

JOINT DETERIORATION AND CHLORIDE-BASED DEICING CHEMICALS

Keywords: calcium oxychloride; critical saturation; deicers; freezing-and-thawing damage; joint deterioration; supplementary cementitious materials.

Question

Why do some concrete pavements and concrete flatwork in freezing-and-thawing damage environments show premature deterioration at joints?

Answer

Salt-rich solutions accumulate in joints in pavements, sidewalks, and other flatwork, particularly when the structures are poorly drained. Deterioration can occur as a result of physical and chemical mechanisms that are driven by cyclic wetting and drying of members exposed to chloride-rich solutions. Physical damage is attributed to the concrete reaching critical saturation, which results in freezing-and-thawing damage. The damage related to chemical attack is due to calcium oxychloride formation, which is expansive. This type of deicer attack differs from D-cracking or deicer scaling. Damage manifests primarily as spalling around the walls of the joint and cracking in the concrete parallel to the joint.

Discussion

Concrete pavements and exterior flatwork generally provide excellent performance in all climates and exposures. Concrete durability is an essential component in delivering the return on investment that makes concrete an economical and sustainable material. In recent years, the industry has seen an increase in premature deterioration at joints and saw cuts in concrete pavements and flatwork in areas where winter storm events demand the application of deicing chemicals, which are most commonly chloride-based. The damage most commonly manifests itself in one of two forms. In the first, concrete at the base of the saw cut deteriorates, often producing cracks parallel to joint walls and within 4 to 6 in. (100 to 150 mm) of the original joint (Wiese et al. 2015) (Fig. 1(a)). These cracks should not be confused with D-cracking (ACI 201.2R). In the second form of damage, micro-cracking along the joint walls causes raveling, where flakes of concrete typically ranging from 1/8 to 1/4 in. (3 to 6 mm) thick are lost from the joint (Wiese et al. 2015) (Fig. 1(b)).

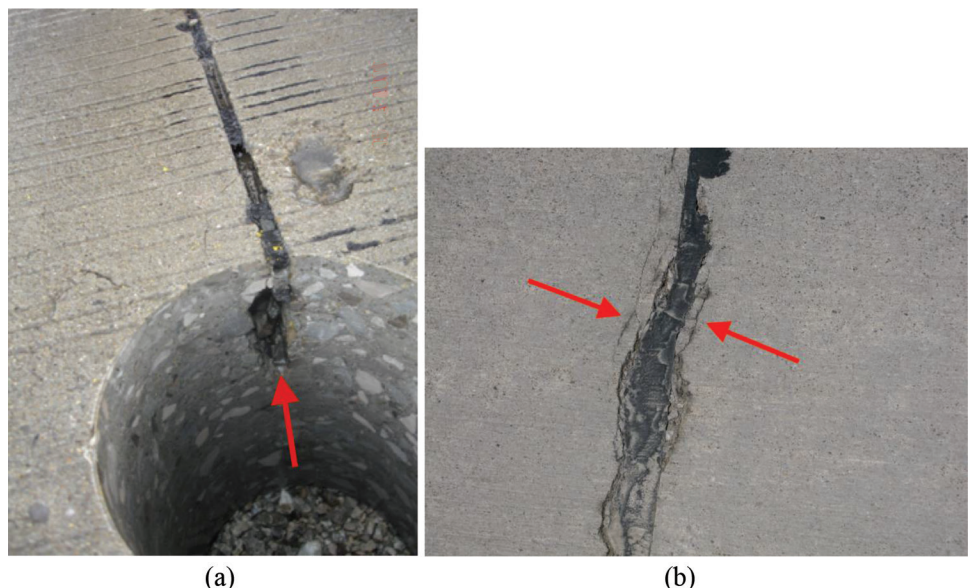


Fig. 1—Photographs showing: (a) damage at the base of a saw cut (red arrow) that leads to cracks parallel to walls of joint (Arribas-Colón et al. 2012) and (b) flaking of the concrete (red arrow) that presents itself as raveling along a joint (photo courtesy of J. Sutter)

