



June 2015

ROAD MAP TRACK 7

**PROJECT TITLE**

**Pavement Joint Deterioration:  
Recent Findings to Reduce the  
Potential for Damage**

**TECHNICAL WRITERS**

Jason Weiss  
Yaghoob Farnam  
Purdue University

**EDITOR**

Sabrina Shields-Cook

**SPONSOR**

Federal Highway Administration

**MORE INFORMATION**

Jason Weiss  
Purdue University  
765-412-8358  
[wjweiss@purdue.edu](mailto:wjweiss@purdue.edu)

The Long-Term Plan for Concrete Pavement Research and Technology (CP Road Map) is a national research plan developed and jointly implemented by the concrete pavement stakeholder community. Publications and other support services are provided by the Operations Support Group and funded by TPF-5(286).

Moving Advancements into Practice (MAP) Briefs describe innovative research and promising technologies that can be used now to enhance concrete paving practices. The June 2015 MAP Brief provides information relevant to Track 7 of the CP Road Map: 7 Concrete Pavement Maintenance and Preservation.

This MAP Brief is available at [www.cproadmap.org/publications/MAPbriefJune2015.pdf](http://www.cproadmap.org/publications/MAPbriefJune2015.pdf).

**“Moving Advancements into Practice”**

**MAP Brief June 2015**

Describing promising technologies that can be used now to enhance concrete paving practices

**Concrete Pavement Joint Deterioration:  
Recent Findings to Reduce the Potential  
for Damage**

**Introduction**

While many concrete pavements provide excellent long-term performance, some concrete pavements have exhibited premature deterioration, primarily at joints and saw-cuts (Figure 1). This joint deterioration is problematic because it compromises the performance and service life of an otherwise healthy concrete pavement. Repairing these joints can be expensive, and these repairs are disruptive to the travelling public.

It is commonly observed that the joints that frequently exhibit this damage contain standing fluid. These joints can develop two main types of deterioration: 1) cracking parallel to the joint, resulting in 1/8 to 1/2 inch flakes of concrete being removed from the joint (green oval in Figure 2) or 2) spalling that begins with a hollowed out region at the bottom of the saw cut (a “soft zone” shown as a red circle at in Figure 2) resulting in a crack to the surface of pavement that is typically four to six inches from the edge of the joint.

This MAP brief provides a short update of recent research findings related to joint deterioration. It is a work in progress and

