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The influence of deicing salt exposure on the gas transport in cementitious materials

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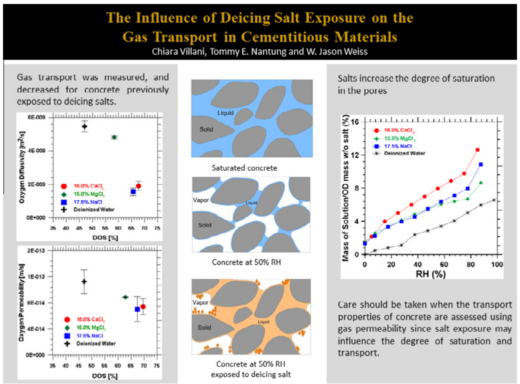
HIGHLIGHTS

- Gas transport properties were measured for concrete previously exposed to deicing salts.
- Gas transport decreases in presence of deicing salts.
- Salts precipitation in the pores during drying appears to have small impact on transport.
- The degree of saturation increases in concrete exposed to deicing salts.
- The increase of the DOS is estimated to be the main reason of reduced gas transport.

GRAPHICAL ABSTRACT



The Influence of Deicing Salt Exposure on the Gas Transport in Cementitious Materials
Chiara Villani, Tommy E. Nantung and W. Jason Weiss

Gas transport was measured, and decreased for concrete previously exposed to deicing salts.

Saturated concrete

Concrete at 50% RH

Concrete at 50% RH exposed to deicing salt

Salts increase the degree of saturation in the pores

Care should be taken when the transport properties of concrete are assessed using gas permeability since salt exposure may influence the degree of saturation and transport.

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ABSTRACT

The gas transport properties of concrete can provide useful information for the prediction of the service life. However, to interpret the transport properties properly, some corrections may be needed to account for the moisture content and the distribution of moisture in the concrete. This paper investigates the influence of deicing salts on gas transport. Specifically, oxygen permeability and oxygen diffusion were examined for mortar samples initially saturated with different deicing salt solutions and then exposed to drying. The presence of deicing was found to increase the degree of saturation of mortar samples and as such it decreases permeability and diffusivity. These findings were further confirmed through desorption analysis. This study suggests that care must be taken when performing investigations on concrete previously exposed to deicing salts either in situ or when this concrete is extracted and used for laboratory testing.

1. Introduction

A considerable portion of building materials research focuses on the study of durability. In concrete research considerable efforts have been dedicated to the development of transport tests that can be used for service life prediction. Specifically, gas permeability and gas diffusivity measurements have attracted the interest of the concrete community due to their quasi-non-destructive nature, the short testing time that is required to perform the test [1], and the high reproducibility of the results [2]. Moreover, several methods have been developed to measure in situ the gas permeability of concrete [3–6].

The description of gas transport is complex and three distinct mechanisms are considered to occur simultaneously or independently. These mechanisms include (1) free-molecule or Knudsen diffusion, (2) molecular or ordinary diffusion and (3) surface

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diffusion [7]. Each mechanism is not completely understood but there is some evidence that it is greatly affected by total pressure, temperature, type of gas considered and properties of pore structure available to gas, in terms of pores size and pores connectivity [7,8].

In the literature many studies have focused on the analysis of the parameters that influence gas transport and gas transport testing. It has been shown that porosity and tortuosity can greatly influence the gas permeability and diffusivity measurements [9,10]. From the idealized gas theory, gas permeability varies with pore diameter squared [11] while gas diffusivity in large pores is independent of the pore size [12,13]. It is important to note however that this depends on both the total porosity and the vapor filled porosity. This points to the fact that the gas transport properties are strongly dependent on the amount of moisture and on its distribution inside the concrete element [2,8]. For specimens with a higher moisture content, the thickness of the layer of moisture that covers the pores walls increases [14,15] causing the decrease of the mean free path of gas molecules [16] and the reduction of gas transport [2]. It has been shown that a reduction in gas transport is considerable when the degree of saturation is greater than 60% since the pores relevant for transport process are increasingly filled as the degree of saturation increases [17,18].

Many concrete structures are exposed to salts due to either a marine environment or the application of deicing salts to pavements [19], bridge decks [20], or parking lots. The presence of deicing salt is known to influence the durability performance of concrete structures. Evidence of salt deterioration has been reported in masonry structures [21], building stones [22], coastal structures [23] and concrete elements [24].

