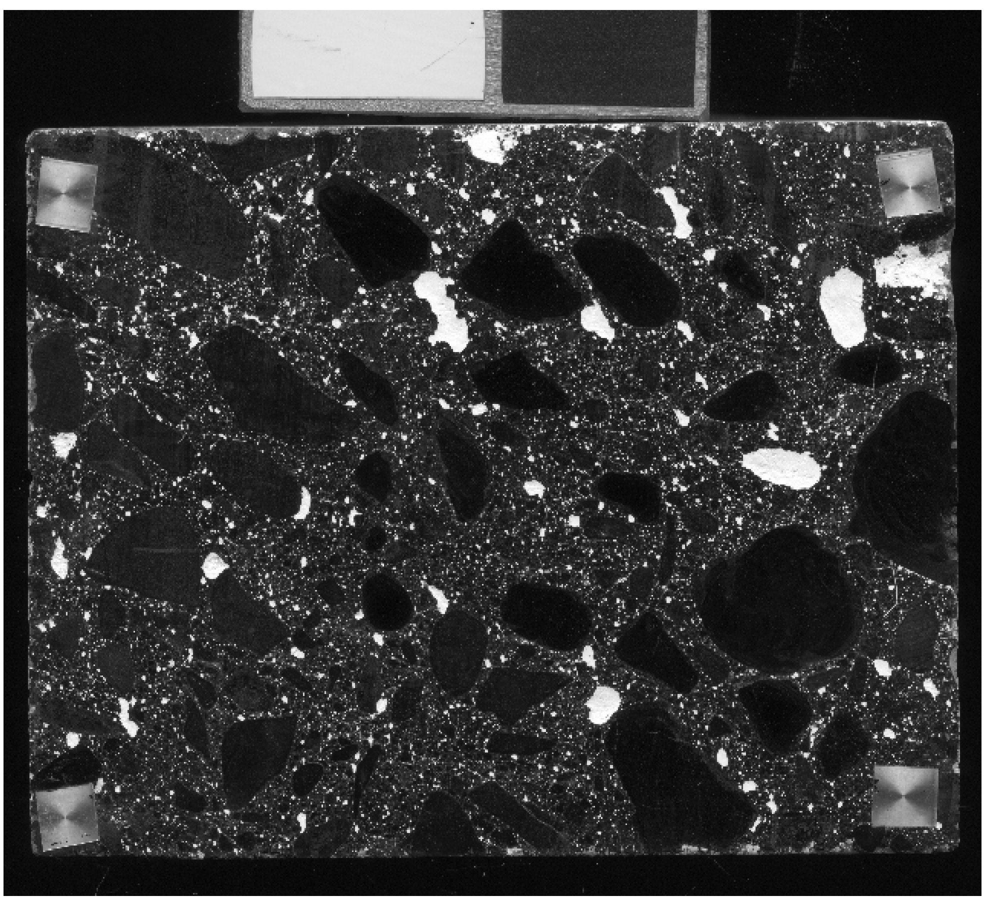

Figure 8: MTO Scanned sample of 6-7% air content

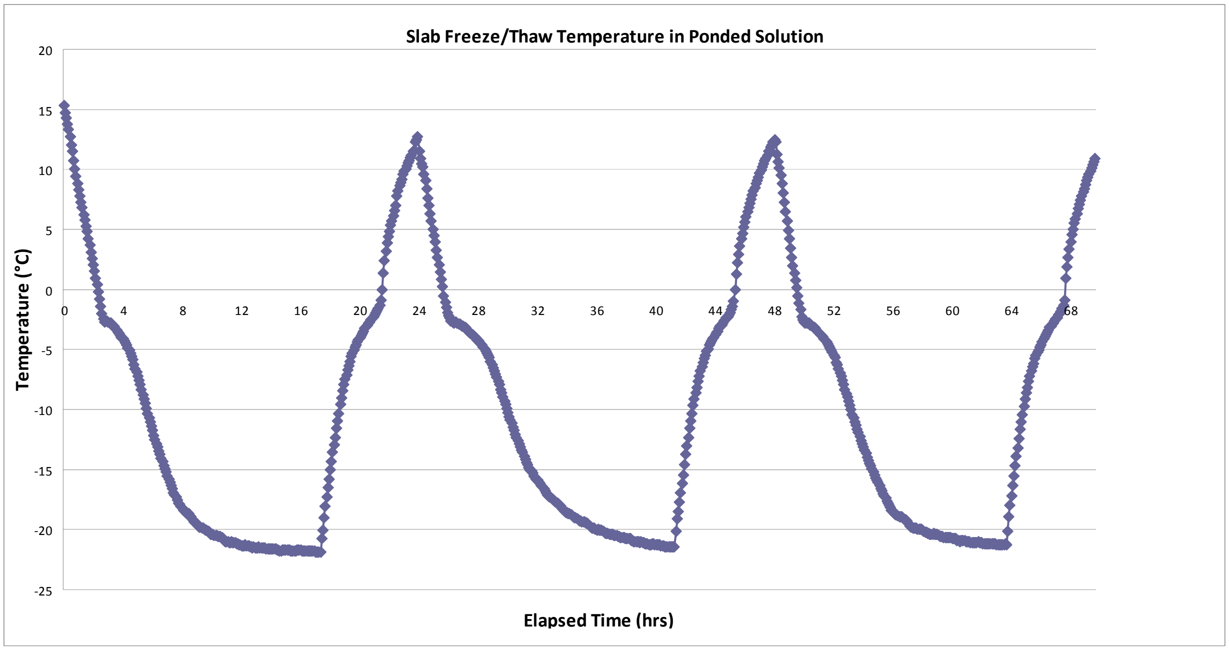

Figure 9. Temperature Cycles 3mm (1/8 in.) above the Surface of Instrumented Slab Immersed in Salt Solution (3% NaCl)

