

## Review

# Sealer and coating systems for the protection of concrete bridge structures

Md. Safiuddin\* and K. A. Soudki

Department of Civil and Environmental Engineering, Faculty of Engineering, University of Waterloo,  
200 University Avenue West, Waterloo, Ontario, Canada N2L 3G1.

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**Concrete bridge structures most often experience different forms of deterioration, such as surface scaling, spalling, and internal frost damage due to environmental and chemical attacks. Sealers and coatings are used to reduce these forms of concrete deterioration by limiting penetration of water and water-borne deleterious agents, such as chlorides and sulphates. Moreover, sealers and coatings are used to resist chemical attack and corrosion damage due to de-icer and anti-icer chemicals, such as NaCl, CaCl<sub>2</sub>, and MgCl<sub>2</sub>. They also facilitate moisture vapour transmission, and thus aid rapid drying and mitigate the effects of corrosion. This paper presents the key aspects of sealers and coatings used for the protection of concrete bridge structures. It highlights different types and selection criteria of sealers and coatings, surface preparation and application methods required for applying these products, and their role in protecting concrete. In addition, the different evaluation methods and performance criteria for sealers and coatings are discussed in this paper.**

**Key words:** Bridge structure, chemical attack, concrete, de-icer and anti-icer, durability, freezing and thawing, moisture vapour transmission, physical attack, sealer and coating, wetting and drying.

## INTRODUCTION

Concrete deterioration is often identified in many components (decks, piers, abutments, girders, and barrier walls) of the bridge structure due to exposures to aggressive environments (freezing and thawing, wetting and drying, extreme temperature changes, etc.) and corrosive chemicals (de-icers, anti-icers, etc.). De-icer and anti-icer chemicals (de-icing and anti-icing salts), such as NaCl, CaCl<sub>2</sub>, and MgCl<sub>2</sub> are regularly used on bridge decks to maintain safe driving conditions during the winter weather in many cold-region countries. Other chemicals, such as calcium magnesium acetate and urea are also used as de-icer or anti-icer to a lesser degree. Darwin et al. (2008), Kozikowski et al. (2007), and Sutter et al. (2008) reported that CaCl<sub>2</sub> and MgCl<sub>2</sub> can cause severe scaling, which not only damages the concrete surface but also accelerates the ingress of deleterious agents (chlorides, sulphates, etc.) and increases the degree of saturation. In such conditions, chlorides can penetrate the concrete cover more rapidly and carbon

dioxide can more easily diffuse from the atmosphere, thus contributing to corrosion of the embedded reinforcing steel. In addition, the increased degree of saturation can cause strength loss due to the formation of ice (Scherer and Valenza, 2005).

The deterioration of concrete in bridge structures can occur due to physical and chemical attacks when exposed to aggressive environments and corrosive chemicals. In cold-region countries, the most common physical deterioration of concrete is caused by the actions of freezing and thawing. This attack is intensified in the presence of de-icer or anti-icer chemicals used in bridge maintenance during winter. As a result, the bridge structures in cold-region countries are often deteriorated due to the internal frost damage and surface scaling of concrete (Filice and Wong, 2001; Julio-Betancourt, 2009). Moreover, the physical distress of concrete in bridge structures can frequently be observed due to wetting and drying with and without de-icer/anti-icer chemicals associated with temperature changes (Darwin et al., 2007, 2008).

Concrete bridge structures require special attention to maintain their durability and service life under aggressive environmental and chemical exposures. Without a

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\*Corresponding author. E-mail: [msafiudd@gmail.com](mailto:msafiudd@gmail.com) or [safiq@yahoo.com](mailto:safiq@yahoo.com).

durability consideration, bridge structures may undergo accelerated deterioration, such as surface scaling, concrete spalling, and corrosion of the embedded reinforcing steel. In this respect, experience confirms the importance of providing protection to concrete bridge structures. Concrete bridge structures can be protected using the following methods (Drochytka and Petranek, 2002):

1. Improving the physical properties of concrete and repair materials;
2. Altering the electrochemical behaviour of steel;
3. Applying surface treatments.