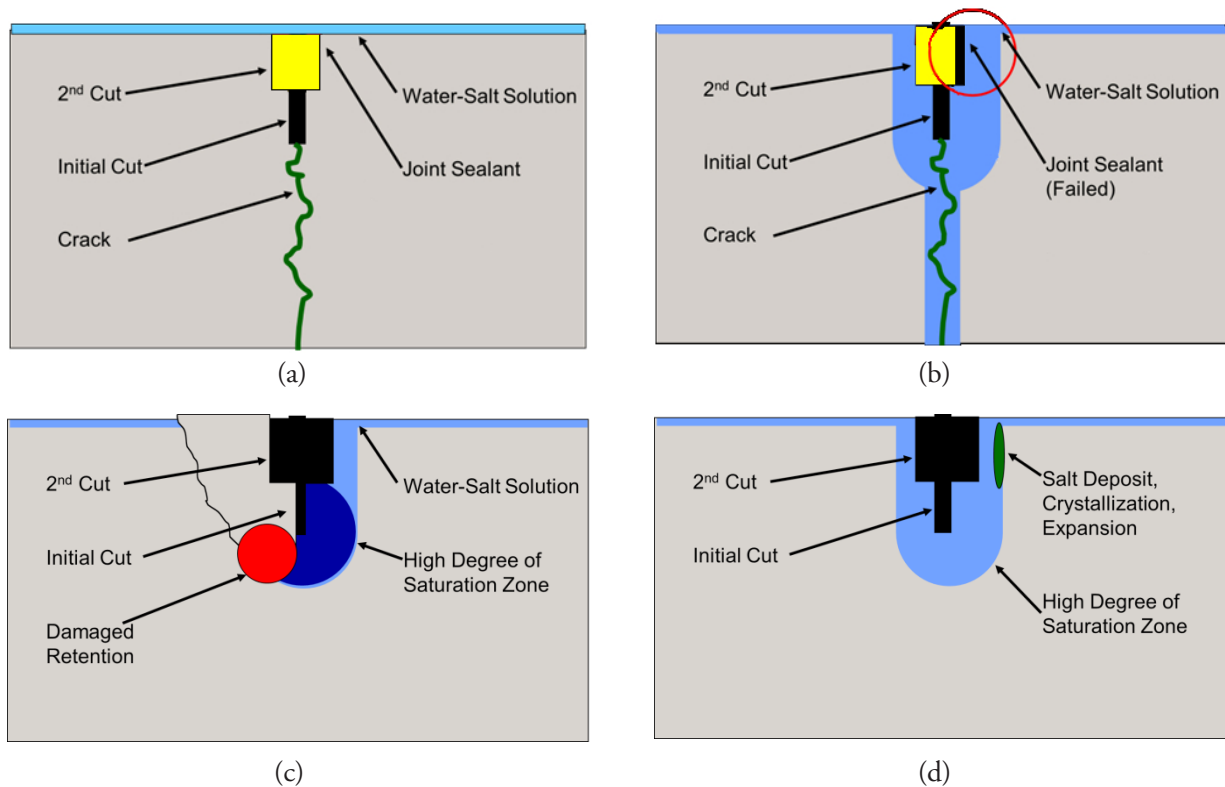
is not intended to be a comprehensive review of the entire problem, as previous reports have been developed discussing damage at joints [1, 2, 3, 4, 5, 6].

Figure 2 shows a construction joint typical of that used by numerous Departments of Transportation (Figure 2). The joint is created by cutting the pavement (the depth of the saw cut is approximately 1/3 the depth of the pavement) shortly after the concrete is placed. The saw cut is placed when the concrete is mature enough to avoid raveling but not so mature that the stresses have built up to cause random cracking before or due to the saw cutting [7].

The intention of this saw cut is to provide stress relief, which can allow cracks to form at the saw cut locations. However, these cracks do not always occur. After several days (to weeks), the saw cut is saw cut again, widening the cut to provide a notch at the top of the joint for the placement of joint sealant. This second cut also allows minor raveling to be removed and attempts to provide a more uniform joint width since some of the opening has already occurred. The joints are then cleaned and dried prior to placement of an optional non-absorptive backer rod. The joint sealant is then placed. If ideal,



Figure 1: Typical examples of joint deterioration of concrete pavements in Indiana



**Figure 2: Potential Degradation Hypothesis: a) an ideal joint, b) a joint with damaged joint sealant but cracked, c) a joint with damaged joint sealant that is uncracked, and d) a joint illustrating potential salt crystallization locations**

this constructed joint will keep water and deicing salt out of joints; however, the sealer may fail by detaching from one of the concrete joint walls as shown in Figure 2b. This allows water and deicing salt to enter the joint and be absorbed by the faces of the saw cut.

In cases where the crack has occurred, the fluid that has entered the volume created by the saw cut will likely drain through the crack at the base of the saw cut into the open graded base. This will increase the degree of saturation and potential reaction along the walls of the saw cut and along the walls of the crack.

When the joint does not crack, the fluid in the joint does not drain (as shown in Figure 2c). The fluid that is pooled in the joint is absorbed by the concrete, developing a zone with a high degree of saturation. The solution in the joint can also become increasingly concentrated over time when deicing salts are added to the surface of the pavement to melt ice and snow. It has been observed that saw cuts may be less susceptible to cracking in some pavements due to increased pavement strength, increased rate of strength development, increased pavement thickness, and reduced joint spacing [12].

