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Deicing Salts and Concrete Pavements

TECHNICAL WRITER

**Lawrence Sutter
Michigan Technological
University**

EDITOR

Sabrina Shields-Cook

SPONSOR

Federal Highway Administration

MORE INFORMATION

**Lawrence Sutter
Michigan Technological
University
lsutter@mtu.edu
906-487-2268**

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“Moving Advancements into Practice”

MAP Brief August 2014

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Deicing Salts and Concrete Pavements

Introduction

Damage related to deicing practices is no longer a matter of speculation; distress related to deicer use has occurred in all cold weather states. This has spawned a renewed interest in understanding the effects that deicing and anti-icing practices can have on concrete pavements.

Snow and ice removal is critical for the safe operation of the road transportation infrastructure and is well summarized by the Snowfighters Handbook (2013). Considerable work has also been published on the relative benefits of different compounds (NCHRP 2007) and how they can be assessed (Chappelow 1992).

This document is focused on summarizing what is known about deicer-related distress and discussing how to make concrete pavements better able to resist the effects of winter maintenance activities. Additional information is available from the South Dakota DOT regarding best practices to help reduce the deleterious impact of deicing chemicals on concrete pavements (Sutter et al. 2008).

Deicing Products

The most common deicers used on pavements are chloride-based salts. These materials are either applied as a dry powder or dissolved in water to form a brine (i.e., mixture of salt and water). The solid or brine may be applied separately, combined (e.g., pre-wetted salt) or mixed with sand.

The primary action of a chemical deicer is to combine with the water present on the road surface to form a water-salt solution with a lower freezing point than pure water. When using salt as a deicer, the intent is to cause the snow/ice to melt. When performing anti-icing, salts are applied to clear surfaces before snowfall to prevent ice from bonding to the pavement.

Historically, dry salt and sand were mixed and spread on roads and bridges. Much of the mixture was lost from the road surface and the mixture would not melt heavy snow or ice layers, but this practice did result in improved traction. However, given that all state DOTs now have clear road policies for winter maintenance, sand or sand/salt mixtures are not adequate. In addition, sand and solid salt become very finely ground as a result of attrition under the wheels of vehicles and become airborne particulates that significantly impact air quality in some localities. Another disadvantage of sand is that the residual material tends to block stormwater drainage systems when the seasons change.

Since the 1930s, sodium chloride (NaCl), the most common of the chloride salts, has been used in the U.S. (Fischel 2001). Originally applied as a solid (i.e., rock salt), it is now commonly applied as brine and is a relatively low-cost material for winter maintenance.

However, its use involves indirect costs because of the potential for corrosion of steel reinforcement in concrete, corrosive damage to automobile bodies, and pollution in soils and water runoff (Neville 1996). In addition, sodium chloride is ineffective when ambient temperatures fall below about 15°F.

Alternatives to NaCl have been adopted by agencies in an effort to deliver clear roads in cold weather while reducing environmental impact. Typically, these products cost more than NaCl, but their overall effectiveness as a deicer allows for a potential reduction in salt use.

Unfortunately, winter maintenance practices do not always capitalize on this ability to use less. The most common alternatives to NaCl are magnesium chloride (MgCl₂) and calcium chloride (CaCl₂). On structures such as airport runways and bridge decks, potassium acetate (KAc) and urea may be employed. Other products based on agricultural

byproducts, such as beet juice, are used by themselves or combined with chloride-based salts to form various proprietary mixtures.