Many surface treatments, such as sealers, coatings, membranes, and impregnation resins are currently used for the protection of concrete bridge structures (Ibrahim et al., 1999; Palle and Hopwood II, 2006; Wenzlick, 2007). It is well accepted that the durability of reinforced concrete primarily depends on the composition and properties of its exposed surface layer (Pigeon et al., 1996). Coatings and sealers are often used to protect this surface layer by retarding the ingress of harmful chemicals (Jones et al., 1995). Sealers are typically classified as either penetrants or surface sealers that do not change the appearance of concrete to any significant degree. Coatings may be clear liquids, but typically are pigmented to improve the aesthetics of concrete and to provide a uniform appearance after restoration work for the bridge structures. Penetrating sealers may be applied to all exposed concrete surfaces, but the use of surface sealers and coatings on trafficked surfaces is generally limited due to their lower abrasion resistance.

To ensure effective performance, penetrating sealers and surface coatings must have adequate adhesion to the substrate, be applied at adequate thickness, and provide good resistance to the ingress of water-borne deleterious agents. Penetrating sealers must be applied at the optimum rate to ensure good penetration into a prepared substrate so that they can considerably reduce the ingress of harmful chemicals. When it is desirable for moisture vapour to transmit from the concrete under a treated surface, both sealers and coatings should also have an acceptable level of "breathability".

The main objective of this study is to provide a review of sealers and coatings, which are used for the protection of concrete bridge structures. In this paper, the mechanisms of concrete damages caused by de-icer and anti-icer chemicals, and the influences of several key factors are highlighted. The effects, application and evaluation methods, and performance requirements of different sealer and coating products are presented. In addition, the selection criteria and surface preparation methods for sealers and coatings are discussed. A number of research needs with respect to the application, performance, and evaluation of sealers and coatings are

also identified.

## DE-ICER AND ANTI-ICER CHEMICALS

Chemicals applied on bridge decks for winter highway maintenance may be categorized as either de-icers or anti-icers. De-icers are applied after snow falls to prevent the formation of ice and to melt existing ice. In contrast, anti-icers are applied before snow fall or at the early stage of precipitation to prevent the formation of bond between ice and road surface. Both de-icer and anti-icer chemicals depress the freezing point of water by reducing the temperature at which ice can form.

De-icer and anti-icer chemicals were first used on roads, highways, and bridge decks in the U.S.A. during the 1940s (TRB, 1991). Currently, the U.S.A applies about 15 million tons of de-icing and anti-icing salts every year (Shi, 2005). In Canada, the use of de-icing and anti-icing salts on highways began during the 1950s (Julio-Betancourt, 2009). De-icer and anti-icer chemicals can be chloride-based or non-chloride-based. However, chloride-based de-icer and anti-icer chemicals are commonly used due to their low cost and relatively high effectiveness (TRB, 2007). The most popular chloride-based de-icer chemical is NaCl, followed by CaCl<sub>2</sub>. In more recent years, MgCl<sub>2</sub> usage has commenced; the producers are promoting it as being more environmentally friendly and less corrosive than NaCl and CaCl<sub>2</sub>. In Southern Ontario of Canada, a formulated chloride-based liquid de-icer/anti-icer, commercially known as "Geomelt S30" has been used (Soudki et al., 2011). It consists of an organic salt accelerator derived from desugared sugar beet juice (marketed under the name of Geomelt 55 concentrate), which is blended with NaCl brine. This product may allow less salt use for the same effectiveness of other de-icers, and an improved "stickiness" of the applied material to pavement surfaces.

De-icer chemicals penetrate the snow-ice layer to break the ice-road surface bond or entirely react on the ice surface to melt it and form slush. Both solid and liquid de-icer chemicals are used depending on the road conditions, degree of precipitation, and temperature. If used in liquid condition, the mass concentration of de-icer chemicals generally varies in the range of 20 to 32% (Julio-Betancourt, 2009). Anti-icer chemicals can also be used in solid or liquid condition. If used in liquid condition, the concentration of anti-icer chemicals should be high enough to prevent them from freezing before or after application. In addition, liquid anti-icer chemicals must have adequate viscosity to stick to the road surface. When used in solid condition, the anti-icer chemicals should start dissolving as soon as they are applied on the road surface. Similar to de-icer chemicals, the mass concentration of liquid anti-icer products varies within the range of 20 to 32%.

