NEBRASKA

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DEPARTMENT OF TRANSPORTATION

# Utilizing Kryton KIM Technology in Bridge Deck and Rail Construction to Protect Against Chloride Ion Penetration


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M&R
MATERIALS & RESEARCH

## Background

In the summer of 2019, representatives from Kryton presented their product, Krystol Internal Membrane (KIM), to researchers at the Nebraska Department of Transportation (NDOT). According to Kryton, “KIM is a hydraulic crystalline admixture used to create permanently waterproof concrete [1].” The KIM reacts with water and un-hydrated cement and forms crystals that seal micro-cracks and prevent water and chloride penetration. Based on product demonstrations and research studies presented to NDOT researchers, the KIM product showed potential for use in Nebraska’s concrete mix designs for new bridge railings to protect those structures against chloride penetration.

## Purpose of the Investigation

The purpose of this investigation was to determine if KIM is a suitable admixture for protecting bridge decks and rails against chloride penetration.

## Laboratory Investigation (Test Methodology)

NDOT investigated KIM as an admixture by testing ponding blocks in accordance with ASTM C672, *Standard Test Method for Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemical* [2] and mini-prisms in accordance with AASHTO Test Standard T380, *Standard Method of Test for Potential Alkali Reactivity of Aggregates and Effectiveness of ASR Mitigation Measures (Miniature Concrete Prism Test, MCPT)* [3]. Researchers designed a matrix of ponding blocks and mini-prisms to compare curing effects, and KIM’s ability to resist chloride penetration, prevent scaling and resist destructive expansion. The matrix is shown in Figure 1. Ponding blocks were loaded with a corrosion-inhibited magnesium chloride product of approximately 27.0-31.0% wt.-wt. ($MgCl_2$) and a sodium chloride brine approximately 23.3% wt.-wt. (NaCl), observing C672 Section 9.1 Note 4. Mini-prisms were soaked in sodium hydroxide (NaOH).

Researchers cast specimens using NDOT mix design 47BD, used for structure applications, as the control samples and using mix design 47BD with KIM as an admixture to form ponding blocks and mini-prism specimens. The T380 forms and Ponding Block forms are shown in Figure 2.

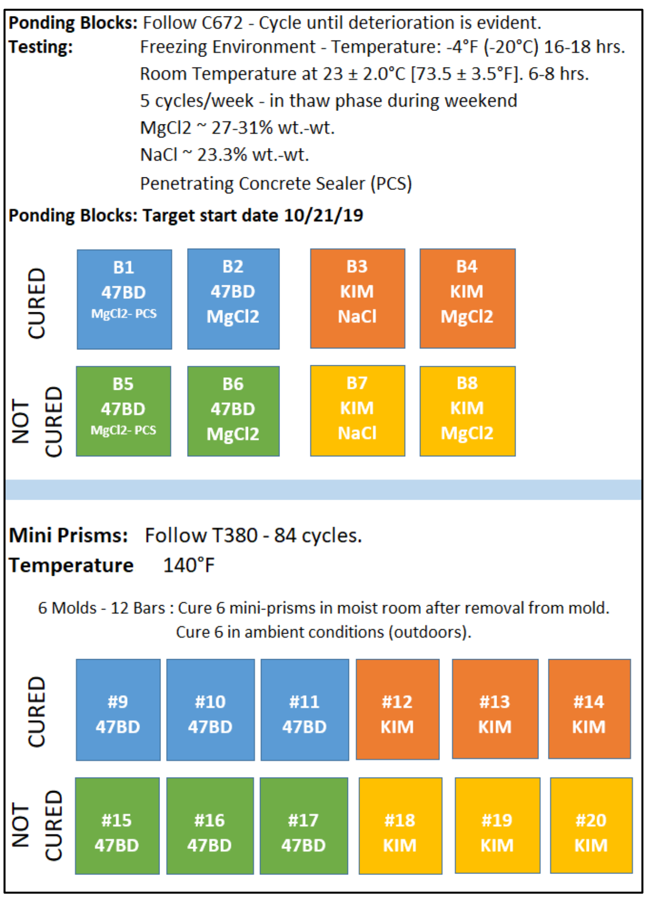


*Figure 1 - Researchers designed a matrix to test KIM with ponding blocks and mini-prisms.*

*Figure 2 - Forms for T380 Mini-prisms (left) and forms for ponding blocks ready for casting.*

## Ponding Blocks

Eight ponding blocks were cast at an outdoor site selected for research. Four blocks, identified as B1, B2, B5, and B6, were cast using 47BD. Four blocks, identified as B3, B4, B7, and B8 were cast using KIM. Blocks B1-B4 were cured in the field for 24 hours using wet burlap. Blocks B5-B8 hydrated without any curing techniques. This produced cured-uncured pairs of blocks for comparison. Table 1 lists the cured and uncured pairs.