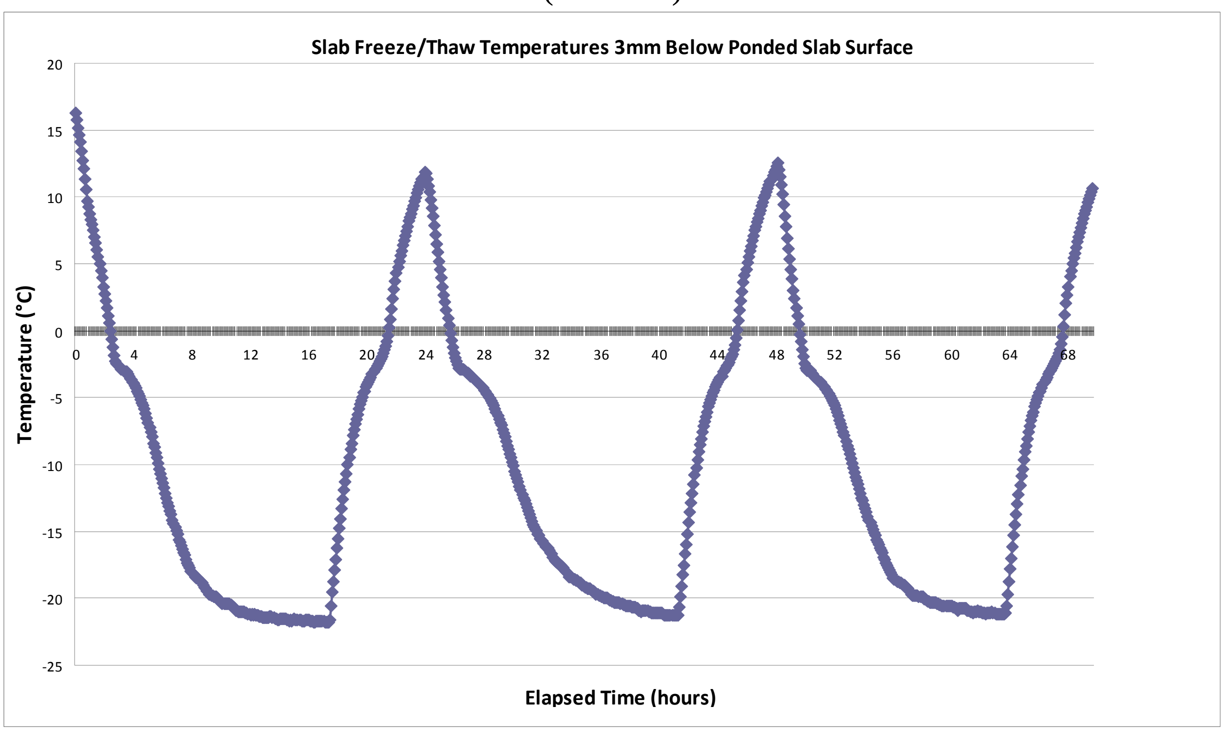

Figure 10. Temperature Cycles 3mm (1/8 in.) below the Ponded Surface of Instrumented Slab

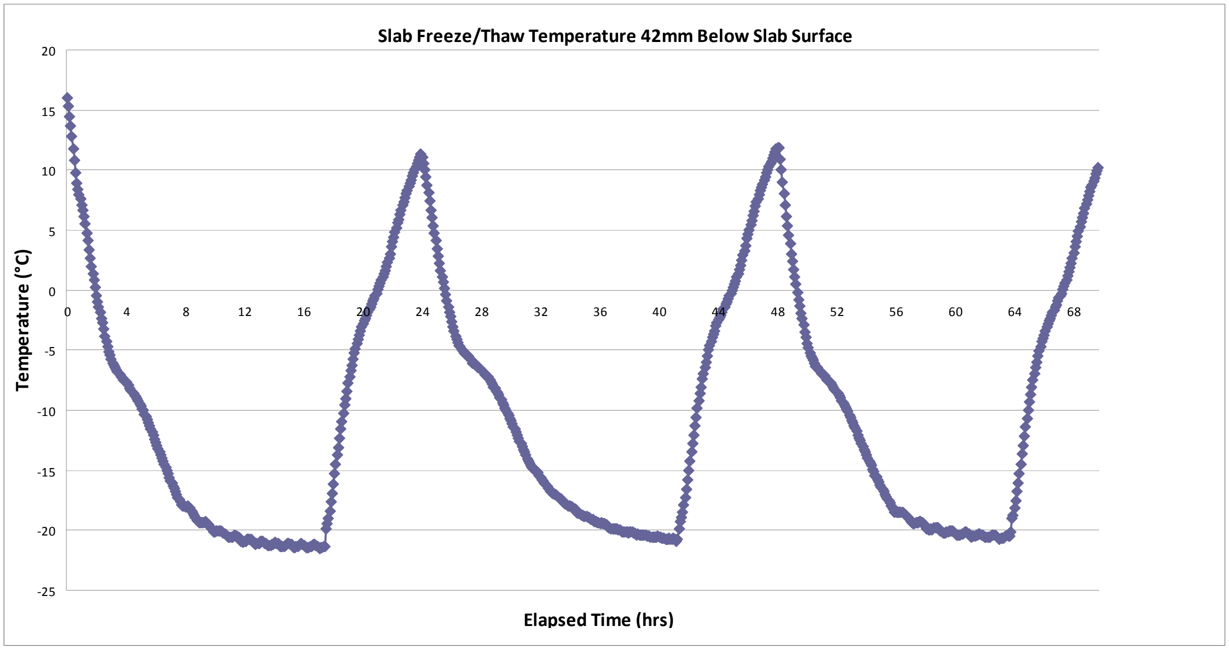

Figure 11. Temperature Cycles 42mm (1.7 in.) below the Ponded Surface of Instrumented Slab

References

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