## CONCRETE DAMAGES CAUSED BY DE-ICER AND ANTI-ICER CHEMICALS

### Damage mechanisms

De-icer or anti-icer chemicals can cause the physical damage (surface scaling, spalling, internal frost damage, etc.) and/or chemical damage (dissolution of hardened cement paste, corrosion of steel reinforcement, etc.) of concrete. The physical effects of de-icers with respect to surface scaling and internal frost damage are well-documented (Darwin et al., 2007, 2008; Hooton and Julio-Betancourt, 2005; Verbeck and Klieger, 1957). Hooton and Julio-Betancourt (2005), and Sutter et al. (2008) reported that NaCl brine is more harmful than  $\text{CaCl}_2$  and  $\text{MgCl}_2$  brines with regard to physical attack, since it has the highest rate of penetration into hardened concrete. Hooton and Julio-Betancourt (2005) observed that 3% NaCl solution causes more scaling than 3%  $\text{MgCl}_2$  solution. They recorded the lowest mass loss due to surface scaling in the cases of  $\text{CaCl}_2$  and  $\text{MgCl}_2$  brines. In contrast, NaCl-based de-icer solution is much less harmful to concrete than  $\text{CaCl}_2$  and  $\text{MgCl}_2$  de-icer solutions with respect to chemical attack (Cody et al., 1996; Sutter et al., 2006). NaCl may lead the formation of chloroaluminate (Friedel's salt), which does not cause any significant expansion in concrete (Julio-Betancourt, 2009). However, the leaching of  $\text{Ca}(\text{OH})_2$  can occur when concrete is exposed to a concentrated NaCl de-icer solution, and thus can slightly affect the properties of concrete (Lea, 1998).

Chloride-based de-icer and anti-icer chemicals are a common source of chloride ions that can penetrate concrete surface. Numerous studies reported that the ingress of chlorides accelerates the corrosion process in reinforced concrete structures by damaging the protective oxide (passive) film of the embedded steel reinforcement (Melchers and Li, 2009; Pruckner and Gjørnv, 2004; Saremi and Mahallati, 2002). In addition, recent research reports showed that  $\text{CaCl}_2$  and  $\text{MgCl}_2$  chemically interact with hydration products and cause dissolution of the hardened cement paste in concrete, thus forming expansive oxychlorides (Sutter et al., 2008; Julio-Betancourt, 2009). The formation of oxychlorides results in cracking, increased permeability, and a substantial loss of compressive strength. Kozikowski et al. (2007) reported that the presence of  $\text{MgCl}_2$  solution results in the formation of magnesium silicate hydrate (M-S-H) and brucite [ $\text{Mg}(\text{OH})_2$ ], which cause concrete deterioration due to physico-chemical changes. M-S-H lessens the concrete strength at the expense of calcium silicate hydrates (C-S-H), and  $\text{Mg}(\text{OH})_2$  accelerates the reinforcement corrosion by reducing the pH of pore solution of the cement paste. Moreover, Darwin et al. (2007, 2008) found that  $\text{CaCl}_2$  and  $\text{MgCl}_2$  cause concrete damage due to both physical and chemical attacks. They also found that the use of  $\text{CaCl}_2$  and  $\text{MgCl}_2$  had a

relatively high negative impact on concrete durability as compared to NaCl. However, limited studies have been conducted to examine the physical and chemical effects of de-icer and anti-icer chemicals when applied onto sealed or coated concrete surface.

### Influence of salt concentration

The nature and extent of concrete deterioration depend on the concentration of de-icer and anti-icer chemicals (salt solutions). At a low concentration of salt solution, the surface scaling of concrete is possible due to the physical attack driven by freezing and thawing of the salt-ice mixture (Hooton and Julio-Betancourt, 2005). The pessimum concentration of de-icer salt solutions for the maximum damage due to physical attack is 3 to 4% by mass (Verbeck and Klieger, 1957; Çopuroğlu and Schlangen, 2008). At lower concentrations ( $\leq 3$  to 4%), the salt solution can be frozen, and the formation of ice and subsequent ice cracking intensify the physical damage on the concrete surface. In contrast, the salt-ice mixture can remain in liquid condition at higher concentrations ( $\geq 3$  to 4%), and therefore the surface scaling of concrete due to freezing and thawing is not expected. However, concrete deterioration can still happen due to chemical attack (Julio-Betancourt, 2009; Sutter, 2008).