Some pavements that do crack may also not drain since the crack remains small or becomes clogged with reaction products (between salts and concrete) or other materials (e.g., sand and dust). Further, the use of increased tie-bar volumes or misaligned dowel bars may limit the opening

of the crack. The high level of saturation that results from the joint not draining can result in freezing damage (in low concentration systems) [8, 9] and/or in chemical reaction in some systems (e.g., the formation of Friedel's salt, Kuzel's salt or Calcium Oxychloride). The "soft zone" (shown as the red circle in Figure 2c) frequently observed at the base of the saw-cut can be explained by increased saturation, microcracking due to saw cutting, and freeze-thaw damage due to hydraulic pressure/osmotic pressure at low concentrations (Figure 2c) [10, 11, 12]. The "soft zone" (Figure 2c) or flaking off in layers that are fractions of an inch thick (Figure 2d) can be explained by a chemical reaction between the salt solution and the cementitious binder.

It is important in this discussion to remember that the fluid that is in the joint is not water. It is a solution that contains deicing salts. Deicing salts are used to depress the freezing point of the water; however they also change the properties of the fluid [13, 14]. Although the addition of deicing salts on the surface of concrete elements is an effective method for melting the ice and increasing the safety of infrastructure, it may also be partially responsible for the issues that develop at the joints in the pavement.

The types of reactions that can occur depend on the type of salt that is used. It appears that NaCl reacts with the sulfo-aluminate phases in concrete and results in damage due to a chemical phase transformation [15], while CaCl<sup>2</sup> and MgCl<sup>2</sup> result in the formation of a calcium oxychloride

[16, 17]. This document will focus on the calcium oxychloride phase which is expansive and can cause damage and cracking.

The calcium oxychloride phase change occurs when calcium hydroxide from concrete reacts with calcium chloride in the presence of water (between 0°C and 50°C depending on salt concentration) [18]. This reaction can be observed by measuring the heat flow of a sample using low-temperature differential scanning calorimetry (LT-DSC). The LT-DSC test is performed by cooling a powdered hydrated cementitious material to -80°C then reheating the material at a slow rate and measuring the heat release due to phase transformation. Figure 3a provides an example of a conventionally hydrated cement paste (OPCP) and a paste (CSCP) that does not contain tri calcium aluminate or calcium hydroxide which was formed by carbonating a silicate cement [19].

It can be observed that the OPCP sample shows three features as it is heated. At approximately -50°C the eutectic solid changes phase becoming a highly concentrated salt liquid (the concentration is the eutectic composition). In the range between the eutectic temperature to ~ -15°C (depending on the concentration of salt), the ice that formed during freezing (pro-eutectic ice) gradually melts resulting in the second feature in the heat flow curve.

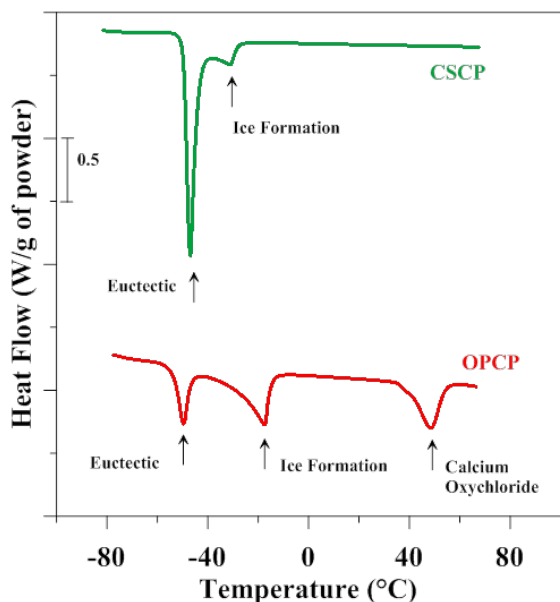
The third feature in the heat flow curve occurs at temperatures approximately 50°C and are associated with the formation of calcium oxychloride. By integrating the heat flow peak associated with the calcium oxychloride, the total heat released can be obtained (which is related to the amount of calcium oxychloride that has formed) (Figure

3b). It can be observed in comparing the OPCP system (with calcium hydroxide, CH) and the CSCP system (a system without calcium hydroxide, CH) when CH is not present, calcium oxychloride cannot form and as a result the samples do not show damage.