*Table 1 - Four pairs of cured and uncured blocks allowed comparison of the curing effect on scaling.*

| Pair | Cured | Uncured |
|---|---|---|
| 1 | B1 | B5 |
| 2 | B2 | B6 |
| 3 | B3 | B7 |
| 4 | B4 | B8 |

After 24 hours the specimens were brought back to the Materials and Research building and cured outdoors for 28 days. After 28 days, blocks B1 and B5 were treated with an NDOT approved silane-based Penetrating Concrete Sealer (PCS). Then the blocks were moved to the PCC lab to begin Freeze-Thaw (F-T) testing.

The ponding blocks were subjected to F-T testing in the environmental chamber in the PCC lab in accordance with C672 as shown in Figure 3. The cycles began on Mondays with ponding the blocks with fresh deicer and placing in the chamber to freeze at -20°C for 6-8 hours. After freezing, the blocks thawed at 23°C for 16-18 hours. The blocks cycled between freeze-thaw temperatures 5 times per week (Monday through Friday). The blocks remained ponded in the thawed state through the weekend, deviating from C672 Section 9.3 which calls for the blocks to remain in the frozen state or kept damp in the thaw state during cycle interruptions. Researchers directed the variation due to personnel shortage on weekends. On Monday mornings, researchers drained and flushed the blocks with distilled water, observed scaling degree, and then re-ponded the blocks with fresh deicer to restart the process. Testing continued for 85 F-T cycles.

*Figure 3 - The ponding blocks were subjected to F-T testing in the environmental chamber.*

C672 provides a key to assigning scaling codes. The values range from 0, no scaling, to 5, severe scaling. More information on the Scaling Codes is provided in Table 2.

*Table 2 - Scaling Codes provided by ASTM C672 were used to compare the 47BD and KIM ponding blocks.[2]*

| |
|---|
| **SCALING CODES: ASTM C672** |
| Rating Condition of Surface |
| 0 - no scaling |
| 1 - very slight scaling (3 mm [1⁄8 in.] depth, max, no coarse, aggregate visible) |
| 2 - slight to moderate scaling |
| 3 - moderate scaling (some coarse aggregate visible) |
| 4 - moderate to severe scaling |
| 5 - severe scaling (coarse aggregate visible over entire surface) |

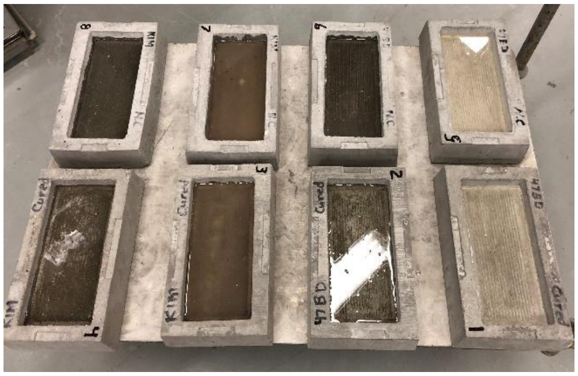


*Figure 4 - Each ponding block was filled with 300 mL of liquid deicing chemical.*

During F-T testing, blocks B3 and B7 were ponded with an NDOT approved NaCl brine prepared in the NDOT chemistry lab. The NaCl brine evaporated in the environmental chamber during the first five F-T cycles. Starting on the sixth F-T cycle, and for the duration of testing, technicians covered blocks B3 and B7 with plexi-glass to prevent evaporation during F-T cycles. The rest of the blocks were ponded with one of the $MgCl_2$-based deicers on contract with the State of Nebraska. The $MgCl_2$ ponded-blocks did not evaporate during testing. To pond the blocks, 300 mL of the respective deicers were poured into the corresponding block, shown in Figure 4.