The commercially available de-icer and anti-icer products are highly concentrated solutions with a concentration in the range of 16 to 32% by mass. In field applications, some dilution occurs during de-icing and anti-icing actions; yet the concentrations of de-icer or anti-icer solutions remain high to avoid the refreezing of salt-ice mixture. At high concentrations, the de-icer and anti-icer solutions are expected to cause chemical attack on concrete surface. Limited research has been carried out to explore the chemical attack phenomenon of de-icer and anti-icer solutions. The current knowledge on the effects of de-icer and anti-icer chemicals are mostly based on low concentrations ( $\leq 3$  to 4% by mass) of chloride solutions. Sutter et al. (2006) reported that a concentrated solution of  $\text{MgCl}_2$  (15% by mass) results in  $\text{Mg}(\text{OH})_2$  (brucite) formation in the outer layer of concrete. They also observed the formation of calcium oxychloride in the presence of  $\text{CaCl}_2$ . The formation of such products is maximized at the pessimum concentration of de-icer solutions. Sutter (2008) reported that the pessimum concentration of  $\text{MgCl}_2$  is 20% and that of  $\text{CaCl}_2$  is 22% with respect to chemical attack; these concentrations cause the maximum damage in concrete. Also, Darwin et al. (2008) reported that higher concentrations ( $\geq 15\%$  by mass) of de-icer chemicals cause concrete deterioration more rapidly than lower concentrations under wetting and drying conditions. Nevertheless, limited studies have been conducted to investigate the effects of both low and high concentrations of de-icer or anti-icer chemicals on

sealed or coated concrete surface.

### Influence of exposure temperature

The ambient and concrete temperatures can influence the effects of de-icer and anti-icer chemicals on concrete damage. The minimum temperatures for applying NaCl, MgCl<sub>2</sub>, and CaCl<sub>2</sub> chemicals are -10, -15 and -25°C, respectively (Mussato et al., 2004; Yehia and Tuan, 1998). No physical damage due to scaling occurs when the temperature is maintained above -10°C in the case of NaCl; the degree of damage increases with decreasing temperature below -10°C (Valenza II and Scherer, 2007). MgCl<sub>2</sub> and CaCl<sub>2</sub> can show similar effects based on their minimum effective application temperatures as mentioned earlier. However, it should be noted that these temperatures will most likely vary depending on the concentration of the chemical used. An increased concentration can lower the minimum effective application temperature, since the freezing point decreases as the concentration increases (Sutter et al., 2008).

The damage of concrete due to chemical attack is also affected by the ambient temperature. Julio-Betancourt (2009) showed that the extent of chemical attack in the presence of de-icer chemicals depends on the exposure temperature; the lower the temperature, the higher the rate of deterioration. In fact, he observed that a lower temperature favours the formation of calcium and magnesium oxychlorides, which are responsible for damage in concrete. The lower temperature also reduces the pessimum concentration of de-icer solutions (Julio-Betancourt, 2009). However, limited studies have investigated the role of temperature on the physical and chemical attack phenomena of corrosive chemicals, particularly when they are used on sealed or coated concrete surface.

### Influence of ice-layer thickness

The deterioration of concrete is significantly influenced by the thickness of ice-layer on the concrete surface. An increased thickness generates more force, and therefore more damage occurs for the same number of freezing and thawing cycles. Çopuroğlu and Schlangen (2008) showed that a 9 mm increase in ice-layer thickness resulted in 40% more mass scaling than a 1 mm thickness after only 3 freezing and thawing cycles. Their study also revealed that the rate of increase in mass scaling per unit depth of de-icer solution lessens beyond 3 mm initial thickness of ice-layer. However, very few studies have investigated the influence of ice-layer thickness in the case of sealed or coated concrete surface.

## SEALERS AND COATINGS

Sealers or coatings are applied as a surface treatment to

protect the underlying concrete. They reduce the penetration of water, de-icer or anti-icer chemicals, and deleterious gases into concrete. To improve concrete durability, sealers/coatings should possess the following properties (Filice and Wong, 2001):

1. Ability to seal or coat new, old or previously sealed/coated surfaces;
2. Ability to reduce or eliminate the ingress of moisture;
3. Excellent ability to transmit moisture vapour from concrete;
4. Good salt scaling resistance;
5. Good chemical resistance;
6. Good resistance to ultra-violet rays;
7. Excellent adhesion to concrete surface.

