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Accelerated laboratory evaluation of surface treatments for protecting concrete bridge decks from salt scaling

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HIGHLIGHTS

- Conducted accelerated lab evaluation of commercial products for concrete protection.
- Three concrete sealers, two crack sealants, and two water repellents were tested.
- Concrete cylinders were subjected to abrasion or 14 F/T cycles + 3 wt.% NaCl.
- All products showed great performance and substantially mitigated salt scaling.
- Resistance to both gas and water penetration is crucial to reduce salt scaling.

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ABSTRACT

In this accelerated laboratory study, several commercial products of surface treatment were included in the test program, including three concrete sealers, two crack sealants, and two water repellents. To characterize the product longevity under traffic, the abrasion resistance of concrete treated by each product was tested. To characterize the product effectiveness against salt scaling, the surface treated concrete cylinders were subjected to the joint action of 15 freeze/thaw and wet/dry cycles and exposure to a diluted deicer simulated by 3 wt.% NaCl solution. The mass loss of these concrete cylinders during the freeze/thaw cycles was periodically measured. For mechanistic investigation, the surface-treated concrete specimens were further tested for their water absorption rates, gas permeability, and water contact angle. For all the laboratory tests, the untreated concrete was used as control. The results confirmed the benefits of using these products to treat the surface of concrete against salt scaling, as all of them exhibited outstanding performance and reduced the mass loss of the concrete by 90% or more. Among them, two products (epoxy-based sealer T48CS and water repellent ATS-42) exhibited the best performance in protecting the concrete from salt scaling and featured the highest resistance to abrasion and generally lower water absorption rates and gas permeability coefficients. The results suggest that high resistance to both gas and water penetration is a crucial property in a good surface sealer, crack sealant or water repellent applied to concrete.

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1. Introduction

The durability of concrete structures has substantial economic, social, and environmental implications. The issue is exacerbated in cold regions where the concrete is at the risk of freeze–thaw cycling and physical and chemical attack by chemical deicers [1]. Physical mechanisms of attack by deicers can lead to damage of Portland cement concrete (PCC) in the common forms of scaling, map cracking, or paste disintegration [2]. Deicers may also pose detrimental effects on concrete infrastructure through their reactions with cement paste and/or aggregates and thus reduce the integrity and strength of the concrete [2–5]. Finally, roadway

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deicers often use chlorides as their freezing point depressant, and the ingress of chloride anions into concrete can induce the corrosion of rebar or dowel bar in concrete and lead to premature deterioration of reinforced concrete [6–9].

Sodium chloride (NaCl) remains the principal roadway deicer in use despite its well-known corrosive effects on metals. The scaling of concrete in the presence of NaCl-based deicers, referred to as "salt scaling", has been recognized as the main cause of frost-related concrete deterioration. It is one of the main culprits contributing to concrete failures of outdoor constructions in cold climate, such as concrete roadways, airfield pavements, bridge decks, sidewalks, and driveways. Scaling refers to the local peeling and gradual damage of the concrete surface, often due to cyclic freezing and thawing [10]. This damage is characterized by the removal of small chips or flakes of binder or mortar [11,12], often leading to the exposure of coarse aggregate. While this surface distress may not cause significant degradation of mechanical properties of the overall concrete, it can expose the concrete to ready ingress of moisture and aggressive salts and accelerate the deterioration of concrete durability [13]. Scaling can occur on concrete surfaces independent of deicer application, as the aqueous solution in the concrete pores near the surface freezes and thaws due to temperature fluctuations and exert expansive forces inside the concrete microstructure. Chloride deicers can aggravate the scaling problem as moisture tends to move toward zones with higher salt concentrations *via* osmosis and adds to the normal hydraulic pressure. The presence of deicers can increase the rate of cooling and thus may increase the number of freeze/thaw cycles in concrete; yet it can also reduce the freezing point of the pore solution and thus may decrease the number of freeze/thaw cycles in concrete. These opposing effects define the physical distress in concrete caused by deicers, and a pioneering laboratory study revealed the worst conditions at a low concentration (5% NaCl) and optimum conditions at a moderately high concentration (13% NaCl) [14]. Another study suggested that concrete containing relatively high concentrations of dissolved salts can provide better resistance to scaling than concrete with plain water in its pores [15].

Early research argued that the best protection against "salt scaling" would be reduction of porosity [14]. It is now generally believed that the use of properly cured, air-entrained concrete would prevent physical damage by the freeze/thaw cycling [16]. For an air-entrained concrete, the spacing factor seems to be its key air void characteristic to allow sufficient resistance to salt scaling [17]. It should be noted that air entrainment only slows the freeze–thaw process instead of preventing it [15].

