



# Damage development in cementitious materials exposed to magnesium chloride deicing salt



Yaghoob Farnam<sup>a,\*</sup>, Andrew Wiese<sup>a</sup>, Dale Bentz<sup>b</sup>, Jeffrey Davis<sup>c</sup>, Jason Weiss<sup>a</sup>

<sup>a</sup> Lyles School of Civil Engineering, Purdue University, 550 Stadium Mall Dr., West Lafayette, IN 47907, USA

<sup>b</sup> Materials and Structural Systems Division, National Institute of Standards and Technology, 100 Bureau Drive, Stop 8615, Gaithersburg, MD 20899, USA

<sup>c</sup> Materials Measurement Science Division, National Institute of Standards and Technology, 100 Bureau Drive, Gaithersburg, MD 20899, USA

## HIGHLIGHTS

- Concrete exposed to MgCl<sub>2</sub> follows the Ca(OH)<sub>2</sub>–CaCl<sub>2</sub>–H<sub>2</sub>O phase diagram.
- MgCl<sub>2</sub> interacts rapidly with concrete developing damage and degradation.
- MgCl<sub>2</sub> causes a significant decrease in fluid ingress into exposed concrete.

## ARTICLE INFO

### Article history:

Received 6 December 2014

Received in revised form 30 March 2015

Accepted 3 June 2015

Available online 15 June 2015

### Keywords:

Brucite  
Concrete  
Deicing salt  
Freeze–thaw  
Damage  
Magnesium oxychloride  
Magnesium silicate hydrate (M–S–H)  
Phase change  
Calcium oxychloride

## ABSTRACT

Magnesium chloride (MgCl<sub>2</sub>) is used in deicing applications due to its capability to depress freezing temperatures to a lower point than other salts such as sodium chloride (NaCl). The constituents of concrete (i.e., pores solution, calcium hydroxide, aluminate phases, and calcium silicate hydrate gel) can alter the MgCl<sub>2</sub>–H<sub>2</sub>O phase diagram when it is used to interpret the performance of concrete. Different chemical reactions may concurrently occur between MgCl<sub>2</sub> and cementitious constituents to form brucite, Friedel's salts, magnesium silicate hydrate, magnesium oxychloride, and/or secondary calcium oxychloride. In this study, it was observed that MgCl<sub>2</sub> can be entirely consumed in concrete by the chemical reactions and produce CaCl<sub>2</sub>. As such, it was found that MgCl<sub>2</sub> interacts significantly with a cementitious material and it follows a response that is more similar to the Ca(OH)<sub>2</sub>–CaCl<sub>2</sub>–H<sub>2</sub>O phase diagram than that of the MgCl<sub>2</sub>–H<sub>2</sub>O phase diagram. Mortar samples exposed to low concentration MgCl<sub>2</sub> solutions (<10% by mass) for a short duration of freezing and thawing showed damage due to ice formation, while for higher concentrations (≥10% by mass), the damage was most likely due to the chemical reactions between MgCl<sub>2</sub> and cementitious constituents at room temperature (23 °C). These chemical reactions occurred rapidly (within 5–10 min) and caused a significant decrease in subsequent fluid ingress into exposed concrete.

© 2015 Elsevier Ltd. All rights reserved.

## 1. Introduction

The widespread use of deicing salt is considered to be a primary cause of the deterioration of concrete structures in cold climates, resulting in costly repairs and early replacement of concrete infrastructure elements. Deicing salts can penetrate into the concrete and cause corrosion of reinforcement, as well as changing the concrete microstructure by participating in aggressive chemical reactions. Changes in concrete microstructure due to aggressive chemical reactions are often accompanied by a decrease in the mechanical properties, a change in transport resistance of concrete,

and damage and degradation. The formation of expansive phases and salt crystallization in concrete pores are thus two major sources of damage and cracking in a concrete exposed to deicing salts [1–7].