Several mechanisms may be associated with deicing salt damage including pressure that develops due to osmosis, crystallization, intermediate compounds, or the increase of the risk of frost damage due to the increase in the degree of saturation [25–27] (Scherer December 2011, Personal Communication). Salts are also responsible of chemical interaction within the concrete, resulting in leaching and decomposition of the hydrated cement products, accelerated concrete carbonation, or alkali-silica reaction [28,29]. Some authors have also reported formation of Friedel's salts, Kuzel's salt or calcium oxychlorides compounds in concrete exposed to deicing salts [30,31]. This paper will focus on the potential influence of deicing salts on the gas transport properties.

The effect of salts on gas transport properties has been studied for rocks [22,32,33]. However, very few studies can be found that investigate the influence of salt on gas transport for concrete. One study was found where salt saturated concretes were preferentially used to help the concrete for use in transuranic waste repository [34,35].

The presence of deicing salts may alter gas transport due to three primary reasons. First, the salts can change the moisture content (degree of saturation) and moisture distribution in the pore structure of the cementitious system. It is known that deicing salts change the density, viscosity, surface tension, and water activity of the solution [19]. Salts change the drying process [36] and decrease the equilibrium relative humidity of the pore solutions [36,37]. Consequently, samples containing deicing salt are likely to have a higher degree of saturation when compared with a sample containing water at the same relative humidity [25,36,38]. Since the degree of saturation is higher in systems containing salts, a lower gas permeability/diffusivity can be expected [2]. Second, the salt can precipitate in the pores [27]. In cementitious systems that initially contain salt solutions, it is known that when the water evaporates the solution becomes more concentrated. The concentration gradient generated causes the salt to begin to diffuse in the concrete, tending to homogenize the salt profile [39]. If however the convective flow is much higher compared to the diffusive flow [32], the system will results in non-homogeneous salts distribution. Non-uniform salt distributions can also develop if the sample has a moisture gradient before the deicing salt is introduced. Finally, the salt could react with the matrix forming reaction products that limit transport.

This paper investigates the influence of deicing salts on gas permeability and gas diffusivity measurements on mortar samples. The effect of moisture content (degree of saturation) and salt precipitation on gas permeability and diffusivity will be investigated. The potential for chemical reactions are not considered in this work as that is being considered in an ongoing study.

2. Materials and samples preparation

Gas permeability, gas diffusivity and desorption tests were performed using mortar. The mortar had a water-to-cement ratio of 0.42 with 55% aggregate by volume. The mixing procedure was in accordance with ASTM C 192 [40].

For gas permeability and gas diffusivity, cylindrical samples (diameter of 102 mm (4 in.) and length of 204 mm (8 in.)) were prepared. The samples were demolded at an age of 24-h and then sealed in double plastic bags for approximately 12 months. The cylinders were then cored using a 68 ± 2 mm diameter bit and cut using a wet saw to obtain samples with a height of 25 ± 2 mm (1 in.) for oxygen permeability measurements. For oxygen diffusivity measurements larger samples were used. The oxygen diffusion samples were obtained from 102 by 204 mm cylinders (4 × 8 in.) using a wet saw to obtain samples with 102 mm (4 in.) of diameter and 50 mm (2 in.) length.

A total of 16 samples were prepared for oxygen permeability and 8 samples were prepared for oxygen diffusivity. Specimens were initially oven dried at 50 ± 0.5 °C and 30 ± 1% RH until constant mass and subsequently submerged in four different aqueous solutions: deionized water, 16% calcium chloride ($CaCl_2$), 15% magnesium chloride ($MgCl_2$) and 17.5% sodium chloride (NaCl). These salts were selected as they are common deicing salts used by American DOTs. Higher concentrations were not investigated as a part of this study. These concentrations were chosen in order to maximize the effect of the increased DOS due to salts presence while minimizing the pore blocking effect due to the formation of other compounds from the reaction between salts and cement paste. In each solution, four oxygen permeability samples and two oxygen diffusivity samples were placed and kept submerged until their mass reached the equilibrium ($\Delta m < 0.2\%$ within 7 days). The specimens were then conditioned in a temperature and humidity controlled chamber at 65%° ± 1% RH and at 23° ± 0.5 °C until equilibrium ($\Delta m < 0.1\%$).

For desorption analysis, smaller cylinders (34 mm of diameter and 50 mm tall) were prepared. The samples were sealed after casting and remained sealed until demolding (at 28 days). Thin slices of mortar (0.80 ± 0.05 mm) were cut from the cylinder using a water cooled diamond tipped wafer cut saw. The slices of material were stored at 23 ± 0.1 °C and 50% ± 2% RH, in a CO_2 free chamber. Prior to testing, samples were submerged for 24 h in aqueous solutions (water, 16.0% calcium chloride $CaCl_2$, 15.0% magnesium chloride $MgCl_2$, and 17.5% sodium chloride NaCl) before they were tested.

Fig. 1. Oxygen permeability – South African instrument.