The mass of each block was measured after 25 F-T cycles. The blocks dried in the environmental chamber at 23°C for one week, then they were weighed in the PCC lab. This was considered the initial mass. After the entire test completed, two final masses were taken. The blocks dried in the environmental chamber at 23°C for one week, were weighed, dried for a second week and weighed again. The two weights confirmed that the mass had stabilized and the specimens had dried completely. All masses were recorded in grams.

## Mini-Prisms

Mini-prisms were cast at an outdoor site chosen for research in accordance with AASHTO Test Method T380 to compare expansion differences between 47BD and KIM. Six mini-prisms were cast using 47BD and six were cast using KIM. For each mix, three mini-prisms were cured and three were not cured at the testing site for 24-hours as shown in Figure 5. The mini-prisms were stripped from the molds and placed in soaking containers filled with NaOH as specified in T380. The specimens for each mix design were measured for expansion in triplicate at 3, 7, 10, 14, 21, 28, 42, 56, 70, and 84 days.

*Figure 5 - Mini-prisms and ponding blocks, field curing. Half of the samples were exposed to ambient conditions, while the other half were cured according to NDOT standards.*

## Results and Discussion

Each block in a cured and uncured pair performed similarly to each other. The uncured pairs progressed to scaling faster than the cured pairs; however, both blocks in a pair finished with the same scaling code at the last reading. The six blocks, B1, B2, B4, B5, B6, and B8, ponded with $MgCl_2$ showed minimal amounts of scaling after 85 F-T cycles. The other two blocks, B3 and B7, ponded with NaCl, showed severe scaling and indicate structures will present durability issues. All eight blocks are shown before and at the end of testing in Figure 6.

*Figure 6 - The ponding blocks before (left) and after testing.*

Blocks B1 and B5, treated with PCS, showed no signs of scaling and were identified as code 0 scaling. The KIM blocks were not treated with PCS, so a direct comparison could not be made between KIM and 47BD if treated with PCS. These results show that treating blocks with PCS provided the best scaling protection of the eight specimens.

Blocks B2, B4, B6, and B8 all showed slight scaling and were identified as code 1 scaling. This indicates that the 47BD blocks (B2, B6) and the KIM blocks (B4, B8) performed equally well when ponded with $MgCl_2$.

Blocks B3 and B7 were both identified as code 4 scaling. None of the 47BD blocks were ponded with NaCl due to limitations in the number of molds available. As a result, no comparison of scaling performance can be made between KIM and 47BD when ponded with NaCl. Table 3 shows the scaling codes of the cured and uncured pairs.

*Table 3 - Block Pair Scaling Codes at the completion of testing.*

| Pair | Cured | Scaling Code – Final Reading | Uncured | Scaling Code – Final Reading |
|---|---|---|---|---|
| 1 | B1 | 0 | B5 | 0 |
| 2 | B2 | 1 | B6 | 1 |
| 3 | B3 | 4 | B7 | 4 |
| 4 | B4 | 1 | B8 | 1 |

## Ponding Block Masses

The masses of each block were recorded after 25 F-T cycles and twice at the end of testing. Testing completed after 85 F-T cycles and two final masses were taken after drying. The blocks dried in the environmental chamber at 23°C for one week (Final Mass 1), were weighed, dried for a second week and were weighed again (Final Mass 2). None of the blocks showed significant mass change due to ponding. The largest mass percent change was -0.450%. The two blocks made with KIM and ponded with NaCl, B3 and B7, showed a slight mass gain. Details of each block are discussed later in the Individual Ponding Block Performance section. The results for all eight blocks are displayed in the graph shown in Figure 7.