Chemical Effects

Portland cement concrete is a mixture of mineral aggregates and sand bound together with a permeable hydrated portland cement paste. A concrete structure may also contain embedded steel for load transfer or for reinforcing purposes. Deicing chemicals can interact deleteriously with all components of a concrete structure. In the simplest terms, this interaction is a two step process where first, the salt dissociates in water (e.g., NaCl becomes separate sodium (Na) and chloride (Cl) ions in water) and second, these individual ions interact with materials in the concrete in a variety of ways:

- Magnesium (Mg) and calcium (Ca) ions interact with hardened cement paste to form a variety of reaction products (discussed below) that may be expansive or may lead to a weakening of the hardened cement paste.
- By design, deicers increase the available water in the concrete either directly from the applied brine or by melting snow and ice. The increased water, coupled with cold temperatures, promotes the leaching of components from the hardened cement paste, thereby weakening the paste or combining with the deicer ions to form deleterious compounds.
- Chloride ions migrate through the concrete and accumulate at depth. If a critical concentration of chloride ions is obtained at the depth of the reinforcing steel, corrosion of the steel can result.

At the heart of chloride-based deicer-related chemical attacks on hardened cement paste is the dissolution of calcium hydroxide ($\text{Ca}(\text{OH})_2$). Calcium hydroxide is a normal constituent of hardened cement paste resulting from the hydration of portland cement. The leaching of calcium hydroxide from concrete increases as temperature decreases, and is maximized near freezing temperatures. Calcium hydroxide dissolution results in an increased hydroxide (OH) concentration in the concrete pore water and free calcium (Ca) ions. The increased OH concentration contributes to other chemical mechanisms of attack but, more simply, as the $\text{Ca}(\text{OH})_2$ leaches, the concrete becomes more permeable; more water can infiltrate, and the cyclical process accelerates.

In concrete exposed to MgCl_2 and CaCl_2 , Ca ions from the deicer or dissolved $\text{Ca}(\text{OH})_2$ interact with dissolved OH and Cl ions, and calcium oxychloride ($3\text{CaO}\cdot\text{CaCl}_2\cdot 15\text{H}_2\text{O}$) can be precipitated at low temperature (e.g., 40°F). Calcium oxychloride is expansive and will cause cracking in the hardened cement paste (Sutter 2008a). Evidence of oxychloride-based expansions are almost impossible to confirm in field samples.

This is because the oxychloride phase quickly loses its water of hydration when exposed to the atmosphere and reverts to either calcium hydroxide or calcium carbonate. However, laboratory confirmation of the effect has been reported (Collepari 1994, Sutter 2008a), and field damage that appears to be deicer-related chemical attack has been identified (e.g., paste softening, paste disintegration). Other potential chemical attack mechanisms include the calcium silicate hydrate (CSH) phase of the hardened cement paste altering to a weaker magnesium silicate hydrate (MSH).

As water percolation through the concrete continues or is exacerbated by dissolved $\text{Ca}(\text{OH})_2$, secondary products form that may not be expansive but will infill the air-void system, thereby reducing the concrete's freeze-thaw durability. The most common occurrence is ettringite depositing inside air voids, but Friedel's salt (calcium-chloro-aluminate) may also precipitate and compromise the air-void system.

Physical Effects

Salts in solution will penetrate the porous microstructure of concrete. Subsequent evaporation may result in salt crystal growth within the concrete, which can result in expansive forces. This is not necessarily a cold weather phenomenon; it can also occur in marine or industrial settings. This is unlikely to occur with MgCl_2 and CaCl_2 because they tend to absorb water from the atmosphere rather than dehydrating and forming crystals.

The mechanism most likely to cause distress in a freezing environment is that of expansion of water or solution as it freezes within the paste's pore structure. Pure water expands about 9% as it freezes. If the concrete pore structure cannot accommodate this expansion, tensile stresses result and the concrete cracks. Cracking leads to more water on the next thawing cycle, meaning cycling through the freezing point can lead to extensive damage accumulation. The damage occurs when the system is saturated above the point where there is sufficient space for the expanding water to move into. That limit is about 85-87% saturation of the total void space in the concrete (Fagerlund 1977, Li 2012).

The air-void system provides space for pressure from freezing fluids to be relieved and also delay saturation as they increase the initial volume of voids in the concrete. However, air voids and other pores can hold hygroscopic salts, such as MgCl_2 and CaCl_2 , which attract water and contribute to the degree of saturation. The salts hold moisture in the concrete and, over time, the concrete increases in saturation until the critical value is reached, a freezing cycle occurs, and cracking results. This mechanism is believed to be the predominant cause of distress associated with deicers, and it requires attention in detailing and maintaining pavements to ensure that all concrete surfaces can dry as much as possible, slowing the process of reaching critical saturation.

