Minimizing the Deleterious Effects of Deicers on Portland Cement Concrete

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Abstract

Every winter, transportation agencies apply a number of different chemicals to their roadway pavements in ongoing efforts to keep them clear of ice and snow. Although effective, many of these materials have potentially adverse effects on the environment and on the vehicles using the roadways, and recently there have been additional concerns expressed regarding their potential deleterious effects on concrete infrastructure (such as scaling, spalling, degradation, and corrosion of embedded steel). A pooled-fund study was recently conducted to study the effects of deicing chemicals on concrete, and from that study a series of strategies were developed to help minimize the effects of deicing chemicals on portland cement concrete. This paper summarizes those guidelines.

1.0 Introduction

The use of various chemicals for snow and ice control is an integral part of the winter maintenance activities of most transportation agencies. Although the use of “road salt” and other deicing materials can be traced back to some of the earliest days of paved roadways, the application of these materials became more widespread, and their need more acute, with the dawning of the Interstate era in the mid-1950s.

In the last few decades, new snow and ice control strategies have been implemented, and a number of new deicing chemicals have been introduced. For example, many agencies now employ both “anti-icing” and “deicing” strategies, in which anti-icing is defined as any treatment applied prior to ice formation to eliminate ice accumulation or facilitate its removal, and deicing is defined as any effort to remove ice from roads or bridges after deposition on the surface (Sutter et al. 2008).

Although conventional road salt (NaCl) historically has seen the greatest use on transportation facilities, a number of different materials are used for snow and ice control, as shown in Table 1 (Levelton 2007). The chloride salts have been commonly used on street and highway pavements and offer many advantages including their low cost and relative effectiveness as a snow and ice control chemical. Unfortunately, these materials also have several disadvantages including their environmental impacts on vegetation, groundwater, wildlife, their corrosive effects on vehicles, and deleterious effects on concrete infrastructure. The organic and nitrogen products listed in Table 1 (i.e. acetates, glycols, and urea) are commonly used on airfield pavements because of concerns about the corrosive effects of chlorides on aircraft. While these materials have demonstrated adequate snow and ice fighting ability, some are very expensive (e.g. acetates) and others may have adverse environmental effects (e.g. glycols, urea).
Table 1. Properties of common snow and ice control materials (adapted from Levelton 2007).

<table>
<thead>
<tr>
<th>Material</th>
<th>Chemical Formula</th>
<th>Forms Used</th>
<th>Effective Min. Temp. °F [ºC]</th>
<th>Median Cost per Ton</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium Chloride</td>
<td>NaCl</td>
<td>Primarily solid, but increasing use of liquid</td>
<td>14 [-10]</td>
<td>$36</td>
</tr>
<tr>
<td>Calcium Chloride</td>
<td>CaCl₂</td>
<td>Mostly liquid brine; some solid flake</td>
<td>-24 [-31.1]</td>
<td>$120</td>
</tr>
<tr>
<td>Magnesium Chloride</td>
<td>MgCl₂</td>
<td>Mostly liquid brine; some solid flake</td>
<td>5 [-15]</td>
<td>$95</td>
</tr>
<tr>
<td>Calcium Magnesium Acetate</td>
<td>[Ca Mg₂(C₂H₅O₂)₂]₆</td>
<td>Mostly liquid and some solid</td>
<td>23 to 27 [-5 to -2.8]</td>
<td>$1280</td>
</tr>
<tr>
<td>Potassium Acetate</td>
<td>KC₂H₅O₂</td>
<td>Liquid only</td>
<td>-76 to -22 [-60 to -30]</td>
<td>n/a</td>
</tr>
<tr>
<td>Glycols</td>
<td>C₃H₈O₂, C₂H₆O₂</td>
<td>Liquid only</td>
<td></td>
<td>n/a</td>
</tr>
<tr>
<td>Urea</td>
<td>(NH₂)₂CO</td>
<td>Mostly solid</td>
<td>19 to 25 [-7.2 to -3.9]</td>
<td>n/a</td>
</tr>
</tbody>
</table>

There are two general forms of deterioration that can occur when concrete is exposed to high concentrations of deicing chemicals:

- **Concrete Degradation.** Degradation of concrete as a result of exposure to deicing chemicals occurs as the result of physical and chemical mechanisms. Physical mechanisms associated with the repeated application of deicing chemicals lead to scaling or crazing of the slab surface, or perhaps spalling of joints or cracks (Van Dam et al. 2002). The primary mechanisms considered are not exactly known, but may involve a combination of increased saturation, thermal stresses generated when a deicer melts ice, and increased osmotic pressures induced as the deicer imbalances the ionic concentration in the capillary pore solution in the concrete (Mindess, Young, and Darwin 2003; Pigeon and Plateau 1995). Moreover, recent studies indicate that chemical alteration of the cement paste can also occur, resulting in dissolution of calcium hydroxide, coarsening of the concrete pore system and the formation of deleteriously expansive oxychloride compounds (Sutter et al. 2008).

- **Corrosion of Embedded Steel.** Corrosion of embedded steel appears as rust colored staining, spalling, cracking, and associated deterioration of the concrete above or surrounding the areas affected by active corrosion. Although steel embedded in concrete forms a thin passivity layer of oxide providing protection from reaction with oxygen and water, this passivity film can be easily broken down under the action of chloride ions. The soluble chloride ion level at which steel reinforcement corrosion begins in concrete is about 0.2 to 0.4 percent by mass of cement (Kosmatka, Kerkhoff, and Panarese 2002). In most transportation structures, the primary source of the chloride ions is from the application of deicing salts, although it can also come from other sources.

Under a pooled-fund study led by the South Dakota Department of Transportation (SDDOT), the effects of deicing chemicals on concrete were investigated and the results incorporated into a document presenting “best practices” guidance on minimizing the effects of deicers on infrastructure concrete. This paper summarizes those guidelines.
2.0 Strategies for Minimizing Effects of Deicers on Concrete Pavement

2.1 Strategy 1: Provide Durable Concrete Mix

The first and foremost strategy for eliminating or reducing the adverse effects of deicing chemicals is the development of a durable concrete mix. Durability is defined as the ability of concrete to resist weathering action, chemical attack, abrasion, or any other process of deterioration (ACI 2001). Inherent in this definition is that different concretes may be exposed to different environmental forces, suggesting that different concrete mixes are required to maintain the same level of durability for different conditions.

Detailed information on the production of durable concrete is provided in a number of documents (for example, Pigeon and Plateau 1995; ACI 1991; ACI 2001; Kosmatka, Kerkhoff, and Panarese 2002; Van Dam et al. 2002; Taylor et al. 2006). Some general guidelines are provided in the following sections.

Minimum Cement Content

In order to minimize the scaling of concrete exposed to severe freeze-thaw, deicer, and sulfate exposures, some sources recommend a minimum cement content of 564 lb/yd$^3$ [335 kg/m$^3$] (Kosmatka, Kerkhoff, and Panarese 2002). These sources indicate that lean concrete (with cement contents of 405 lb/yd$^3$ [240 kg/m$^3$] or less) are particularly vulnerable to deicer scaling. On the other hand, some references state that a minimum cement content is not necessary as long as the concrete can be easily placed and has sufficient strength, low permeability, and an adequate air-void system (TRB 1999; Taylor et al 2006).

Supplementary Cementitious Materials

Supplementary cementitious materials (SCMs), which include materials such as fly ash, ground granulated blast furnace slag (GGBFS), and silica fume, are often used in concrete mixtures to improve workability and enhance durability. SCM materials also produce a denser, significantly less permeable microstructure that is less susceptible to chemical and physical attack.

Concrete mixtures made with SCMs have exhibited variable performance with respect to deicer scaling resistance. Often poor performance of concrete mixtures that include SCMs can be traced to improper curing. Generally, these mixtures require longer times to achieve ultimate strength and permeability because the pozzolanic reaction is much slower than is the normal hydration reactions between portland cement and water. The ACI 318 building code states the maximum dosage of fly ash and GGBFS should be 25 and 50 percent by mass of the cementing materials, respectively (Kosmatka, Kerkhoff, and Panarese 2002). Actual dosage rates must be established for the specific materials being used based on the specific application.

Water Quality

Acceptance criteria for mixing water used in the production of concrete are given in AASHTO T26. In general, the water should be relatively free of chlorides, sulfates, alkalies, and other potential contaminants or impurities.