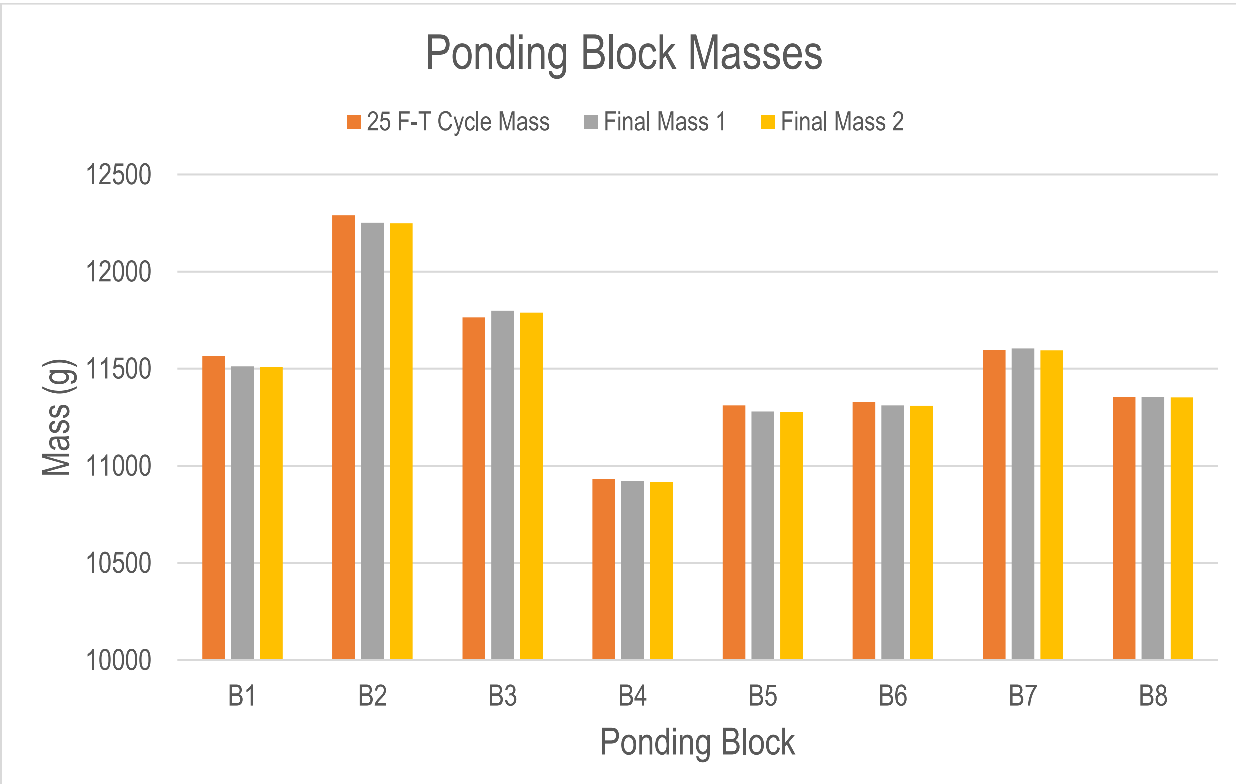


*Figure 7 - The ponding blocks were weighed after 25 F-T cycles and twice at the end of testing. No significant mass change occurred.*

## Individual Ponding Block Performance

### B1

Block B1 was made of 47BD, cured, and treated with PCS. It was ponded with $MgCl_2$. This block showed no scaling and was assigned a scaling code of 0. The block is pictured before and after testing shown in Figure 8. The mass of B1 decreased by 56 grams, or 0.48% of its 25-cycle mass.


*Figure 8 - B1 before testing (left) and after 85 F-T cycles showed no scaling.*

### B2

Block B2 was made of 47BD and cured. It was ponded with $MgCl_2$ and shows little sign of scaling and was assigned a scaling code of 1. The block is pictured before testing began and after testing shown in Figure 9. B2 maintained a moist appearance after drying for two weeks in the environmental chamber. This is likely due to the absorption and retention of water and oils from the deicing chemicals. The mass of B2 decreased by 42 grams, or 0.34% of its 25-cycle mass.


*Figure 9 - B2 before testing (left) and after 85 F-T cycles showed little to no scaling.*

## B3

Block B3 was made of KIM and cured. It was ponded with NaCl. The block is pictured before testing began and after testing shown in Figure 10. The mass of B3 increased by 24 grams, or 0.20% of its 25-cycle mass. The mass increase is likely due to the reaction between water and KIM, which would retain the mass of the reacted water within the structure.


*Figure 10 - B3 before testing (left) and after 85 F-T cycles showed moderate-heavy scaling on the rim and outer surfaces of the block.*

Throughout testing, researchers observed the formation of a crystalline structure on the rim and outer surfaces of the ponding block, shown in Figure 11. Samples of the crystals were collected and analyzed in the NDOT chemistry lab. The results indicated that the crystal formation was NaCl.