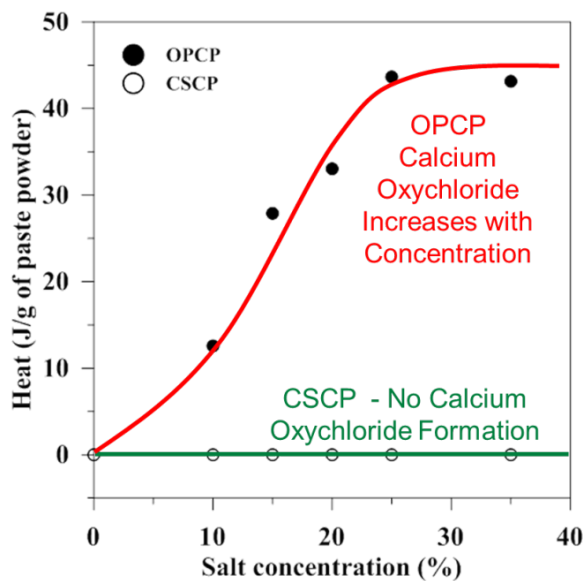
Recent research has suggested that damage associated with calcium oxychloride (like that shown at pavement joints) can be avoided in concrete through 1) changes in the binder composition (use of supplementary cementitious materials, SCM) or 2) the use of a 'sealer' that limits the contact between the salt solution and the calcium hydroxide. The following section will provide an update of recent results.

Figure 4 illustrates results from LT-DSC testing on two cementitious systems where conventional Type I portland cement systems are compared with those systems containing SCM (20 % Class F Fly Ash, 45 % Slag, and 3 % silica fume mass replacements). It can be noticed that the chemistry of the cement has some impact on the amount of calcium oxychloride that forms, and is presumably due to the amounts of tricalcium aluminate (C<sup>3</sup>A) and the ratio of tricalcium silicate (C<sup>3</sup>S) to dicalcium silicate (C<sup>2</sup>S), and the degree of hydration as this will influence the amount of calcium hydroxide that is produced.

Testing other samples have shown variations in the amount of calcium oxychloride that forms depending on the chemistry of the cement used. It can be noticed that when SCM are used, there is a reduction in the calcium hydroxide due to dilution (replacing the cement that produces CH with an alternate material) and due to the CH consumption through a pozzolanic reaction with



(a)



(b)

Figure 3: a) Typical LT-DSC plot illustrating the heat flow associated with phase changes – notably the phase change associated with formation of calcium oxychloride and b) the amount of calcium oxychloride that has formed

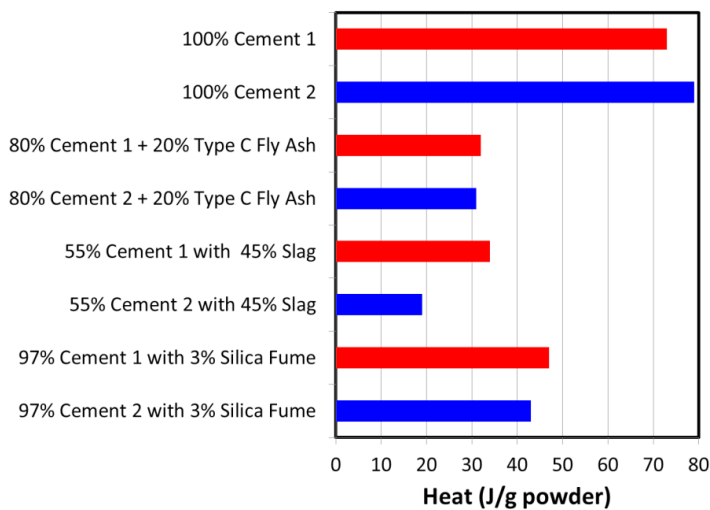


Figure 4: An example of the role of cementitious binder on the heat release associated with the formation of calcium oxychloride