### Types of sealer and coating

Sealers and coatings are generally categorized as follows:

1. Penetrating sealers: low viscosity materials, such as silane or siloxane, which are "flood coated" to achieve a nominal penetration (typically 1 to 3 mm) into the prepared concrete substrates. By lining, but not blocking capillary pores, they produce hydrophobic reactions, which repel water and provide a high degree of "breathability".
2. Surface sealers: medium viscosity/low solids materials, such as low solids epoxy and urethane and reacted methyl methacrylate, which form films on the surface; the films are not measurable and they do not penetrate within the capillary pores to any degree. They typically have a moderate degree of "breathability".
3. Barrier or surface coatings: high viscosity/high solids materials, such as acrylic, epoxy and urethane, which form measurable coatings that do not penetrate capillary pores. The applied coatings typically have degrees of "breathability", which vary from low to none.
4. Impregnating polymers: ultra-low viscosity monomer materials, such as high molecular weight methacrylate, styrene and acrylonitrile, which are applied using special drying and vacuum techniques to ensure deep penetration; when reacted, the polymers block the capillary pores. They typically have a "breathability" varying from low to none.

In Canada, the Alberta Transportation and Utilities (ATU) department categorizes concrete sealers/coatings as follows (ATU, 2009):

1. Type 1: Penetrating sealers. These products are intended for use on traffic bearing surfaces subjected to abrasion, and therefore must not affect skid resistance. Type 1a is a sub-classification for use on concrete surfaces where the relative moisture content is less than

or equal to 55%. Type 1b is a sub-classification where such relative moisture content is less than or equal to 70%. Type 1c is a sub-classification for high performance, low volatile organic compounds (VOC) penetrating sealers for new bridges and overlays with low water/cement ratios where the relative moisture content is less than or equal to 80%.

2. Type 2: Clear film forming sealers. These sealers form a film on concrete surfaces and are intended for use on non-traffic bearing surfaces. They are also known as surface sealers. Type 2a is a sub-classification for one-component clear products that are suitable for use on concrete surfaces where the relative moisture content is less than or equal to 70%. Type 2b is a sub-classification for two-component clear products where such relative moisture content is less than or equal to 70%.

3. Type 3: coloured film forming sealers. These sealers are intended for use on concrete surfaces aesthetically important and highly exposed to public view. These are typically pigmented materials with a high solid content. They are also known as surface coatings.

### Effects of sealers and coatings

Sealers and coatings improve the durability of concrete and thus extend the service life of concrete structures. Porter (1975) showed that the use of sealers/coatings greatly decreased surface scaling due to freezing and thawing in the presence of water, although they had poor resistance when exposed to the sun and outdoor weathering. The Kentucky Transportation Center reported that an appropriate sealer/coating system can protect concrete from corrosion and de-icing salt damages by inhibiting the chloride penetration (Palle and Hopwood II, 2006). In contrast, it has been shown that penetrating sealers are not as effective as surface coatings in improving the scaling and corrosion resistances of concrete (Ibrahim et al., 1999; Wenzlick, 2007). However, the performance of penetrating sealers can be improved by an over-coat application of a surface sealer or coating (Ibrahim et al., 1999).

The application of sealer or coating can significantly impede the transport of water (with or without harmful agents) into concrete by either rendering the surface region hydrophobic or forming a physical barrier. Some systems combine these two effects by the application of dual-component products. A reduction in water uptake can improve freeze-thaw durability (Litvan, 1992) and the resistance to alkali-aggregate reactions (Filice and Wong, 2001). Al-Dulaijan et al. (2000), Ibrahim et al. (1999), and Oshiro and Tanigawa (1988) reported that surface coatings significantly reduce the chloride permeability and reinforcement corrosion in concrete. Ho and Harrison (1990) reported that surface coatings substantially inhibit the ingress of carbon dioxide that leads to carbonation in concrete. McCarter (1996) showed that surface coatings restrict the passage of water into concrete but transmit

moisture vapour from concrete, and thus facilitate drying of concrete elements. He also showed that some surface coatings can significantly increase the resistivity of concrete and improve the resistance to scaling due to chemical attack. The scaling resistance of concrete was also reported to greatly depend on the adhesion strength of a surface coating (Al-Dulaijan et al., 2000; Oshiro and Tanigawa, 1988). However, none of the aforementioned studies focused the effect of high concentration of de-icer and anti-icer chemicals, while investigating the performance of sealers or coatings.