*Figure 11 - NaCl deposited on the rim and outer surfaces of the ponding block during F-T testing.*

Federal Highway Administration sponsored research declared “capillary absorption, hydrostatic pressure, and diffusion are the means by which chloride ions can penetrate concrete” [4]. Capillary absorption occurs when the liquid deicer contacts the dry concrete and is drawn into the concrete pores by capillary action. Hydrostatic pressure causes chloride penetration when a hydraulic head is applied to the faces of the concrete. Diffusion is driven by a concentration gradient where ions transport towards lower concentrations. Conditions for the three mechanisms were favorable, however researchers cannot definitively conclude that the mechanisms are responsible for the transport of sodium and chloride ions and the formation of the salt crystals on the outer surface of the block.

*Figure 12 - The concrete blistered where NaCl deposits were.*

Researchers observed mild scaling on the ponded surfaces, where some of the tyning eroded and small aggregate was exposed. The most severe scaling occurred on the outer surfaces of the ponding block where the NaCl deposits were located. The concrete looked blistered and bubbles in the paste formed. The concrete in this condition was very brittle and flaked off even when gently touched, exposing aggregate. A close-up photo of the blistering is shown in Figure 12.

## B4

Block B4 was made of KIM and cured. It was ponded with $MgCl_2$ and only showed slight scaling and was assigned a scaling code of 1. This block was comparable to B2 in terms of scaling performance. The block is pictured before testing began and after testing shown in Figure 13. B4 also maintained a moist appearance after drying for two weeks in the environmental chamber.  The mass of B4 decreased by 56 grams, or 0.48% of its 25-cycle mass.


*Figure 13 – B4 before testing (left) and after testing showed light scaling after 85 F-T cycles.*

## B5

Block B5 was made of 47BD, was not cured, and treated with PCS. It was ponded with $MgCl_2$. This block showed no scaling and was assigned a scaling code of 0. The block is pictured before and after testing shown in Figure 14. The mass of B5 decreased by 34 grams, or 0.30% of its 25-cycle mass.

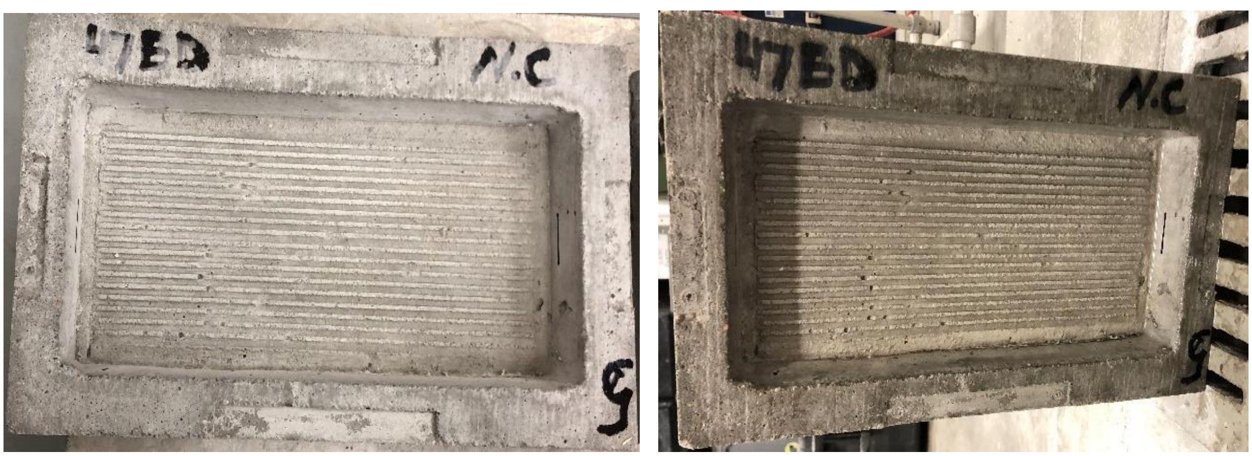


*Figure 14 - B5 before testing (left) and after testing showed little signs of scaling after 85 F-T cycles.*

## B6

Block B6 was made of 47BD and was not cured. It was ponded with $MgCl_2$. This block showed little scaling and was assigned a scaling code of 1. The block is pictured before and after testing shown in Figure 15. B6 also maintained a moist appearance after drying for two weeks in the environmental chamber.  The mass of B6 decreased by 17 grams, or 0.15% of its 25-cycle mass.