the SCM. For the limited materials used in this study, the following observations can be made. The calcium oxychloride was reduced to 39%-44% of that of the straight cement system when 20% Class C fly ash was used. The calcium oxychloride was reduced to 24%-46% of that of the straight cement system when 45% slag was used to replace cement. The calcium oxychloride was reduced to 54%-64% of that of the straight cement system when 3% silica fume was used. While the amounts of reduction will vary depending on the concentration and chemical composition of the components, it can be noticed that in each case the use of the SCM resulted in a substantial reduction in the amount of calcium oxychloride formation, which results in less damage in the concrete.

A testing methodology is being developed to optimize binder composition to reduce damage [20], and research is needed to relate the science used in this approach to field observations. Tests on cored samples with and without a sealer show that while calcium chloride is present in the plain cementitious sample, the sealer limits the contact between the salt solution and calcium hydroxide, resulting in the no appreciable calcium oxychloride being formed [21].

As previously mentioned, there are two main factors that contribute to the damage that is observed at joints in concrete pavements: at low salt concentrations the damage is primarily that of classic hydraulic and osmotic pressure, while at high salt concentrations the damage can be associated with alternative forms of damage associated with phases that form due to the chemistry of the cement and salt being used (e.g.,  $\text{CaCl}_2$  and  $\text{MgCl}_2$  salt can result in the formation of calcium oxychloride). Research to date has focused primarily on examining the cementitious binder in the presence of a single salt; however, in practice it is common to use more than one salt or to use salt blends. Ongoing research is being conducted to better understand the role of blending salts [20].

These results can explain several observations that occur in the field. For example, this describes the “flaking of relatively small thicknesses of powder” from the surface of the saw cut, since the penetration of high concentrations of salts can be limited due to the filling of pores [22, 23]. Once the calcium oxychloride forms, it can cause damage that spalls the surface, resulting in the repetition of this process when new salt solution comes in contact. This also explains why aggregates are observed to dislodge from cut surfaces (at saw cut joints) or to “pop out” of the top surface of the concrete. The formation of calcium oxychloride occurs in the presence of calcium chloride and calcium hydroxide, and, since calcium hydroxide is known to preferentially form at the interface between the aggregate and the matrix, this would be expected to occur disproportionately at the aggregate paste interface.

It should be noted that some concrete pavements show damage from the top of the pavement while other pavements show damage from both the top and bottom of the pavement. It is hypothesized that the damage that occurs from the bottom of the pavement can be reduced by improving drainage and using a layer that provides a break in capillarity that can minimize the sorption of water from the bottom surface of the pavement.

In pavements damaged from the top of the concrete, it is anticipated that this damage occurs from salt applied to the surface and ponding at the joints or low points in the pavements. To reduce the potential for this damage, the sealant in the joints should be monitored to make sure it is intact and not allowing fluid into the joint. Further, it appears that backer rod creates a space at the base of the joint where fluid can pond and the practice of using backer rod should be reconsidered as it may be more effective to ‘fill the joint’ thereby minimizing the space for the deicing fluid to connect. Additional recommendations would include using more SCMs or using concrete sealants.

## Recommendations

A test method has been developed that uses a low temperature differential scanning calorimeter (LT-DSC) to evaluate the potential reactivity of a cement paste and a salt solution by measuring the heat associated with calcium oxychloride formation [24]. This method can be used to optimize the composition of the paste (by altering the volume of SCM) to minimize the calcium oxychloride that forms.

The use of supplementary cementitious materials (SCMs; e.g., fly ash, slag, and silica fume) have been shown to reduce the formation of calcium oxychloride and damage when cementitious materials are exposed to deicing salts. The benefits of SCMs can be linked to the consumption of calcium hydroxide through a pozzolanic reaction, the

reduction of calcium hydroxide through dilution (use of less cement), and the reduction in permeability.