Another factor related to physical mechanisms of distress is the effect of the salts on the number of freeze-thaw cycles. If air temperatures are cycling through 32°F but stay above the freezing temperature of the salt solution, the number of cycles will be reduced. However, as air temperatures go down, the presence of salts may increase the number of cycles. Depending on the season, the effects of salts on the total number of cycles may be small.

It has been proposed that lower-strength brine solutions would slow the rate of deicer-related distress. Although deicer brines typically have high salt concentrations (e.g., 15%-30% salt by weight), dilute solutions are more problematic and are most associated with distress.

As an example, the standard scaling resistance test (ASTM C672) uses a 4% solution of CaCl_2 because data by Verbeck (1957) showed that damage is markedly accelerated at these concentrations. As concentrations increase or decrease, the rate of damage accumulation is decreased. It is true that lowering the deicer concentration would reduce the absolute amount of salt delivered, and by extension would reduce the amount of salt available to deposit within the concrete. However, in terms of freezing point, there is a minimum concentration brine solution that can be delivered using conventional distribution equipment.

Effects on aggregates

Some limestone aggregates may be attacked by chloride salts. Typically these are aggregates that are also prone to D-cracking, compounded by the presence of clay contaminants that may react with the chlorides to cause added expansion. This sensitivity may be assessed by elemental analysis of the aggregates.

Detecting deicer attack

Although there is no single set of descriptors for physical or chemical deicer attack, for distress occurring at concrete joints there are some common observations. Initially, distress is commonly observed as shadowing around joints (Figure 1a), followed by cracking parallel to the joint (Figure 1b).

As cracking increases, there is a visible loss of material in the form of thin flakes of paste being removed from the surface (Figure 2a) or, in many cases, larger wedges of concrete breaking free (Figure 2b). The shadowing and cracking continues to propagate parallel to the joint, and the material loss also continues and the joint deterioration advances.

Regarding chemical attack, common observations include a softening of the concrete paste and separation of the aggregate from the cement paste (i.e., the concrete disintegrates) (Figure 3).

Calcium hydroxide and calcium carbonate exudate may be seen in some cases within cracks near the disintegration (Figure 4).



Figure 1a. Initial stage of joint deterioration



Figure 1b. Progression of joint deterioration



Figure 2a. Further progression of joint deterioration showing loss of thin flakes



Figure 2b. Further progression of joint deterioration showing loss of larger wedges



Figure 3. Example of paste disintegration



Figure 4. Exudate visible along cracks parallel to the deterioration front

On flatwork, a common observation is scaling (Figure 5a) or mortar flaking (Figure 5b); however, this is difficult to associate with deicers as the same distress is associated with improperly finished concrete.

Recommendations

Safety is the primary consideration, and activities to keep roads safe will not be compromised. Therefore, it is imperative that the concrete pavement industry produces pavements that are able to resist the aggressive environment that will be imposed with increasing use of brine-based deicing systems using chloride salts.

On the other hand, agencies also need to use the range of products available to them wisely. Some cities adopt a policy of prohibiting salting on streets in their first season. This allows the concrete to gain additional maturity before it is exposed to the rigors of heavy salting. Some cities are also



Figure 5a. Example of scaling



Figure 5b. Example of flaking

adopting a practice of only using NaCl when temperatures are above 15°F and resorting to other products only at lower temperatures—and then sparingly. At least one city has reported a slowing of distress by adopting this policy. Consideration may also be given to flushing pavements to remove the salts periodically, but this may not always be practical. It is important to prevent water and salt solutions from being trapped in the joint. This can be improved by ensuring that drainage details are adequate and by avoiding leaving a void below the backer rod.