*Figure 15 - B6 before testing (left) and after testing showed little signs of scaling after 85 F-T cycles.*

## B7

The block is pictured before and after testing shown in Figure 16. Block B7 was made of KIM and was not cured. It was ponded with NaCl. The pond showed light to moderate scaling, however the rim and outer surfaces significantly deteriorated and scaled by the end of testing.


*Figure 16 - B7 before testing (left) and after testing showed severed signs of scaling after 85 F-T cycles.*

Figure 17 - A corner broke off of B7 during F-T testing. The block also exhibited a high degree of deposits.

A large chunk of the corner of B7 broke off between the 75th and 80th F-T cycles. The block also had a large amount of deposits and crystal formation on the rim and outer surfaces of the block. The missing corner and crystal formations are shown in Figure 17.

Researchers observed the formation of long, hair-like crystals on the ponding blocks, shown in Figure 18 and collected a sample. NDOT chemists analyzed the sample using XRF. The results indicate the sample was 99% NaCl. Calcium and silicon were present at about 0.57% and 0.138% respectively. Magnesium, potassium, iron, and sulfur were detected in less than 1000 ppm. Other elements were likely introduced by cement paste or KIM crystals potentially formed on the surface. The hair-like crystals could not be isolated and therefore the chemical composition cannot be determined.

Figure 18 - Long, hair-like crystals formed on B7.

The mass of B7 only decreased by 2 grams, or 0.02% of its 25-cycle mass, despite the block breaking at the corner. This is likely due to the absorption of water and water reacting with KIM. As KIM reacts the mass of the water becomes bound in the crystal formation.

## B8

Block B8 was made of KIM and was not cured. It was ponded with $MgCl_2$ and only showed slight scaling and was assigned a scaling code of 1. This block was comparable to the cured KIM block, B4, in terms of scaling performance. The block is pictured before and after testing shown in Figure 19. B8 also maintained a moist appearance after drying for two weeks in the environmental chamber. The mass of B8 decreased by 3 grams, or 0.03% of the 25-cycle mass.


Figure 19- B8 before testing (left) and after testing showed light sign of scaling after 85 F-T cycles.

## Mini-Prisms

All four mix designs, 47BD cured, 47BD uncured, KIM cured, and KIM uncured, passed the T380 test with less than 0.02% expansion permitted by the test. Technicians in the PCC laboratory reported the following expansions for the specimens: 47BD cured — 0.008%; 47BD uncured — 0.012%; KIM cured — 0.013%, and KIM uncured — 0.016%. For both 47BD and KIM mixes, the cured specimens showed less expansion than the uncured specimens. This highlights the importance of curing concrete structures properly. The KIM samples expanded slightly more than the 47BD samples possibly due to the formation of KIM crystals within the sample. All four mix designs adequately protected against ASR expansion. The expansions of each mix design are graphed in Figure 20.