The increased incidence of premature deterioration of joints correlates broadly in time with changes in the materials and strategies used to deice pavements and flatwork. For many years, owners, such as state departments of transportation, municipalities, and private property owners, used sodium chloride (NaCl), frequently in the form of rock salt, as the primary chemical agent for deicing. Rock salt or, in some applications, solid calcium chloride (CaCl_2), was dispersed as granules on pavements to form a brine with the snow and ice. Having a lower freezing point, the resulting brine melted thin ice layers, reduced ice bonding, and improved the efficiency of plowing. Evolution of winter maintenance practices led to use of liquid brines being sprayed on pavements rather than dispersal of solid pellets or granules of salts. In some areas, brines are sprayed on pavements before a storm event to prevent the formation of ice (anti-icing). Calcium chloride and magnesium chloride (MgCl_2) are both common components of deicing brines owing to having a freezing point lower than NaCl brines. (Minimum freezing point: NaCl -6°F [-21°C]; MgCl_2 -28°F [-34°C]; CaCl_2 -58°F [-50°C].) For winter maintenance of pavements, the brines used are commonly mixtures of two or more different chlorides. Magnesium chloride became very common due to its availability and low cost relative to the other chloride deicers. As a result of these changes, concrete flatwork and pavements today see higher concentrations of more-effective but also more-damaging chemicals, often with greater frequency, than ever before (Weiss et al 2016).

With the implementation of these new salts and delivery strategies, most agencies charged with maintaining pavements saw significant decreases in accidents from icy roads (Kuemmel and Hanbali 1992). These salts are also commonly used on sidewalks, stairs, and building entrances to keep walkways clear of ice. Because there is a clear benefit to public safety, the use of these materials and delivery systems is expected to continue. The purpose of this note is to provide information regarding the damage mechanisms associated with traditional, as well as newer, deicer chemicals and joints, and give recommendations on how to minimize the potential for this damage to occur.

Deicing salts and concrete saturation at joints

Joints and cracks in concrete pavements are most likely to experience increased degree of saturation as salt solutions collect in these openings. Contributing factors include surface ponding, ineffectively-sealed joints that allow the ingress of salt solutions (brines), and inadequate subsurface drainage that prevents the brine from draining away in a timely manner. This increases the degree of saturation of the concrete as well as its salt content as the brine permeates the concrete (Spragg et al. 2011). In addition, cyclic wetting and drying increases the salt concentration. These factors contribute to deterioration mechanisms, which are described in the following section.

Physical and chemical deicer damage mechanisms

Both physical and chemical mechanisms associated with deicers cause damage in pavement and flatwork joints. The physical damage results from higher levels of fluid saturation in the concrete, which leads to conventional freezing-and-thawing damage (ACI 201.2R). The chemical mechanisms involve reactions between chloride and the cementitious matrix; in particular, research has identified the production of a secondary phase known as calcium oxychloride (Sutter et al. 2006; Suraneni et al. 2016a), which is a particular concern for joint durability.

Saturation and physical damage mechanisms—There is a strong correlation between the degree of saturation and freezing-and-thawing damage in concrete (Peterson et al. 2013; Li et al. 2012). A critical degree of saturation exists that, if exceeded, can result in freezing-and-thawing damage after just one cycle of freezing, even in concrete that has a suitable water-cementitious materials ratio (w/cm) and an adequate air-void system. This critical degree of saturation ranges from 78 to 91 percent for properly air-entrained concrete (Todak et al. 2015).

Figure 2 illustrates a model that describes the interaction between air volume and the degree of saturation over time in a concrete mixture (Todak et al. 2015). Initially, absorbed water fills the gel and capillary pores. The degree of saturation associated with the filling of gel and capillary pores is shown by the circle where the

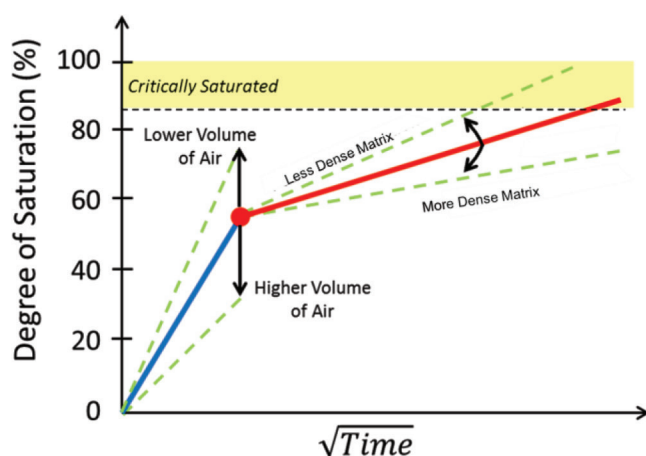


Fig. 2—A conceptual illustration of the sorption-based freezing-and-thawing model (after, Todak et al. 2015).