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Salt scaling resistance – The effect of curing and pre-saturation

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ABSTRACT

The effect of pre-saturation and three curing methods (standard 14-day, 3-day curing, and curing compound) on salt scaling resistance was studied in three concrete types including plain, 25% fly ash and 35% slag. The concrete made with slag showed the highest salt scaling resistance in accordance with ASTM C 672, its proposed replacement method, and the 3-day curing method followed by the plain concrete followed by the concrete made with fly ash. According to the method using the curing compound, the plain concrete showed the highest salt scaling resistance followed by slag concrete followed by fly ash concrete.

1. Introduction

In cold climates, de-icing salts (NaCl, $CaCl_2$) are regularly used to prevent the freezing of water on horizontal surfaces of concrete structures such as roadways and walkways. Unfortunately, this exposure results in salt scaling, one of the major durability issues of the concrete. Salt scaling is defined by Valenza and Scherer [1] as the "superficial damage caused by freezing a saline solution on the surface of a concrete body" which can advance into concrete over time [2] and takes place by the removal of "small flakes or chips" of the paste [3,4] with the removal of very few small aggregates [4]. Not only is salt scaling visually unpleasing (due to the exposure of the coarse aggregate), but also the surface of a scaled specimen would be more sensitive to the penetration of fluids and detrimental ions like chloride. Although beyond the scope of this paper, several mechanisms for salt scaling were included in an excellent review by Valenza and Scherer [5].

Although using supplementary cementing materials as a partial cement replacement results in a comparable or improved mechanical properties and durability of concrete [6–10], these concretes may have a poor salt scaling resistance, particularly in laboratory tests [11–15]. Many researchers indicated that the salt scaling resistance decreases by the addition of fly ash [6–10,13–22] which could be partly related to their lower strength at short moist curing periods (3–28 days) [19–21]. A reduction in salt scaling resistance was also reported when slag was added to the concrete [23–25]. Afrani and Rogers [13] addressed two potential reasons for the increased amount of scaling residue in slag concretes; firstly, the early finishing before the bleeding has stopped due to the late set of slag concrete which may form a weak layer with a high w/c ratio so close to the surface, and secondly, not enough curing duration due to a lower hydration of slag concrete at normal temperature. For this reason, many government agencies in Canada (municipalities, provincial departments of transportation) usually limit the maximum replacement amount of fly ash and slag to 20% or less in the concrete mixtures exposed to de-icing salts [6].

Increased salt scaling resistance of a Class F fly ash concrete mixture was observed when the moisture equilibrium was achieved before the salt scaling test [26] which is verified by other researchers who also addressed the increased salt scaling resistance by extended moist curing [12,27,28]. In contrast, Bilodeau et al. [20,29] indicated that in fly ash concrete, extending the moist curing period in the laboratory (from 28 to 91 days) decreased the salt scaling resistance while an improvement in the salt scaling resistance was observed by decreasing the drying period before the salt scaling test.

Curing compounds are frequently used where extended moist curing is not feasible or desired. Radlinski et al. [30] suggested that a thin layer of curing compound prevents salt and moisture penetration; reduces the saturation degree of the pore system in the very top layer; and results in the good performance at the early age in these specimens. Gebler and Klieger [17] indicated that in concrete mixtures containing 25% fly ash, a slightly better salt scaling resistance using a curing compound at 23 °C was observed than

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air curing and moist curing at this temperature. It has been reported that using the sealers or curing compounds (surface treatment) postpones the surface scaling, but has no influence on the salt scaling resistance at the end [14,24,31–33]. Valenza and Scherer [1] mentioned that in treated specimens, most of the cracks form in places with little or no treatment, and develop to a depth under the treated layer, and therefore, result in the removal of this layer. Other researchers also reported the better performance of some curing compounds than long moist curing periods [28,34,35] or covering the specimens under burlap and plastic sheet [36].

There are several test methods regarding salt scaling including ASTM C 672 [37], the capillary suction of de-icing chemicals and freeze–thaw test (CDF) [38], the Swedish Standard SS 13 72 44 [39] also known as Borås method, BNQ NQ 2621-900 [40], and the proposed replacement method for ASTM C 672 which is based on the method developed by Bureau de Normalisation du Quebec (BNQ). The current ASTM C 672 method has been reported to be more severe than field experience; i.e., concrete that fails the standard test has been observed to perform satisfactorily in the field [6,11,12,36,41–44]. The particular concern from the point of view of the replacement method is the severity of osmotic effects in samples not pre-saturated with salt solution. Cordon [16] addressed the osmotic pressure as one of the major reasons of the salt scaling. Bouzoubaa et al. [6] mentioned that the 1-week pre-saturation period as used in the BNQ standard may balance the ions between the saline solution on top surface and the top layers' voids, decrease the osmotic pressure and result in less salt scaling. They found the ASTM C 672 method more severe in the laboratory than the field and addressed the BNQ procedure as a better means to evaluate the salt scaling resistance of concrete incorporating the supplementary cementing materials. They reported greater scaling residue and higher visual rating of specimens tested in accordance with ASTM C 672 than the BNQ standard in fly ash and slag concretes.

2. Scope

The experimental program was planned to study the salt scaling resistance of concrete surfaces exposed to freezing-and-thawing cycles in the presence of de-icing chemicals investigating the following variables:

- The comparison of current ASTM C 672/C 672M [37] with its proposed replacement method (the effect of 1 week pre-saturation).
- The effect of different curing regimes including the standard 14-day moist curing method, 3-day curing, and the application of a curing compound. The latter two are more likely in practice.