Valenza and Scherer [13,18] and Jana [19] have reviewed the mechanisms, factors and characteristics influencing the concrete scaling. It is believed that proper air entrainment, finishing, and curing can provide far better protection for concrete than other solutions [19]. While this minimizes physical damage induced by salt precipitation and crystallization, the optimization of concrete properties cannot effectively address the chemical attack to concrete by salt solution. For instance, it has been reported that sodium chloride solution can cause softening of the concrete paste and increase its porosity, through the leaching of calcium cations from cement hydrates or the dissolution of the Portlandite, i.e., $Ca(OH)_2$ [3,20].

In this context, many efforts have been made to protect concrete from chloride-based deicers, among which surface treatments are widely implemented by transportation agencies to preserve their bridge decks and other structures. The application of a surface treatment is recommended for additional protection, especially when the concrete lacks proper air entrainment or has other deficiencies related to curing or finishing. By design, the surface treatment slows down the ingress of water and salt solutions, and thus useful to remedy the risks associated with freeze/thaw damage, salt scaling, and rebar or dowel bar corrosion for concrete in cold regions [19]. Commercially available products for concrete surface treatments can be classified into three groups: sealer or coating (that forms a continuous film on the skin of concrete), pore blocker (that reacts with Portlandite and forms insoluble products), and pore liner (that repels water) [21,22].

A number of studies have evaluated the performance of different types of surface treatments as a means of protection for concrete. Mamaghani et al. reported an evaluation of five sealer treatments for protecting the concrete bridge decks. An ultra-low-viscosity epoxy sealer was found to be the most efficient at enhancing the concrete's resistance to scaling and chloride penetration [23]. Zhao et al. evaluated the use of six surface treatments for concrete durability and demonstrated that a three-layer epoxy system and a silane-based surface treatment could significantly enhance the concrete's resistance to chloride, air and water [24]. Medeiros and Helene and Almusallan et al. also examined the performance of several surface treatments on the durability of concrete and found epoxy and polyurethane products to be highly effective in enhancing the concrete's resistance to chloride diffusion, water absorption and chemical corrosion [21,25]. Numerous studies have investigated and confirmed the benefit of silane-based pore liners on the durability of concrete [26–31]. Ghoddousi et al. reported that the most effective treatment for the corrosion resistance of reinforced concrete was the combination of a "silane + sioxane" primer with an acrylics top coat [32]. They concluded that no single coating could improve the resistance of concrete to all types of deterioration [32]. Medeiros and Helene and Moon et al. concluded that the double or triple coating systems were more effective for concrete durability than those with a single coating [21,33].

Only limited studies have been conducted to evaluate various surface treatments for better resistance of concrete to freeze/thaw damage or salt scaling [26,30]. There is still a need to focus on the surface treatments suitable for preserving concrete in the presence of NaCl-based deicers and to reveal the main characteristics of surface treatments that protect the concrete from salt scaling.

The objective of this study is to evaluate the performance of select products for surface treatment of Portland cement concrete structures, particularly their effectiveness in protecting the concrete from potential damage caused by NaCl deicer and freeze/thaw cycling (a.k.a., salt scaling).

In this accelerated laboratory study, several commercial products of surface treatment were included in the test program, including three concrete sealers, two crack sealants, and two water repellents. To characterize the product longevity under traffic, the abrasion resistance of concrete treated by each product was tested. To characterize the product effectiveness, the surface treated concrete cylinders were subjected to the joint action of 15 freeze/thaw (F/T) and wet/dry (W/D) cycles and exposure to a diluted deicer simulated by 3 wt.% NaCl solution. The mass loss of these concrete cylinders during the freeze/thaw cycles was periodically measured. To help interpret the difference in product performance, the surface-treated concrete specimens were tested for their water absorption rates, gas permeability, and water contact angle. For all the laboratory tests, the untreated concrete was used as control.

2. Experimental

2.1. Concrete constituents, mixing, and curing

An ASTM specification C150-07 Type I/II GU Portland cement from Diamond Mountain, MT was used. Coarse aggregates (with maximum size of 9.5 mm) and fine aggregates (clean, natural silica sand, maximum size of 4.75 mm) were purchased from the JTLGroup (Belgrade, MT). A chemical agent, triethylolamine (TEA) was used for accelerating the early-age strength of concrete. The mix proportion of concrete is summarized in Table 1. Note that a half dosage of air entraining

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