Among the most common deicing chemicals, MgCl<sub>2</sub> is perceived as being particularly effective in melting ice and snow due to its ability to depress the freezing temperature of a solution to a lower temperature than other salts (Fig. 1). However, concrete exposed to MgCl<sub>2</sub> de-icing salt typically exhibits changes in its microstructure due to chemical reactions, including formation of brucite, Friedel's salts, magnesium silicate hydrate (M–S–H), magnesium oxychloride, and/or secondary calcium oxychloride; these changes can be accompanied by severe cracking, even if the concrete does not experience any freezing and thawing cycles [5,8–13]. Shi et al. [11] reported a significant strength loss of the concrete exposed to MgCl<sub>2</sub> solution.

\* Corresponding author.

E-mail addresses: [yfarnam@purdue.edu](mailto:yfarnam@purdue.edu) (Y. Farnam), [awiese@purdue.edu](mailto:awiese@purdue.edu) (A. Wiese), [dale.bentz@nist.gov](mailto:dale.bentz@nist.gov) (D. Bentz), [jeff.davis@nist.gov](mailto:jeff.davis@nist.gov) (J. Davis), [wjweiss@purdue.edu](mailto:wjweiss@purdue.edu) (J. Weiss).

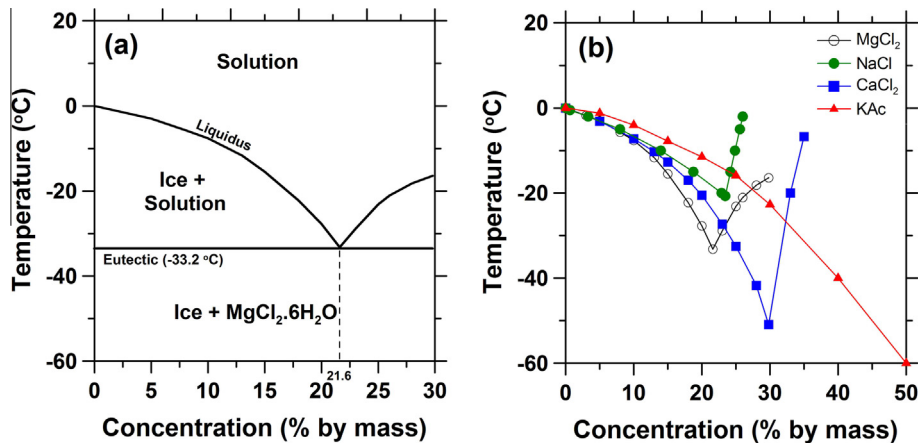
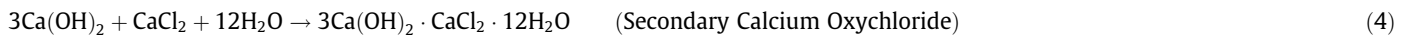
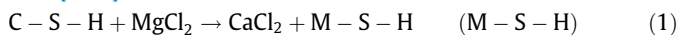
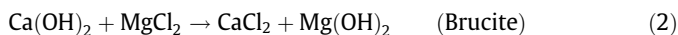
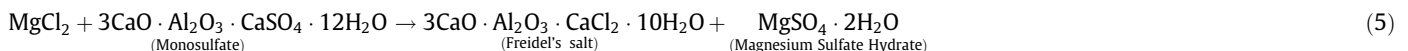


Fig. 1. (a) Phase diagram for  $\text{MgCl}_2\text{-H}_2\text{O}$  and (b) comparison of freezing temperature for aqueous  $\text{MgCl}_2$  with  $\text{NaCl}$ ,  $\text{CaCl}_2$ , and  $\text{KAc}$  (potassium acetate) deicing chemicals.

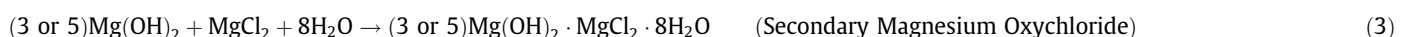
$\text{MgCl}_2$  deicers can react with the cement paste to produce M–S–H and brucite ( $\text{Mg}(\text{OH})_2$ ). As described in Eq. (1), non cementitious magnesium silicate hydrate is formed by replacing the calcium from the cementitious calcium silicate hydrate (C–S–H) with magnesium. The formation of M–S–H was reported to produce damage in concrete and it appears to be a gradual and slow reacting product [8,14].