### Selection of sealers and coatings

The performance of a sealer or coating depends not only on its quality, type and/or properties, but also on the exposure conditions both during application and in service, condition of the underlying concrete surface (smoothness, roughness, moisture level, etc.), substrate preparation techniques, and how it is applied. Therefore, the selection of a sealer or coating must be made after full consideration of many factors (Table 1), which can influence the achievement of its adequate performance.

### Surface preparation for sealers and coatings

Surface preparation is typically required before the application of sealers or coatings onto concrete surface. Most manufacturers require that new concrete should be at least 28 days old, and any contamination that may interfere with adhesion or penetration, such as form oils and curing compounds, should be removed (Attanayaka et al., 2003). For similar reasons, oil, grease, rubber and other contaminants should be removed from old concrete. Additionally, the carbonated surface layer of old concrete should be removed so that chemical reactions requiring high alkalinity may be improved (Cady, 1994).

The most common surface preparation techniques include abrasive-blasting (sand or grit-blasting), blast-track (shot-blasting), and high pressure water-blasting. A damp, saturated surface-dry or dry conditioned substrate is required prior to the application of sealers and coatings depending on the specific type of surface treatment.

### Application of sealers and coatings

Sealers and coatings are typically applied on concrete surface by roller, airless spray, and squeegee or brush/broom (Filice and Wong, 2001). Attanayaka et al. (2003) reported that the proper application of a penetrating sealer increases its efficiency, and surface flooding is the preferred method. Ho and Harrison (1990) reported that the effectiveness of surface coatings improves with increasing thickness. They found that the

**Table 1.** Factors to be considered in sealer/coating selection (adapted from Basheer et al., 1997; Shields et al., 1992).

Feature	Consideration
Type and condition of concrete substrate	New or old concrete Surface condition (prior treatment, roughness, contamination, etc.)
Exposure environment	Atmospheric, buried, marine, etc. Presence of moisture Presence of pollutants Aggressive chemicals
Nature of concrete protection needed	Abrasion Acid/chemical attack Alkali-aggregate reaction Carbonation Chloride permeability Freezing and thawing Salt scaling Sulphate attack Water absorption Wetting and drying
Sealer/coating durability	Abrasion resistance Adhesion strength Chemical resistance Colour retention Elasticity Film hardness Impact resistance Moisture vapour transmission Toxicity UV resistance Water resistance
Service condition	Skid resistance
Application of sealer/coating	Methods of application Surface preparation Temperature dependence Tolerance to substrate moisture Site access

Table 1. Contd.

	Coverage rate or number of coats required
	Film thickness
Overall cost	Labour cost
	Material cost
	Maintenance cost

thicker coating layer enhances protection against carbonation by reducing the diffusion of carbon dioxide. They also found that a coating applied to a sand-blasted formed concrete substrate is less effective than when it is applied at a similar coverage rate to a non-prepared surface. This is because the sand-blasting typically produces a roughened profile, requiring an increased coverage rate to achieve a uniform film formation thickness that is free from defects, such as holidays or pin-holes. However, the sand-blasting is still required to achieve effective adhesion of the coating and an increased coverage rate is therefore typically recommended.

### Evaluation of sealers and coatings

American Society for Testing and Materials (ASTM) has several test methods to evaluate the performance of coatings. ATU has developed several test methods for evaluating the performance of sealers and coatings when applied onto concrete surface (ATU, 2000a, 2000b, 2000c). Cady (1993) used a two-pin mode soil resistance meter to evaluate the effectiveness of concrete sealer or coating with respect to electrical resistance. Also, ASTM, American Association of State Highway and Transportation Officials (AASHTO), and Canadian Standards Association (CSA) have a number of test methods for concrete that can be used with necessary modifications to evaluate the performance of sealers and coatings. The lists of AASHTO, ASTM, ATU, and CSA test methods/practices/specifications are appended (Appendix).