Water-to-Cementitious Ratio

The $w/cm$ is the mass of the water in the mix divided by the mass of cementitious materials (portland cement + supplementary cementitious materials). The $w/cm$ selected for a mix design must be the lowest value required to meet anticipated exposure conditions, with recommended values as follows (Kosmatka, Kerkhoff, and Panarese 2002):
Concrete exposed to freezing and thawing in a moist condition or deicers: \( \leq 0.45 \)

For corrosion protection for reinforced concrete exposed to deicers: \( \leq 0.40 \) (unless an additional 0.5 inch [12.5 mm] of concrete cover is added).

In general, a lower \( w/cm \) results in a less permeable concrete, suggesting that a lower \( w/cm \) provide better protection from deicer attack. However, a recent study indicates that lower \( w/cm \) mixtures do not perform better than mixtures with a higher \( w/cm \) with regards to chemical attack by deicers (Sutter et al. 2008). Thus, other methods (such as using SCMs) should be employed in conjunction with a low \( w/cm \) to help achieve reduced permeability.

**Aggregates**

Strong and durable aggregates should be used that are not reactive or susceptible to freeze-thaw or moisture damage. Such aggregates should have a proven track record of acceptable performance or should meet the requirements ASTM C295 (*Standard Guide for Petrographic Examination of Aggregates for Concrete*) to characterize the physical and chemical properties of the aggregate, with supplemental laboratory testing conducted to further define the physical and chemical stability of the aggregate (Van Dam et al. 2002).

The largest nominal maximum coarse aggregate size that is practical for the job conditions should be used (Taylor et al. 2006; Kosmatka, Kerkhoff, and Panarese 2002). For pavements, both ACI and PCA recommend that the maximum aggregate size should be less than one-third the slab thickness and three-quarters of the free space between reinforcing bars or reinforcing bars and formwork (ACI 1991; Kosmatka, Kerkhoff, and Panarese 2002). Although the use of 0.75- to 1.0-inch [19 to 25.4 mm] top sizes is commonly used by highway agencies, several agencies are returning to the use of larger (1.5 to 2 inch [38 to 51 mm]) maximum coarse aggregate sizes.

Traditionally, gap-graded aggregate mixtures have been used in the production of concrete, in which coarse aggregates (particle sizes greater than 3/16 inch [4.75 mm]) are combined with fine aggregates (smaller than 3/16 inch [4.75 mm]). This often leaves a gap in the intermediate-sized aggregate around the 3/8 inch [9.5 mm] size, which may make the resultant mixture more susceptible to segregation and shrinkage, and may exhibit poor workability and placeability. The use of well-graded aggregates that contain a balanced variety of sizes are expected to help maximize the aggregate volume, reduce shrinkage and permeability, and enhance workability (Shilstone 1990; Taylor et al 2006).

**Air-Void System**

An effective air-void system is needed to protect the hardened concrete from freeze-thaw damage and deicer scaling (Van Dam et al. 2002). An air-void system is established using air entraining agents that create small, stable air voids in the hardened concrete that serve as “relief valves” to dispel osmotic and hydraulic pressures caused by water freezing in the capillaries and pores of the cement paste (Kosmatka, Kerkhoff, and Panarese 2002). Typical entrained air contents for concrete mixes range from about 4 to 8 percent, and are dependent upon the severity of the environmental exposure and the nominal maximum coarse aggregate size (see Table 2).
Table 2. Recommended total air contents (Kosmatka, Kerkhoff, and Panarese 2002).

<table>
<thead>
<tr>
<th>Nominal Maximum Size Aggregate, inch [mm]</th>
<th>Average Air Content, Volume Percent¹</th>
<th>Severe Exposure²</th>
<th>Moderate Exposure³</th>
<th>Mild Exposure⁴</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 3/8 [9.5]</td>
<td>9</td>
<td>7</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>3/8 [9.5]</td>
<td>7.5</td>
<td>6</td>
<td>4.5</td>
<td></td>
</tr>
<tr>
<td>1/2 [12.5]</td>
<td>7</td>
<td>5.5</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>3/4 [19.0]</td>
<td>6</td>
<td>5</td>
<td>3.5</td>
<td></td>
</tr>
<tr>
<td>1 [25.0]</td>
<td>6</td>
<td>4.5</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>1-1/2 [37.5]</td>
<td>5.5</td>
<td>4.5</td>
<td>2.5</td>
<td></td>
</tr>
<tr>
<td>2 ⁵ [50]</td>
<td>5</td>
<td>4</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>3 ⁵ [75]</td>
<td>4.5</td>
<td>3.5</td>
<td>1.5</td>
<td></td>
</tr>
</tbody>
</table>

