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Supplementary Materials.

# Fact sheet 5
# Risk of concrete scaling during freeze/thaw cycles in presence of de-icing salt

## 1. Introduction

There is a risk of scaling degradation for concrete that is subjected to freeze/thaw cycles in the presence of de-icing salts (NaCL, $CaCl_2$). However, scaling is also sometimes observed in concrete that is subjected to freezing and thawing without the presence of de-icing salts as well as in concrete exposed to salt (seawater) without exposure to freezing/thawing cycles. These two instances are not discussed in this sheet.
In order to prevent scaling damage, it is necessary to pre-emptively protect against the problems related to simple freezing (see fact sheet on “concrete damage by internal freezing”). This sheet discusses instances salting that are considered as "frequent" (between 10 and 30 days per year) and "very frequent" (more than 30 days per year).

## 2. Consequences

- Concrete scales from the surface to the core of concrete with significant mass loss.
- Cracking or removal of aggregate that is not considered susceptible to freezing.

## 3. Physiochemical mechanisms

Given that all scaling pathologies cannot be explained in the same way and are the subject of constant research, the scientific and technical communities are not able to agree upon a single model that explains this phenomenon, though they are able to rank the different influential parameters. A summary of the different mechanisms identified in the literature is given in [8] and [9].

Nevertheless, the mechanisms below are frequently identified:
- the core of the concrete, which contains fewer chloride ions in solution, freezes more easily than the surface. The result is an expansion of the core when it is frozen, along with shrinkage on the surface: the resulting differential stresses create a tensile break within the paste,
- the freezing temperature of water is a direct function of pore diameter and of the concentration of dissolved salts.

As it is suggested in [9], the severity of the damage caused by the combined action of freeze-thaw cycles and de-icing salts is mainly due to the surface's greater susceptibility to frost (higher volume of paste and therefore, greater porosity) and to winter conditions that exacerbate defects by maintaining saturation, by subjecting the surface to thermal shocks, and by creating saline concentration gradients (osmosis, freezing layer by layer).

## 4. Main models

There is no agreed-upon predictive model (as of 2015). However, several models have been published, such as Valenza and Scherer's model [1, 2], for example, to explain concrete behavior in laboratory tests.

## 5. Influential parameters

"Material" parameters:
- product composition: the paste tensile strength, the aggregate susceptibility to frost),
- transport properties of liquid water andchlorides,
- structure of the porous network:
  - entrained air, trapped air (quantity and spatial distribution).
  - pore size and distribution.

"Environment" parameters:
- cycle type (thermal and hydrological conditions),
- degree of inclination of the structure (horizontal surface, drainage, inclined surface),
- presence of salts (type, concentration, frequency of application).

## 6. Steps of the test protocol to be studied:

Tests generally involve exposing to freeze/thaw cycles samples that have one surface in contact with a given volume of brine.
- Test sample preparation methods. Compaction methods have a strong influence on the structure of the porous network. The test surface must be un damaged and may be influenced by the mould type and preparation (choice of wax).

- Curing length and conditions:
    - age of the concrete. Strong impact on concretes that experience freezing before 28 days curing.
    - curing in liquid water: impact of temperature only.
    - curing in air: impact of $CO_{2(g)}$ content, temperature and relative humidity on concrete surface carbonation and hydration.
- Observance of freezing/thawing cycles. Adjustment of the climatic chamber, placement of temperature probes, brine depth.
- Brine composition. Pessimum effect of the chloride concentration on the scaled mass. Impact of the brine (concentration, homogeneity, and depth) on thermal regulation.
- Assessment of real exposed surface.

The quantity of interest is the cumulative mass loss of scales expressed in gram per square meter. It is influenced by the method of scales collection and by the effective test surface area.

## 7. Standard testing methods

| Name | Cure | Thermal cycle | Duration | Comment |
|---|---|---|---|---|
| XP P18-420:2012 [3] | 150x150x150 mm Cube.<br>14 days in water.<br>Cubes sawed between 7 and 14 days.<br>Up to 28 days in air (20°C, 65% RH).<br>After 28 days, 3-day resaturation with 3 mm of tap water.<br>After 31 days, the water is replaced with a 3% NaCl salt solution for the test. | -20 + 20°C | 3 months | In France, testing is done on the formed surface.<br>Thresholds are available [4]. |
| DD EN 12390-9:2006 [5], Slab test | 150x150x150 mm Cube.<br>7 days in water at 20°C, then up to 25 days in air (20°C, 65% RH, 45 g/$m^2$/h and 300-1100 ppmv $CO_2$)<br>The block is sawed after 21 days, configured on the 25th day<br>After 28 days, 3-day resaturation with 3 mm of tap water.<br>After 31 days, the water is replaced with a 3% NaCl saline solution when the test starts. | -20 / +20°C | 3.3 months | Test surface: sawed face. |
| EN 12390-9:2006 [5], Cube test | 100x100x100 mm Cubes.<br>7 days in water at 20°C, then up to 27 days in air (20°C, 65% RH, 45 g/$m^2$/h and 300-1100 ppmv $CO_2$)<br>After 27 days, the cubes are placed in containers that are filled with a 3% NaCl solution (complete immersion)<br>On the 28th day, the test begins. | -15 / +20°C | 3 months | |
| EN 12390-9:2006 [5], CF/CDF Test | 150x150x150 mm Cubes and separation plate.<br>7 days in water at 20°C, then up to 28 days in air (20°C, 65% RH, 45 g/$m^2$/h and 300-1100 ppmv $CO_2$)<br>Resaturation on the 28th day through capillary absorption and beginning of the tests.<br>Freezing medium:<br>- CF Test: demineralized water.<br>- CDF Test: 3% NaCl solution. | -20 / +20°C | CDF Test: 2 months<br>CF Test: 3 months | |

## 8. Performance assessment

To ensure the freeze-thaw performance of a composition, a product should meet the performance requirements of both internal frost resistance and scaling resistance.

For aspects related to simple freezing, the fact sheet on internal freezing may be consulted. For simple freezing, the assessment method is “absolute” binary. The assessment method for scaling is also “absolute” binary.

For standard XP P18-420:2012 [3] mentioned in the previous table, the threshold values from the recommendations for the durability of concrete subjected to freezing may be used [4].

## 9. References

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