New concrete pavements should be designed to resist the aggressive environments imposed by deicing salts. Recommendations include the following:

- Maximum w/cm = 0.40–0.42
- Minimum air behind the paver = 5%
- Use supplementary cementitious materials (SCMs, e.g., slag cement and fly ash) accompanied with the necessary curing regimes required by SCMs.
- If a saw cut is to be sealed, leave out the backer rod and completely fill the kerf.
- Apply curing compound to the saw face.
- Ensure that joints can drain.
- Provide adequate drainage to dry out the system periodically while preventing pumping and still maintaining stability.
- Avoid salting new concrete for one season if possible.
- Use penetrating sealants to slow deicer and water ingress.

For existing roads that are starting to show distress, recommendations include the following:

- Consider applying penetrating sealants on the saw face to decrease permeability.
- If seals are present, ensure that they are maintained.
- Review salting practices.

Partial-depth or full-depth repairs are appropriate, depending on the depth of distress. Care should be taken to ensure that an intimate bond is provided between new and old concrete to prevent water penetrating the interface. Consideration may be given to an overlay-based approach, depending on the degree of damage, along with other factors such as connections with other roads and services.

For more information

For more information about deicer salts and concrete pavements, contact Professor Lawrence Sutter, Michigan Technological University, lsutter@mtu.edu, 906-487-2268.

References

- Chappelow, C. C. and D. Darwin. 1992. Handbook of Test Methods for Evaluating Chemical Deicers. SHRP H-332, Washington, DC: Strategic Highway Research Program, National Research Council.
- Collepari, M., Coppola, L., & Pistolesi, C. (1994). Durability of Concrete Structures Exposed to CaCl₂ Based Deicing Salts. Durability of Concrete, ACI SP-145. V.M. Malhotra, Ed., Third International Conference, Nice, France. pp. 107-120.
- Fagerlund, G., "The Critical Degree of Saturation Method of Assessing the Freeze/thaw Resistance of Concrete and the International Cooperative Test of the Critical Degree of Saturation Method of Assessing the Freeze/thaw Resistance of Concrete," Mater. Struct., Vol. 1977(10), 1977, pp. 217-229 and 231-253.
- Fischel, M. 2001. Evaluation of Selected Deicers Based on a Review of the Literature. Report No. CDOT-DTD-R-2001-15, Denver, CO.:Colorado Department of Transportation.
- Li, W., Pour-Ghaz, M., Castro, J. & Weiss, J. W. 2012. Water Absorption and Critical Degree of Saturation Relating to Freeze-Thaw Damage in Concrete Pavement Joints. Journal of Materials in Civil Engineering, 24, 299-307.
- NCHRP REPORT 577, "Guidelines for the Selection of Snow and Ice Control Materials to Mitigate Environmental Impacts," National Cooperative Highway Research Program, Transportation Research Board, Washington, D.C., 2007.
- Neville, A. M. 1996. Properties of Concrete. 4th edition, New York: John Wiley and Sons, Inc.
- Snowfighters Handbook, The Salt Institute, 2013, http://www.saltinstitute.org/wp-content/uploads/2013/07/Snowfighters_HB_2012.pdf, Accessed July 2014.
- Sutter, L.L., K.W. Peterson, and T.J. Van Dam, "Investigation of the Long Term Effects of Magnesium Chloride and Other Concentrated Salt Solutions on Pavement and Structural Portland Cement Concrete," Implementation Guide SD2002-01, South Dakota Department of Transportation, Pierre, South Dakota, April 2008.
- Sutter, L.L., K.W. Peterson, and T.J. Van Dam, "Investigation of the Long Term Effects of Magnesium Chloride and Other Concentrated Salt Solutions on Pavement and Structural Portland Cement Concrete," Final Report SD2002-01, South Dakota Department of Transportation, Pierre, South Dakota, April 2008a.
- Verbeck, G. and Klieger, P., (1957) "Studies of 'Salt' Scaling of Concrete" Highway Research Board Bulletin No.150. Washington, D.C.: Transportation Research Board. 1-13.