¹ Project specifications often allow the air content of the concrete to be within -1 to +2 percentage points of the table target values.
² Concrete exposed to wet-freeze-thaw conditions, deicers, or other aggressive agents.
³ Concrete exposed to freezing but not continually moist, and not in contact with deicers or aggressive chemicals.
⁴ Concrete not exposed to freezing conditions, deicers, or aggressive agents.
⁵ These air contents apply to the total mix, as for the preceding aggregate sizes. When testing these concretes, however, aggregate larger than 1-1/2 inch [37.5 mm] is removed by handpicking or sieving and the air content is determined on the minus 1-1/2 inch [37.5 mm] fraction of mix. (Tolerance on air content as delivered applied to this value.)

However, it is not the total air content that is important to the durability of the mix, but rather the distribution of the air voids within the concrete microstructure. It is desired that the “spacing factor” (designated as $L$ and generally thought of as the average distance between any point in the paste and an air void) be less than 0.008 in (0.2 mm) (Kosmatka, Kerkhoff, and Panarese 2002; Taylor et al. 2006).

Admixtures

Accelerating admixtures are commonly added to a concrete mix in order to achieve high early strength, but the most common accelerating admixture—calcium chloride, which is also a commonly used deicing chemical—is known to promote corrosion of embedded steel, and may have other negative effects on concrete durability, including increasing drying shrinkage and adversely affecting the pore structure. If these issues are a concern, then non-chloride accelerators should be used.

Water-reducing admixtures may be added to concrete mixtures to reduce the amount of water required to produce concrete of a given consistency. Reductions of 5 to 10 percent are common, allowing the use of a lower w/cm while maintaining a desired slump, and having the beneficial effect of increasing strength and reducing permeability (Van Dam et al. 2002).

Corrosion inhibitors (such as calcium nitrite, sodium nitrite, and phosphates) may be added to concrete used in parking structures, marine structures, and bridges that are exposed to chloride salts. These admixtures react chemically to either block the corrosion reaction of the chloride ions with the steel (anodic inhibitors) or by reacting with the steel surface to interfere with the reduction of oxygen (cathodic inhibitors) (Kosmatka, Kerkhoff, and Panarese 2002).
Laboratory Tests

Two tests are available that can assist in evaluating the capabilities of concrete to resist deicer scaling and corrosion of embedded steel. These tests are described below:

- **ASTM C672, Standard Test Method for Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals.** This test method ponds the top surfaces of concrete specimens with a standard solution of calcium chloride and water or other chemical deicers and subjects the specimens to a series of freeze-thaw cycles.

- **ASTM C1202, Standard Test Method for Electrical Indication of Concrete’s Ability to Resist Chloride Ion Penetration.** This test method (sometimes referred to as the rapid chloride penetration test) measures the electrical conductivity of a concrete specimen, which is used as a surrogate indicator for the permeability of the concrete. The test provides a way of comparing the relative resistivity of different samples, using the following guidelines:
  - > 4,000 Coulombs Passed: High Chloride Permeability
  - 2,000 to 4,000 Coulombs Passed: Moderate Chloride Permeability
  - 1,000 to 2,000 Coulombs Passed: Low Chloride Permeability
  - 100 to 1,000 Coulombs Passed: Very Low Chloride Permeability
  - <100 Coulombs Passed: Negligible Chloride Permeability

These laboratory tests should be considered along with recommended mix design guidelines in order to ensure the development of a durable concrete mixture.

2.2 Strategy 2: Perform Effective Concrete Construction

From a construction standpoint, there are a number of factors that can affect this outcome, from the ambient and seasonal construction conditions to the placement and consolidation efforts, to the finishing and curing practices. Some of these key construction factors are described in the following sections.

