Mitigating Deicing Salt Damage to Concrete Pavements and Bridges

by Dr. Prannoy Suraneni, University of Miami, and Dr. Jason Weiss, Oregon State University

Deicing salts, which are typically rock salt and other chloride-based salts such as calcium chloride ($CaCl_2$) and magnesium chloride ($MgCl_2$), are commonly used in the United States to melt ice on the surface of pavements and bridges.[1,2] These chloride-based salts are an economical technology that increases driver and pedestrian safety, but they may have negative effects on concrete pavements and bridges, such as salt scaling and steel corrosion. These salts also exacerbate freeze-thaw damage in concrete.

While the damaging effects of salts are understood reasonably well, an additional form of chemical damage associated primarily with the use of high concentrations of $CaCl_2$ and $MgCl_2$ has been recently discovered. Because the use of such salts has been increasing, concrete pavements and bridge decks are increasingly showing signs of this type of chemical damage, which occurs due to the formation of a deleterious phase known as calcium oxychloride (CAOXY) and forms primarily along the joints and at low points in concrete pavements and bridge decks (Fig. 1).[1,2]

This type of damage is generally visible around the end of the first decade of service life and can be expensive to repair. Notably, CAOXY damage does not require freezing temperatures to occur and can happen at any time of the year. This article summarizes CAOXY damage mechanisms, testing methods, and damage mitigation. We hope that sharing this information will encourage others to adopt steps to minimize such damage and extend the life of our concrete infrastructure. Further details about CAOXY damage are found in references 1–3.

Damage Mechanisms

When chloride-based salt solutions are applied on concrete surfaces, they are slowly transported inside the concrete. A portion of these chlorides from $CaCl_2$ then reacts with calcium hydroxide ($Ca(OH)_2$), which is a phase that is found in most concretes, leading to the formation of the deleterious CAOXY phase, as shown in the following equation:[1–4]

$$CaCl_2 + 3Ca(OH)_2 + 12H_2O \rightarrow 3Ca(OH)_2 \bullet CaCl_2 \bullet 12H_2O$$

The CAOXY causes damage and loss of strength and elastic modulus because it is expansive, cracking the surrounding matrix.[1]

Testing Methods

Historically, damage caused by CAOXY formation was assessed by submerging concrete in concentrated $CaCl_2$ or $MgCl_2$ solutions and studying the reduction of properties such as compressive strength or elastic modulus over time.[5] Such testing provides valuable information; however, it is time-consuming. Nondestructive methods such as ultrasonic pulse velocity and bulk resistivity can monitor concrete property evolution and reduce testing effort.

Thermogravimetric analysis can be used to estimate the amounts of CAOXY that can potentially form in cement pastes. In this test, a small amount of powdered cement paste is heated to over 600°C; the mass loss between 380°C and 460°C is used to quantify the amount of $Ca(OH)_2$. The relationship between $Ca(OH)_2$ and CAOXY amounts that form in cement pastes is linear; therefore, the $Ca(OH)_2$ amount can be used to estimate the CAOXY amount.[1,3] A limitation of this analysis is that the $Ca(OH)_2$ must be accessible to the salt for it to react, which may not always happen when the concrete has carbonated.[6]

Low-temperature differential scanning calorimetry (LT-DSC) is a direct method to determine CAOXY amounts. Powdered cement paste is mixed with an equal mass of 20% $CaCl_2$ solution. The mixture is then inserted into the LT-DSC device and subjected to a cooling-heating cycle ranging in temperature from –90°C to 50°C. The heat associated with the formation of CAOXY can be measured, and the amount of CAOXY can then be computed. This method has been adopted by the American Association of State Highway and Transportation Officials as AASHTO T365.[7]

Damage Mitigation

Because the primary phase that leads to concrete damage is $Ca(OH)_2$, damage can be reduced by reducing

Figure 1. Example of concrete pavement joint damage showing cracking parallel to the joint and spalling and cracking at the joint. Photos: Jason Weiss.