The formation of brucite is caused by  $\text{MgCl}_2$  reacting with  $\text{Ca}(\text{OH})_2$  as shown in Eq. (2). The brucite usually forms on the surface of concrete samples as an outer layer product [5,8,15–17]. The brucite appears to be a dense and homogeneous product [17]. It is also reported that the brucite layer can slow down concrete deterioration due to deicing salt exposure by hindering ingress of the chloride solution into the concrete [8].



Formations of magnesium oxychloride and calcium oxychloride were also reported in concrete with  $\text{MgCl}_2$  as secondary reactions [5,7,10], since  $\text{CaCl}_2$  and  $\text{Mg}(\text{OH})_2$  should be formed first by reactions described in Eqs. (1) and (2). Two common phases of magnesium oxychloride are typically reported to exist, containing either 3 or 5  $\text{Mg}(\text{OH})_2$  molecules, so called the 3-form and 5-form, respectively (Eq. (3)) [7,18–20]. The addition of small quantities of hydraulic aluminate minerals (such as CA,  $\text{C}_3\text{A}$ , and  $\text{C}_4\text{AF}$ ) can convert the 5-form magnesium oxychloride to 3-form magnesium oxychloride ( $3\text{Mg}(\text{OH})_2 \cdot \text{MgCl}_2 \cdot 8\text{H}_2\text{O}$ ) [20]. It was also reported that the 5-form phase can alter to 3-form over time and that the 3-form is more stable than the 5-form [19]. In concrete exposed to  $\text{MgCl}_2$ , therefore, it is expected that 3-form magnesium oxychloride exists due to the usual presence of  $\text{C}_3\text{A}$  and  $\text{C}_4\text{AF}$ . The 3-form magnesium oxychloride is unstable and can dehydrate and lose water at temperatures around 65 °C [19].



The formation of calcium oxychloride can be described as in Eq. (4). Calcium oxychloride was found as platey-shaped crystals in concrete exposed to  $\text{MgCl}_2$  [1,5,10,12]. The formation of calcium oxychloride has been reported to be very expansive and destructive within the cementitious matrix [1,5]. Calcium oxychloride can form at temperatures above the freezing point of water [1,21] and is unstable at room temperature and lower levels of relative humidity [9,22–24].

$\text{MgCl}_2$  deicers can also cause formation of calcium chloroaluminate phases such as Freidel's salt [8,25–28]. A possible reaction for the formation of Freidel's salt in the presence of  $\text{MgCl}_2$  salt, for example, is shown in Eq. (5) [28]. The formations of magnesium oxychloride, calcium oxychloride, and M–S–H were reported as primary sources for severe deterioration. In contrast, brucite, magnesium sulfate, and Freidel's salt are not generally reported as very destructive components [5,7,8,10,16,29].

In previous studies [1–4,30–32], the influence of  $\text{NaCl}$  and  $\text{CaCl}_2$  deicing salts on damage development in cementitious materials has been investigated. It was found that chemical reactions between the matrix and salt solution can result in the formation of additional phases that can cause severe damage in cementitious materials. For  $\text{NaCl}$ , the source of this chemical phase transition appears to be most likely due to the presence of aluminate phases within the concrete. In the  $\text{CaCl}_2$  case, the additional phase change was mainly due to the formation of calcium oxychloride, and calcium hydroxide was the main source of this reaction. While the use of  $\text{NaCl}$  and  $\text{CaCl}_2$  deicing salts are relatively common practices to remove ice and snow from the surface of roadways and pavement,  $\text{MgCl}_2$  is also used in some regions. For  $\text{MgCl}_2$ , there have been attempts to investigate the potential physical and chemical changes that may be caused by  $\text{MgCl}_2$  deicing salts and lead to damage development [5,7,8,10,16,29]. However, the interaction between  $\text{MgCl}_2$  and the cementitious material constituents (i.e.,

Download English Version:

<https://daneshyari.com/en/article/6720409>

Download Persian Version:

<https://daneshyari.com/article/6720409>

[Daneshyari.com](https://daneshyari.com)