Weather Management

The placement of concrete under extreme weather conditions can be detrimental to the development of durable concrete, and contractors should have weather management plans in place to deal with such conditions, particularly hot- and cold-weather paving. Tables 3 and 4 provide guidelines for hot- and cold-weather paving.

In addition, the occurrence of untimely rain events may also cause problems during paving. If a rainfall event occurs during paving, the contractor should halt paving operations immediately and cover the freshly placed concrete. No attempts should be made to remove any excess water on the surface, as this actually serves to work the water into the surface paste making it more vulnerable to scaling (Kohn et al. 2003). Rain-damaged concrete—if significant—can be addressed through diamond grinding of the concrete surface.
Table 3. Hot weather paving recommendations (adapted from Kohn et al. 2003).

1. Do not exceed the maximum allowable w/cm ratio or the manufacturer’s maximum recommended dosage of any admixture.
2. Retarding admixtures may be used if their performance has been verified during trial batches.
3. The substitution of slag, Class F fly ash, or natural pozzolans for part of the cement may be an option.
4. Class C fly ashes with high contents of Al₂O₃ may cause problems associated with premature stiffening.
5. Air contents can be corrected by increasing the dosage of air entraining admixture.
6. Early age thermal cracking may be prevented by ensuring that the temperature of the plastic concrete is as low as practical. It should not exceed 90°F [32.2°C].
7. Avoid the use of hot cement or fly ash provided by the supplier.
8. Mixing water may be chilled, or chipped ice may be used in substitution for some of the water.
9. Mixing and transporting equipment may be painted white or a light color to minimize the heat absorbed from the sun.
10. Schedule concrete placements for nighttime.
11. The base should be moistened before the concrete is placed to keep the temperature down and to keep it from absorbing water from the concrete.
12. The concrete should be placed and finished as rapidly as possible and curing compound applied at the earliest possible time. The use of a white curing compound will reflect the sun’s heat.
13. Steps should be taken during hot weather to reduce the rate of evaporation from the concrete. The rate of evaporation is a function of air temperature, concrete temperature, relative humidity, and wind speed. When the rate of evaporation is predicted to be above 0.2 lb/ft²/hr [0.98 kg/m²/hr], provide fog spraying or use an approved evaporation retardant as appropriate.
14. If conditions of temperature, relative humidity, and wind are too severe to prevent plastic shrinkage cracking, or corrective measures are not effective, paving operations must be stopped until weather conditions improve.

Table 4. Cold weather paving recommendations (adapted from Kohn et al. 2003).

1. Concrete mixture designs developed for placement at cooler temperatures normally have higher cement content than those used in hot weather.
2. The use of slag, fly ash, and pozzolans should be reduced or eliminated unless they are required to control alkali-silica reaction or to provide some degree of resistance to sulfate attack. In the later case, the total cementitious materials content may need to be increased, or the cement changed to Type III instead of Type I/II.
3. The required dosage of air entraining admixture should be lower than the dose at normal temperatures.
4. Because the concrete will take longer to set, there is also some danger of plastic shrinkage cracking, especially if the concrete is much warmer than the ambient air or if the wind is blowing.
5. An accelerating admixture conforming to ASTM C494 Type C or E may be used, provided its performance has been previously verified by trial batches.
6. Do not use admixtures containing added chlorides. Also, do not use calcium chloride.
7. Aggregates must be free of ice, snow, and frozen lumps before being placed in the mixer.
8. The temperature of the mixed concrete should not be less than 50 °F [10°C].
9. Concrete should not be placed when the temperatures of the air at the site or the surfaces on which the concrete is to be placed are less than 40 °F [4.4°C].
10. Covering and other means of protecting the concrete from freezing must be available before starting placement.
11. The concrete temperature should be maintained at 50 °F [10°C] or above for at least 72 hours after placement and at a temperature above freezing for the remainder of the curing time (when the concrete attains a compressive strength of 3,000 lb/in² [20.6 kPa]).
12. Corners and edges are the most vulnerable to freezing. Completely remove and replace any concrete that is damaged by freezing.
Consolidation

The goal of consolidation is to effectively remove entrapped air from the concrete system so that a dense and uniform concrete mixture results. In slip-form paving operations, the contractor will establish a suitable vibrating frequency for the paver-mounted vibrators that, in combination with the paving rate and the mixture characteristics, will produce a well-consolidated mixture (Van Dam et al. 2002). Typically, a vibrator frequency of 5,000 to 8,000 vibrations per minute is satisfactory for most mixtures at vibrator speeds greater than 3 ft [0.9 m] per minute (Taylor et al. 2006). It is important to recognize that any changes in paving speed should also necessitate changes in vibrator frequency in order to avoid segregation problems and loss of entrained air.