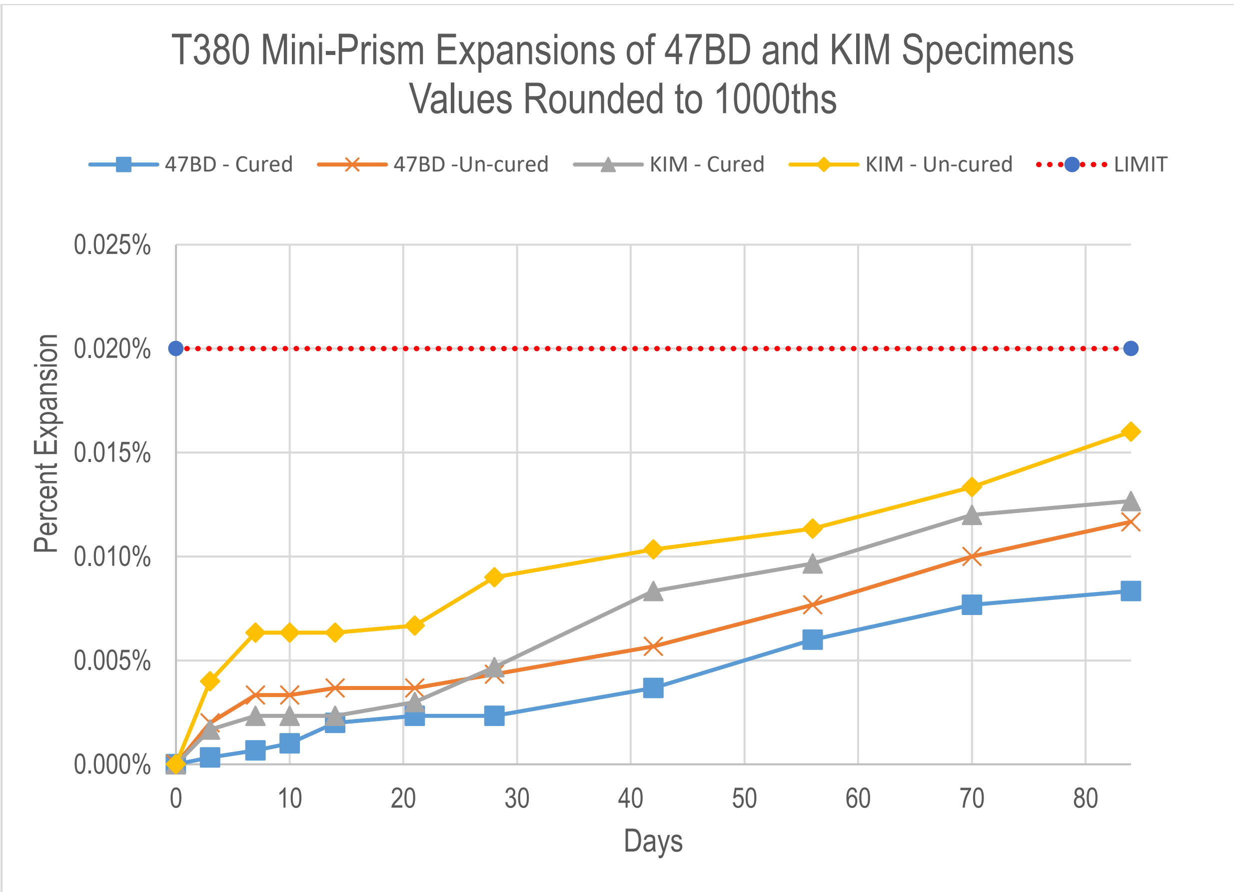


*Figure 20 - T380 expansions comparing 47BD and KIM mixed specimens.*

## Conclusions and Recommendations

NDOT engineers conclude that C672 is not the most suitable test for determining KIM's performance, as KIM's intended use is to seal micro-cracks in concrete more than it is to prevent scaling. Furthermore, C672 testing in a laboratory is not necessarily representative of a product's field performance. Ponding blocks made of 47BD and ponding blocks made of KIM performed identically when ponded with the same material. Considering these factors, researchers cannot draw a conclusion as to whether KIM enhances concrete from the results of C672 testing.

During C672 testing, researchers made two notable observations; that properly cured concrete is vital to the long-term health of the structure, and that currently approved PCS provided the best, and most immediate, protection against scaling caused by deicing chlorides. Researchers recommend the continued use of PCS according to NDOT best management practices.

Expansion of KIM samples in T380 testing slowed near the end of the testing period, and indicate that KIM may be useful in sealing micro-cracks and limiting expansion due to ASR. Further investigation into the durability of KIM enhanced concrete is recommended.

Based on the results of testing and after discussion with industry professionals, the researchers conclude that further study of KIM is necessary to determine if KIM can enhance the performance of NDOT mix designs.

## Future Work

Continued interest in KIM warrants further investigation in a second project phase to determine if it can enhance the performance of NDOT mix designs. Materials and Research engineers propose testing samples following standards T380 and NDOT Wet & Dry (W&D) testing.

- T380 testing - mini-prisms using Type I/II cement with KIM to determine feasibility for KIM to be used in rapid repair projects.
- W&D testing - cylinders using Type I/II cement with KIM. W&D testing will reveal KIM's ability to mitigate micro-cracking.

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| | Jake Sweitzer | |

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