### Performance criteria for sealers and coatings

The performance criteria for the durability and durability-related properties of concrete sealers and coatings are listed in Tables 2 to 4. These performance criteria deal with physical (adhesion, resistance to freeze-thaw/salt scaling, and resistance to weathering), transport (water absorption, waterproofing, chloride permeability/penetration, crack sealing ability and moisture vapour transmission), and electrical (electrical resistance) properties of concrete treated with sealer or coating.

None of these criteria considers the chemical attack mechanisms of de-icer or anti-icer chemicals to evaluate the performance of sealers and coatings when applied on concrete surface.

### RESEARCH NEEDS

More research is needed in the following areas:

1. Performance of concrete sealers and coatings under different aggressive environments, such as freezing and thawing, wetting and drying, and extreme temperature changes with different chemical exposures.
2. The chemical attack of de-icer and anti-icer solutions, and their damage mechanisms on concrete surface treated with sealers or coatings.
3. The influence of high concentration of de-icers or anti-icers on the protective performance of concrete sealers and coatings.
4. The influences of temperature and ice-layer thickness on the protective performance of concrete sealers and coatings.
5. Identification of proper surface preparation techniques for concrete substrate for applying sealers and coatings.
6. Detection of appropriate application methods for applying sealers and coatings onto concrete surface.
7. Standardization of test methods and development of performance criteria for concrete sealers and coatings.

### CONCLUDING REMARKS

1. Environmental factors such as freezing and thawing, wetting and drying, etc., can result in concrete deterioration in bridge structures; the damage can be accelerated by de-icer and anti-icer chemicals commonly used for highway maintenance during winter.
2. The most common forms of deterioration are surface scaling, spalling, and corrosion induced cracking and/or delamination of concrete. The degree of damage greatly depends on the type and concentration of de-icer or anti-icer solution, exposure temperature, ice-layer thickness, as well as on the severity of the mechanisms of attack.
3. The application of sealers or coatings can protect the concrete from damages caused by the aggressive

**Table 2.** Various performance criteria for concrete sealers/coatings (Cady, 1993; Wenzlick, 2007).

Method	Property	Performance criteria
Salt scaling (ASTM C 672/C 672M)	Scaling resistance to salt exposure under freezing and thawing	Rating "0", no scaling after 100 cycles
Crack sealing (Modified AASHTO T 259)	Ability of crack sealing	Water leaking time ratio of sealed and unsealed concrete $\geq 2$
Absorption by water saturation technique (ASTM C 642)	Water absorption as an indicator of durability	Maximum 1% after 48 hours; maximum 2% after 50 days
Chloride ion penetration (AASHTO T 259)	Penetrated chloride value as an indicator of corrosion resistance	Maximum 0.76 - 1.0 pcy at 0.50 - 1.0 in (0.451 - 0.593 kg/m <sup>3</sup> at 12.7 - 25.4 mm) depth after 90 days of ponding
Accelerated weathering (ASTM D 822)	Weathering resistance	Slight colour change
Salt spray resistance (ASTM B 117)	Adhesion	No loss of adhesion after 300 cycles
Two-pin mode soil resistance meter	Electrical resistance	> 200 - 400 k $\Omega$

**Table 3.** Waterproofing performance criteria for concrete sealers/coatings (ATU, 2009).

Sealer/coating type	Minimum waterproofing performance (as compared to control specimens <sup>1</sup> ) (%)	
	Before abrasion	After abrasion
Type 1a	82.5	75.0
Type 1b	-	86.0
Type 1c	-	85.0
Type 2a	82.5	N/A
Type 2b	90.0	N/A
Type 3	75.0	N/A

<sup>1</sup>Unsealed/uncoated concrete specimens**Table 4.** Moisture vapour transmission performance criteria for concrete sealers/coatings (ATU, 2009).

Sealer/coating type	Minimum vapour transmission (as compared to control specimens <sup>1</sup> ) (%)
Type 1a	-
Type 1b	70.0
Type 1c	85.0
Type 2a	35.0
Type 2b	20.0
Type 3	35.0

<sup>1</sup>Unsealed/uncoated concrete specimens

environmental and chemical exposures. The performance of sealers and coatings depends on the type and

properties of the selected product, and on the effectiveness of the surface preparation and application



techniques.

4. More research is needed to evaluate the performance of concrete sealers and coatings under different aggressive environments and chemical exposures; standardization of test methods and development of performance criteria are also required for the successful application of these products.