When using hand-held vibrators, these devices should be inserted into the mix at an angle to the concrete surface and should not be used to move concrete laterally as this could cause segregation. Furthermore, they should not be allowed to vibrate in a fixed position for an excessively long period of time.

Embedded Steel

Embedded steel (e.g., dowel bars, tie bars) may be susceptible to corrosion in the presence of a chloride environment. Because dowel bars and tie bars are placed across a joint, they are especially susceptible to the ingress of both moisture and chloride ions. To combat the potential for corrosion, most dowel bars and tie bars are coated with a thin protective layer, with epoxy being the most commonly used material.

For reinforcing steel located within a slab, the provision of adequate cover is essential in order to prevent corrosion. An absolute minimum cover of 2 inches [51 mm] is required, with a design cover of 2.5 inches [63.5 mm] recommended in order to ensure adequate protection (Van Dam et al. 2002).

Finishing

After concrete placement, some hand finishing may be needed to help embed large aggregate particles, fill any apparent voids, or correct small imperfections (Van Dam et al. 2002). However, it should be kept to a minimum so as to avoid overworking of the surface and causing scaling. Moreover, if the hand finishing is done before the bleed water has disappeared, there is a greater chance of working the bleed water into the concrete, again affecting the durability of the near-surface concrete. In general, the need for hand finishing can be minimized by selecting a workable concrete mixture and properly operating the paving equipment (Kohn et al. 2003).

Curing

The purpose of curing is to enhance hydration and strength gain by maintaining the moisture and temperature of the concrete immediately after placement and finishing (Kosmatka, Kerkhoff, and Panarese 2002). Over the years, a number of different curing methods and materials have been used, including ponding or fogging, wet burlap, plastic sheeting, and curing compounds. Some form of wet curing is considered most beneficial because it effectively maintains the presence of mixing water within the concrete, but such practices are not practical for large paving projects.

The application of liquid membrane-forming curing compound is the most commonly used method of curing. These are organic materials that form a skin over the surface of the concrete and help reduce the loss of mixing water (typically limiting water evaporation to about 20 percent of that of unprotected concrete) (Taylor et al. 2006). Curing compounds are merely
temporary coatings on the surface, and will break down and degrade with exposure to sunlight and traffic.

Liquid membrane-forming curing compounds are governed by ASTM C309 and AASHTO M 148. These materials can be either resin-based or wax-based, and may also be clear or white pigmented, with many agencies specifying white-pigmented, resin-based materials. However, products meeting these specifications can exhibit highly variable performance (Vandenbossche 1999), and it is suggested that agencies test curing compounds for their moisture-retention properties in accordance with ASTM C156.

General guidelines on the use of curing compounds are provided below (Van Dam et al. 2002; Kohn et al. 2003; Poole 2006; Taylor et al. 2006):

- Do not apply the curing compound to concrete that is still bleeding or has a visible sheen of water on the surface.
- Apply the curing compound immediately after texturing. Any delay, particularly during hot, windy conditions, can cause significant harm to the concrete resulting in plastic shrinkage cracking.
- Apply the curing compound uniformly to the concrete surface as well as the sides of the slab. Automated equipment is more effective at providing uniform coverage, and hand-operated equipment should be used only on small areas.
- Recommended curing compound application rates are:
  - 200 ft²/gal [5 m²/l] for normal paving.
  - 150 ft²/gal [3.7 m²/l] for fast-track concrete.
  - 100 ft²/gal [2.5 m²/l] for thin slabs.
- AASHTO recommends a 3-day curing period for pavements and a 7-day curing period for structures, including bridge decks (AASHTO 1998). The latter is increased to 10 days if more than 10 percent SCMs are included in the mix.