The use of sealers has shown the potential to limit the interactions between the salt solution and the calcium hydroxide. As such the use of concrete sealers has the potential to reduce joint damage. While three-year survey has provided positive results, these sites should be monitored for a longer time period [25].

Many state highway agencies (SHAs) have limitations on the use of SCMs due to either the amount of replacement permitted or the time of the year they can be used (late fall restrictions). It is the authors' understanding that these limits are due to concerns with scaling or slow strength development. It is proposed that SHAs reconsider these restrictions for general construction (bridge decks, hand pours, and sidewalks) separately from restrictions for concrete pavements. While this may be a valid concern for high slump mixtures, it may be of less concern for slip-form pavements. This is due to the fact that slip-form pavements are very unlikely to scale due to their low slump, which limits the formation of a weak surface layer [26] and increased pavement thickness which alters the temperature gradients [27].

## References

1. Taylor, Peter C., Preventing Joint Deterioration in Concrete Pavements A Summary of Current Knowledge; MAP Brief 6-1, National Concrete Pavement Technology Center, Ames, Iowa, 2011, 4 pages.
2. W. Jones, Y. Farnam, P. Imbrock, J. Sprio, C. Villani, J. Olek, et al., An Overview of Joint Deterioration in Concrete Pavement: Mechanisms, Solution Properties, and Sealers, 2013. doi:10.5703/1288284315339.
3. L. Sutter, K. Peterson, G. Julio-Betancourt, D. Hooton, T.V. Dam, K. Smith, The deleterious chemical effects of concentrated deicing solutions on Portland cement concrete, Final Report for the South Dakota Department of Transportation, 2008
4. H. Lee, R.D. Cody, A.M. Cody, P.G. Spry, Effects of various deicing chemicals on pavement concrete deterioration, in: Mid-Continent Transp. Symp. 2000 Proc., 2000: pp. 151-155
5. Farnam, Y., Bentz, D. P., Sakulich, A., Flynn, D., and Weiss, W. J., (Accepted) "Using A Low Temperature Guarded Comparative Longitudinal Calorimeter and Acoustic Emission to Measure Freeze and Thaw Damage in Mortars Containing Deicing Salt" *Advances in Civil Engineering Materials*
6. Todak, H., Lucero, C., and Weiss, W. J., (2015) "Why is the Air There? Thinking about Freeze-Thaw in Terms of Saturation," *Concrete In Focus*
7. Raoufi, K., Radlinska, A., Nantung, T., and Weiss, W. J., (2008) "Practical Considerations To Determine The Time And Depth Of Saw-Cuts In Concrete Pavements," *Transportation Research Record*
8. W. Li, M. Pour-Ghaz, J. Castro, J. Weiss, Water absorption and critical degree of saturation relating to freeze-thaw damage in concrete pavement joints, *J. Mater. Civ. Eng.* 24 (2012) 299-307. doi:10.1061/(ASCE)MT.1943-5533.0000383
9. Yang, Z., Weiss, W. J., and Olek, J., (2005) "Using Acoustic Emission For The Detection Of Damage Caused By Tensile Loading And Its Impact On The Freeze-Thaw Resistance Of Concrete," *CONMAT 2005*
10. Yang, Z., Weiss, W. J., and Olek, J., (2006) "Water Transport in Concrete Damaged by Tensile Loading and Freeze-Thaw Cycling," *ASCE Journal of Civil Engineering Materials*, Vol. 18, No. 3, pp. 424-434
11. Yang, Z., Weiss, W.J., Olek, J., and Nantung, T., (2005) "Assessing Damage, Sorptivity, Air Content and Strength of PCCP in Indiana" 8th International Conference on Concrete Pavements, pp. 128-148
12. Raoufi, K., Nantung, T. E., and Weiss, W. J., (2010) "Numerical Analysis Of Saw-Cutting: The Influence Of Environmental Conditions", *ACI Special Publication*
13. Spragg, R., Castro, J., Li, W., Pour-Ghaz, M., Huang, P., and Weiss, W. J., (2011) "Wetting and Drying of Concrete in the Presence of Deicing Salt Solutions", *Cement and Concrete Composites*, Volume 33, Issue 5, May, Pages 535-542
14. Villani, C., Spragg, R., Pour-Ghaz, M., and Weiss, W. J., (2014) "The Influence of Pore Solution Properties on Drying In Cementitious Materials," *Journal of the American Ceramic Society*
15. Farnam, Y., Bentz, D. P., Hampton, A., and Weiss, W.J., (Accepted) "Acoustic Emission and Low Temperature Calorimetry Study of Freeze and Thaw Behavior in Cementitious Materials Exposed to NaCl Salt," *Transportation Research Board*
16. Y. Farnam, S. Dick, A. Wiese, J. Davis, D. Bentz, and J. Weiss (Submitted), The Influence of Calcium Chloride Deicing Salt on Phase Changes and Damage Development in Cementitious Materials, Submitted to the *Journal of Cement and Concrete Composite*, Elsevier (Under Review).
17. Y. Farnam, A. Wiese, D. Bentz, J. Davis, and J. Weiss (2015), Damage Development in Cementitious Materials Exposed to Magnesium Chloride Deicing Salt, Accepted for Publication in the *Journal of Construction and Building Materials*, Elsevier (In Press).