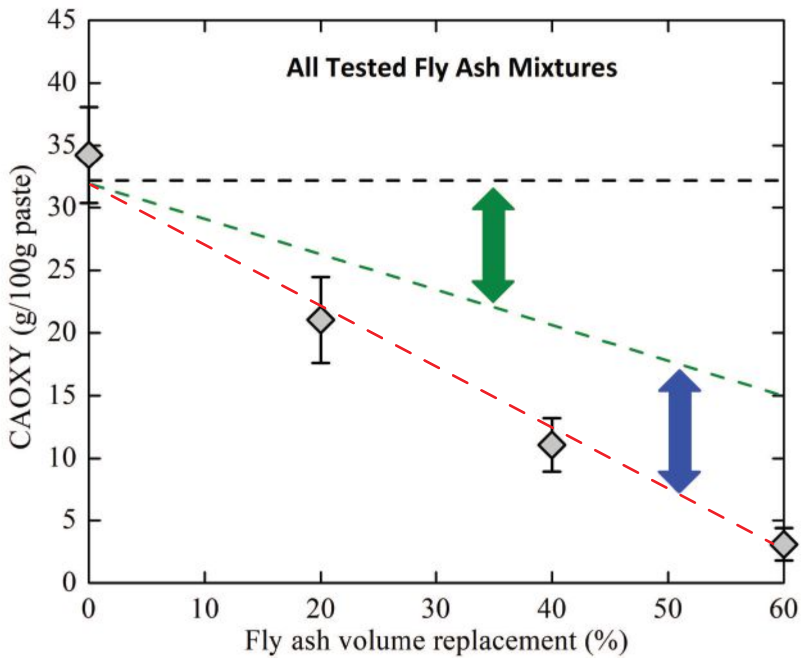

Figure 2. The reduction in CAOXY content as fly ash content increases in cementitious pastes. This reduction results from a combination of dilution (green arrow = less cement in the paste) and pozzolanic reaction (blue arrow = fly ash reacts with calcium hydroxide to form non-CAOXY phases). Figure: Adapted with permission from Reference 8.

$Ca(OH)_2$ content in concrete. The use of concrete containing supplementary cementitious materials such as fly ash and slag is an easy and practical way to reduce the formation of CAOXY and therefore the damage caused by it (Fig. 2).[1,8] These materials reduce the $Ca(OH)_2$ content by dilution (reducing the amount of cement) and pozzolanic reaction (materials react with $Ca(OH)_2$ to form other phases). The exact amounts of fly ash and slag required to mitigate damage depend on several factors; in most cases, the use of these materials as more than 30%–35% of the cementitious materials is likely to minimize damage.[1,8] The amount of CAOXY found through LT-DSC decreases linearly as the amount of fly ash or slag increases.

Adequate air entrainment is another effective way to reduce damage. The role of air in damage mitigation is complex, but one effect of air is that it acts as a valve to reduce pressure by providing space for the expansive CAOXY phase to form. Concrete mixture proportions with air contents of 6% or greater show reduced CAOXY damage.[1,5] However, as air voids fill over time due to the deposition of expansive phases, their usefulness in damage mitigation is reduced.

Other ways to reduce damage include the following:[1]

- Use blends of deicing salts to reduce the amount of reactive salt.
- Use concrete carbonation because the carbonation reaction consumes $Ca(OH)_2$.
- Use concrete topical treatments to reduce the ingress of salts.

Summary

This article describes a source of cracking and spalling damage in concrete pavements and bridges associated with the use of calcium chloride and magnesium chloride salts. The recently developed LT-DSC test method adopted as AASHTO T365 can be used to evaluate the susceptibility of concrete to this kind of damage. Practices to mitigate damage caused by CAOXY include the use of air entrainment, supplementary cementitious materials, and topical treatments. A

Dr. Prannoy Suraneni is an assistant professor in the civil, architectural, and environmental engineering department at the University of Miami in Coral Gables, Fla., and Dr. Jason Weiss is a professor and head of the School of Civil and Construction Engineering at Oregon State University in Corvallis.

References

1. Smith, S.H., C. Qiao, P. Suraneni, K.E. Kurtis, and W.J. Weiss. 2019. "Service-Life of Concrete in Freeze-Thaw Environments: Critical Degree of Saturation and Calcium Oxychloride Formation." *Cement and Concrete Research* 122: 93–106.
2. Jones, W., Y. Farnam, P. Imbrock, J. Spiro, C. Villani, M. Golias, J. Olek, and W. J. Weiss. 2013. "An Overview of Joint Deterioration in Concrete Pavement: Mechanisms, Solution Properties, and Sealers." West Lafayette, IN: Purdue University. https://doi.org/10.5703/1288284315339.
3. American Concrete Institute (ACI) Committee 201. 2019. *Joint Deterioration and Chloride-Based Deicing Chemicals (Technote)* (ACI 201.3T-19). Farmington Hills, MI: ACI.
4. Galan, I., L. Perron, and F.P. Glasser. 2015. "Impact of Chloride-Rich Environments on Cement Paste Mineralogy." *Cement and Concrete Research* 68: 174–183.
5. Sutter, L., T. Van Dam, K.R. Peterson, and D.P. Johnston. 2006. "Long-Term Effects of Magnesium Chloride and Other Concentrated Salt Solutions on Pavement and Structural Portland Cement Concrete: Phase I Results." *Transportation Research Record* 1979: 60–68.
6. Ghantous, R.M., Y. Farnam, E. Unal, and J. Weiss. 2016. "The Influence of Carbonation on the Formation of Calcium Oxychloride." *Cement and Concrete Composites* 73: 185–191. https://doi.org/10.1016/j.cemconcomp.2016.07.016.
7. American Association of State Highway and Transportation Officials (AASHTO). 2017. *Standard Method of Test for Quantifying Calcium Oxychloride Amounts in Cement Pastes Exposed to Deicing Salts* (AASHTO T365-17). Washington, DC: AASHTO.
8. Suraneni, P., V.J. Azad, O.B. Isgor, and W.J. Weiss. 2017 "Use of Fly Ash to Minimize Deicing Salt Damage in Concrete Pavements." *Transportation Research Record* 2629: 24–32.