**Drying Period**

Newly placed concrete requires an absolute minimum of 30 days of environmental exposure before being subjected to deicing chemicals to enhance its scaling resistance (Kosmatka, Kerkhoff, and Panarese 2002). This requirement reveals the potential vulnerability of late season concrete construction, which may not have an adequate drying time before being exposed to deicers.

### 2.3 Strategy 3: Employ Effective Post-Construction Mitigation Measures

Even when durable concrete has been produced and effectively constructed, there are a number of post-construction mitigation measures that can be taken to help further minimize the potential deleterious effects of deicing chemicals. Some of these recommended activities are described below.

**Improved Winter Maintenance Practices**

More agencies are developing formal winter maintenance plans that incorporate “best practices” for the application of deicing chemicals. This is part of a comprehensive approach that recognizes the external costs associated with the use of these chemicals, particularly as they apply to environmental effects including, among others, surface and groundwater contamination,
vegetation damage, soil impacts (increased alkalinity and reduced permeability), and wildlife toxicity (Levelton 2007). In addition, there are societal costs associated with the use of deicing chemicals such as vehicle corrosion and infrastructure deterioration (Levelton 2007). All of these factors are positively affected by reducing the amount of deicing chemicals applied, suggesting that efforts need to be made to use them more judiciously and, when applied, to ensure their maximum effectiveness.

**Selection of Deicing Chemicals**

Deicing chemicals can have different effects on the durability of the concrete, depending upon the chemical used and its concentration. Figure 1 shows the partial phase diagrams for mixtures of water and common deicing chemicals, showing the freezing point of the water-deicer solution as a function of the concentration of deicing chemical. Note that for all deicing chemical brines, a minimum freezing point (called the eutectic temperature) is obtained at a specific concentration (called the eutectic composition) and exceeding that concentration serves to increase the freezing temperature. Thus, when conditions permit, solution strengths should be reduced to achieve the lowest freezing point needed for the pavement and ambient temperatures.

![Figure 1. The partial phase diagrams for mixtures of water and common deicing chemicals (Sutter et al. 2008).](image)

Research has shown that, regardless of the distress mechanism, reducing deicer solution concentrations reduces the magnitude of distress and distress progression rate (Sutter et al. 2008). Thus, any effort to reduce deicer application concentrations or rates will result in less damage to concrete structures. It is also recommended that MgCl$_2$ and CaCl$_2$ should be applied with an initial concentration less than the pessimism level with respect to concrete deterioration (i.e., 20 percent for MgCl$_2$ and 22 percent for CaCl$_2$) (Sutter et al. 2008).

There are trade-offs that must be weighed when selecting a deicer. For example, laboratory research indicated that NaCl brines have a minimal effect on hydrated cement paste, whereas a clear mechanism for chemical attack of hydrated cement paste in concrete was shown for the MgCl$_2$ and CaCl$_2$ deicers (Sutter et al. 2008). However, it is recognized that NaCl is more corrosive to steel and therefore it is not benign when used as a deicing chemical. Additionally, it
is recognized that MgCl$_2$ and CaCl$_2$ are effective at lower temperatures and are commonly used because of this fact. Assuming MgCl$_2$ and CaCl$_2$ will continue to be used, it is even more critical that durable concrete mixture designs be employed by SHAs using these chemicals.

### Use of Surface Sealers

Surface sealers effectively reduce or prevent the ingress of moisture, chloride ions, sulfate ions, and other substance that may contribute to damaging reactions in the concrete (Sutter et al. 2008). Concrete surface sealers may be divided into a number of different families, with one such grouping as follows (Cady 1994):

- Water repellants, which penetrate concrete pores to some degree and coat pore walls rendering them hydrophobic (e.g., silanes, siloxanes).
- Pore blockers, which have sufficiently low viscosity to penetrate and seal the pores in concrete while leaving little or no measurable coating on the surface of the concrete (e.g., resins, linseed oil).
- Barrier coatings, which are too viscous to penetrate pores to measurable depths but form surfacing coatings of significant thickness and block the pores (e.g., epoxies, urethanes, and acrylics).

Although all surface sealers can slow the penetration of deicing chemicals, one study showed that siloxane sealants were particularly effective at slowing the ingress of deicing chemicals into concrete or mortar; silane sealants were also effective, but to a lesser extent (Sutter et al. 2008).