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**APPENDIX****Test methods, practices and specifications for concrete, sealers, and coatings*****AASHTO test methods***

1. AASHTO T 22: Standard method of test for compressive strength of cylindrical concrete specimens.
2. AASHTO T 161: Standard method of test for resistance of concrete to rapid freezing and thawing.
3. AASHTO T 259: Standard method of test for resistance of concrete to chloride ion penetration.
4. AASHTO T 260: Sampling and testing for chloride ion in concrete and concrete raw materials.
5. AASHTO T 277: Standard method of test for electrical indication of concrete's ability to resist chloride ion penetration.

***ASTM standard practices and test methods***

1. ASTM B 117: Standard practice for operating salt spray (fog) apparatus.
2. ASTM C 39/C 39M: Standard test method for compressive strength of cylindrical concrete specimens.
3. ASTM C 215: Standard test method for fundamental transverse, longitudinal, and torsional frequencies of concrete specimens.
4. ASTM C 642: Standard test method for density, absorption, and voids in hardened concrete.
5. ASTM C 666/C 666M: Standard test method for resistance of concrete to rapid freezing and thawing.
6. ASTM C 672/C 672M: Standard test method for scaling resistance of concrete surfaces exposed to deicing chemicals.
7. ASTM C 793: Standard test method for effects of accelerated weathering on elastomeric joint sealants.
8. ASTM C 1152/C 1152M: Standard test method for acid-soluble chloride in mortar and concrete.
9. ASTM C 1202: Standard test method for electrical indication of concrete's ability to resist chloride ion penetration.
10. ASTM C 1543: Standard test method for determining the penetration of chloride ion into concrete by ponding.
11. ASTM C 1645/C 1645M: Standard test method for freeze-thaw and de-icing salt durability of solid concrete interlocking paving units.
12. ASTM D 522: Standard test methods for mandrel bend test of attached organic coatings.
13. ASTM D 822: Standard practice for filtered open-flame carbon-arc exposures of paint and related coatings.
14. ASTM D 1653: Standard test methods for water vapour transmission of organic coating films.
15. ASTM D 1654: Standard test method for evaluation of painted or coated specimens subjected to corrosive environments.
16. ASTM D 2243: Standard test method for freeze-thaw resistance of water-borne coatings.
17. ASTM D 2794-93: Standard test method for resistance of coatings to the effects of rapid deformation (impact).
18. ASTM D 3273: Standard test method for resistance to growth of mold on the surface of interior coating in an environmental chamber.
19. ASTM D 3274: Standard test method for evaluating degree of surface disfigurement of paint films by microbial (fungal and algal) growth or soil and dirt accumulation.
20. ASTM D 4541: Standard test method for pull-off strength of coatings using portable adhesion testers.
21. ASTM D 4585: Standard practice for testing water resistance of coatings using controlled condensation.
22. ASTM D 4587: Standard practice for fluorescent UV-condensation exposures of paint and related coatings.
23. ASTM D 5894: Standard practice for cyclic salt fog/UV exposure of painted metal (alternating exposures in a fog/dry cabinet and a UV/condensation cabinet).
24. ASTM D 6489: Standard test method for determining the water absorption of hardened concrete treated with a water repellent coating.
25. ASTM E 96/E 96M: Standard test methods for water vapour transmission of materials.

***Alberta Transportation and Utilities (ATU) specifications and test methods***

1. B388: Specification for concrete sealers.
2. BT001: Test procedure for measuring the vapour transmission, waterproofing, and hiding power of concrete sealers.
3. BT005: Test procedure for measuring the waterproofing performance of core samples taken from sealed concrete surfaces.
4. BT002: Test procedure for alkaline resistance of penetrating sealers for bridge concrete.

***CSA test methods***

1. CSA A23.2-24A: Test method for the resistance of unconfined coarse aggregate to freezing and thawing.
2. CSA A23.2-4B: Sampling and determination of water-soluble chloride ion content in hardened grout or concrete.
3. CSA A23.2-9C: Compressive strength of cylindrical concrete specimens.
4. CSA A23.2-11C: Water content, density, absorption, and voids in hardened concrete, grout or mortar.
5. CSA A23.2-21C: Test method for length change of hardened concrete.