3. Materials and procedures

The coarse and fine aggregates used in this experimental research were obtained from local sources near Montreal, Quebec. The fineness modulus of the fine aggregate was calculated to be 2.64. The nominal maximum aggregate size of the crushed limestone coarse aggregate was 10 mm. The bulk density of the fine and coarse aggregates were determined to be 1610 kg/m^3 and 1470 kg/m^3, respectively.

In this study, Portland cement, fly ash, and slag were used as cementitious materials. Only one type of Portland cement, General Use Hydraulic cement (Type GU), was used in all concrete mixtures. The cement was provided by St. Lawrence Cement, Joliette, Quebec, Canada and its chemical analysis is given in Table 1; the table also includes the analyses of the Type F fly ash and Grade 100 slag.

To achieve adequate cement dispersion at the relatively low water to cement ratio used, a mid-range water-reducing admixture meeting ASTM C 494 [45] Type A and F – was added to the mixing water. A high-range water-reducing admixture was used to attain the target slump (75 ± 15 mm) and an air-entraining admixture meeting ASTM C 260 [46] was added to meet the required air content (6 ± 1%).

Table 1
The chemical analysis of the cement used in the concrete mixtures (%).

	Cement	Fly ash	Slag
Alkalies (Na_2O_e)	0.88	1.9	0.4
Loss on ignition	2.2	2.65	−0.75
Insoluble residue	0.7	–	–
Free lime	0.8	–	–
SiO_2	20.6	52.5	38.6
Al_2O_3	4.5	25.4	11.6
Fe_2O_3	2.7	6.6	0.5
CaO	62.7	6.1	37.9
MgO	2.0	1.6	9.5
SO_3	3.6	0.9	3.0

Table 2
Mixture proportions used in this research.

	Plain	Fly ash	Slag
(w/c) ratio	0.40	0.40	0.40
Water, kg/m^3	160	160	160
Fine aggregate, kg/m^3	670	670	670
Coarse aggregate, kg/m^3	1100	1100	1100
Cement, kg/m^3	400	300	260
Fly ash, kg/m^3	–	100	–
Slag, kg/m^3	–	–	140

In this research, three different concrete types were made; plain concrete, 25% fly ash and 35% slag. The replacement levels were chosen to represent those typically used in practice. Due to the capacity of concrete mixer, two batches of each mixture were produced. The mixture designs are given in Table 2. Concrete mixing in this study was conducted in accordance with ASTM C 192 [47]. The entire mid-range water-reducing admixture and half of the high-range water-reducing admixture were added to the mixing water and were mixed thoroughly while the air-entraining admixture was added to the fine aggregate. Coarse aggregate and some of the mixing water including water-reducing admixtures were added to the mixer. Then the mixer was started and the fine aggregate, cement, the rest of the water, and fly ash or slag (when required) were added to the mixer while it was running. After all ingredients were in the mixer, the concrete was mixed for 3 min, followed by a 3-min rest, followed by a 2-min final mixing period. The other half of the high-range water-reducing admixture was added to the concrete in the mixer during the 3-min rest period. Compressive strength, slump, and air content were determined for each mixture and are given in Table 3.

In this research, plastic containers with a roughly rectangular shape having a surface area of 0.0554 m^2 and a depth of 90 mm were used as moulds for the scaling slabs. For each combination of variables to be tested, two duplicate specimens were made. The concrete was poured into the moulds in one layer, rodded, levelled with several passes of a wood strike-off board and brushed with a medium-stiff brush as the final finishing operation as per ASTM C 672. As well, three 100 mm by 200 mm cylinders were prepared from each concrete mixture for the compression test.

The concrete specimens were immediately covered with a plastic sheet, without any contact with the concrete surface, right after the final finishing. The slab specimens and cylinders were removed from the moulds at an age of 20–24 h after addition of water to the concrete mixture (beginning of casting) and were submerged in lime saturated water. Both water storage tanks (with lime-saturated water) as well as moist rooms or cabinets are permissible curing methods. The scaling specimens were removed from the moist storage at the age of 3 or 14 days and were stored in the air until 28 days at the laboratory temperature of 23 ± 2 °C while the cylinders were kept in moist storage until the age of 28 days. Fourteen days of wet curing is prescribed in both the current and proposed standard; the 3 day curing was investigated since shorter curing periods are commonly used in practice. In cases where used, a curing compound, meeting ASTM C 309, was sprayed on the surface of the scaling specimens after the brushing at a coverage of 135 mL/m^2 surface area. These specimens were not covered with plastic or stored in limewater.

The salt scaling resistance was evaluated according to two different procedures, ASTM C 672/C 672M [37] and its proposed replacement method. Both methods moist cure the specimens for 14 days followed by an additional 14 days in air. The added step in the proposed replacement method is a 7 day presaturation period starting at 28 days. For testing the scaling resistance, 4% calcium chloride solution was ponded on the top surface of the cast and cured specimens. To maintain a pond on top of the specimen, a flexible plastic material (designed for use as flooring baseboard having 3 mm thickness and 65 mm height) was adhered to the specimen along the perimeter of the top surface of the specimens with silicone based glue (Fig. 1). Approximately 40 mm of the plastic baseboard projected beyond the top of the specimen's surface to maintain enough height for the saline solution (6 mm depth) and to prevent splashing on transport of specimens.