The application of any surface sealer should be done only on concrete that is clean and allowed to dry for at least 24 hours at temperatures above 60°F [15.6ºC]; at least 28 days should be allowed to elapse before applying sealers to new concrete (Kosmatka, Kerkhoff, and Panarese 2002). Surface sealers may need to be reapplied after 3 to 5 years.

### 3.0 Summary

Deicing chemicals are commonly used as part of winter maintenance activities to provide for safe and efficient travel on the nation’s roadways. While effective, these materials also present a potential adverse effect on concrete infrastructure, including pavement, bridges, culverts, and other concrete members.

This paper provides guidelines for reducing the effects of chloride salts and other deicers on pavement and structural concrete, and these are summarized in Table 5. Overall, it is most economical to address the long-term durability of concrete structures during the initial mix design and construction processes, but steps can also be taken in the selection and application of deicing materials, and in the protection of the concrete after placement, to effectively balance safety and durability.
Table 5. Summary of strategies to minimize effects of chemical deicers.

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Recommended Activities</th>
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<tbody>
<tr>
<td><strong>Durable Mix Design</strong></td>
<td><strong>GOAL:</strong> Preparation of dense, impermeable mix to resist penetration of deicing chemicals</td>
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<tr>
<td></td>
<td>• Inclusion of supplementary cementitious materials (SCM) to decrease permeability</td>
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<tr>
<td></td>
<td>• Low w/cm (0.45 max) to decrease permeability if protection from corrosion is sought</td>
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<tr>
<td></td>
<td>• Durable aggregates not reactive or susceptible to freeze-thaw</td>
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<tr>
<td></td>
<td>• Largest nominal maximum coarse aggregate size practical for the project</td>
</tr>
<tr>
<td></td>
<td>• Consideration of the use of well-graded aggregates</td>
</tr>
<tr>
<td></td>
<td>• Establishment of adequate air-void system targeted to severity of environmental exposure</td>
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<tr>
<td></td>
<td>• Avoid use of chloride-based accelerators</td>
</tr>
<tr>
<td></td>
<td>• Consideration of water-reducing admixtures and corrosion inhibitors, as appropriate</td>
</tr>
<tr>
<td></td>
<td>• Assess scaling resistance and electrical conductivity through ASTM C672 and ASTM C1202, respectively.</td>
</tr>
<tr>
<td><strong>Effective Construction</strong></td>
<td><strong>GOAL:</strong> Construction of well-consolidated concrete free of plastic shrinkage cracks (and other early-age cracking) and without surficial defects</td>
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<tr>
<td></td>
<td>• Avoid construction under extreme weather conditions</td>
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<td></td>
<td>• Perform adequate consolidation to remove entrapped air. Ensure internal vibration is effectively applied and vibrating frequency is matched to paving speed.</td>
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<td></td>
<td>• Use corrosion-resistant dowel bars or tie bars at joints and cracks.</td>
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<td></td>
<td>• Ensure reinforcing steel has adequate concrete cover (2.5 inches [63.5 mm] suggested).</td>
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<td>• Ensure bleed water has disappeared before finishing, and avoid overworking surface.</td>
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<td></td>
<td>• Provide adequate curing using an effective curing compound. Make sure that the proper amount is uniformly applied to the surface.</td>
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<td></td>
<td>• Employ a 30-day “drying period” before applying deicing chemicals to new concrete.</td>
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<tr>
<td><strong>Post-Construction Mitigation</strong></td>
<td><strong>GOAL:</strong> Minimize deleterious effects of deicing chemicals on in-service concrete structures</td>
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<tr>
<td></td>
<td>• Minimize the application of deicing chemicals and maximize effectiveness of each deicing application.</td>
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<td></td>
<td>• Use deicing chemicals at lowest possible concentration levels (less than pessimum amount).</td>
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<td></td>
<td>• Consider increased use of sodium chloride brines wherever possible.</td>
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<tr>
<td></td>
<td>• Employ surface sealers (particularly the use of siloxanes or possibly silanes) in areas of heavy deicing applications to reduce ingress of chemicals.</td>
</tr>
</tbody>
</table>
4.0 References


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