18. K. Peterson, G. Julio-Betancourt, L. Sutter, R.D. Hooton, D. Johnston, Observations of chloride ingress and calcium oxychloride formation in laboratory concrete and mortar at 5°C, *Cem. Concr. Res.* 45 (2013) 79–90. doi:10.1016/j.cemconres.2013.01.001
19. C. Villani, Y. Farnam, T. Washington, J. Jain, J. Weiss, (2015) Performance of Conventional Portland Cement and Calcium Silicate Based Carbonated Cementitious Systems During Freezing and Thawing in the presence of Calcium Chloride Deicing Salts, *Transportation Research Record*
20. Weiss, W. J., (2014) “SPR 3864: Performance of Deicing Salts and Deicing Salt Cocktails”, *JTRP Research Proposal*
21. Golias, M., Castro, J., Peled, A., Nantung, T., Tao, B., and Weiss, J., (2012) “Can Soy Methyl Ester (SME) Improve Concrete Pavement Joint Durability,” *Transportation Research Record*, Vol. 10 p. 60-68
22. Y. Farnam, T. Washington, and J. Weiss (2015), The Influence of Calcium Chloride Salt Solution on the Transport Properties of Cementitious Materials, Accepted for Publication in the *Journal of Advances in Civil Engineering*, Hindawi (Tentatively Accepted)
23. Lucero, C. L., Spragg, R. S., Bentz, D. P., Hussey, D. S., Jacobsen, D. L., and Weiss, W. J., (submitted) “Using Neutron Radiography to Measure the Absorption of Calcium Chloride Solution in Mortar”
24. Villani, C., Farnam, Y., Monical, J., Unal, E., and Weiss, W. J., (to be submitted) “Using Low Temperature Differential Scanning Calorimetry to Quantify Calcium Oxychloride Formation for Different Cementitious Materials in the Presence of CaCl<sub>2</sub>,”
25. Weiss, W. J., and Tao, B., (2015-Submitted) “Final Report - SPR 3523: Evaluation of Sealers and Waterproofers for Extending the Life Cycle of Concrete,” *JTRP Final Report*
26. Neuwald, A., Krishnan, A., Weiss, W. J., Olek, J., and Nantung, T. E., (2003) “Curing And Its Relationship To Measured Scaling In Concrete Containing Fly Ash,” *Transportation Research Board* (on CD)
27. Mehta, J.K., Olek, J., Weiss, W. J., and Nantung, T., (2005) “Effect of Surface Evaporation and Slab Thickness on the Scaling Resistance of Concrete Containing Fly Ash” *8th International Conference on Concrete Pavements*, Colorado Springs, Co, August 14-18, 2005