The interplay between inner and outer frost damage and its implication for accelerated freeze-thaw testing

Hasholt, Marianne Tange

Published in:
Proceedings of the XXII Nordic Concrete Research Symposium

Publication date:
2014

Citation (APA):
Hasholt, M. T. (2014). The interplay between inner and outer frost damage and its implication for accelerated freeze-thaw testing. In Proceedings of the XXII Nordic Concrete Research Symposium (pp. 21-24). Norsk Betongforening.

The interplay between inner and outer frost damage and its implication for accelerated freeze-thaw testing

Marianne Tange Hasholt
Associate professor, M.Sc., Ph.D.
Department of Civil Engineering
Technical University of Denmark
E-mail: matah@byg.dtu.dk

ABSTRACT

In the present project salt frost scaling was registered during an accelerated freeze-thaw test (CEN/TS 12390-9). After the test, inner damage was evaluated by observing the crack patterns on fluorescence impregnated plane sections. The results indicate that the developments of inner and outer damage are linked processes. The link is related to the moisture transport in the concrete, as both inner cracking and scaling change if a moisture barrier is implemented parallel to the test surface, 25 mm below the test surface.

Key words: Frost action, salt frost scaling, inner frost damage, testing.

1. INTRODUCTION

In a cold climate, concrete that is not frost resistant can suffer from inner damage in the form of cracks and outer damage in the form of surface scaling /Pigeon & Pleau., 1995/. Concrete deterioration during frost action has been a subject of research for more than 60 years, but still the degradation mechanisms are not fully understood. One of the remaining questions is the interplay between development of inner and outer damage. It is not known if surface scaling is a consequence of inner damage or if surface scaling contributes to starting or accelerating development of inner damage – or if inner and outer damage are caused by two different mechanisms that act independent of each other, as supposed by /Valenza & Scherer, 2007/.

The development of both inner and outer frost damage depends on the availability of freezable water and therefore also on moisture transport in the concrete. In a BSc project, specimens with artificial barriers for moisture movement were prepared for freeze-thaw testing to see how it influenced the development of inner and outer frost damage /Hedegaard & Kleiter 2013/.

2. EXPERIMENTAL WORK

2.1 Materials

It was the intention to test a non-frost resistant type of concrete. It was decided to use concrete with w/c = 0.45 without air entrainment. The following constituents were used:

- *Cement*: CEM I 52.5 N (LA), 475 kg per m³ concrete
- *Aggregate*: Sea sand and crushed granite (maximum size 11 mm), environmental class E (Extra aggressive), i.e. suitable for production of concrete exposed to frost action.

The air content of the fresh concrete was 1.4% measured by pressuremeter (natural air content).

2.2 Test methods

The air void structure of the hardened concrete was evaluated by the method described in EN 480-11: *Admixtures for concrete, mortar and grout - Test methods - Part 11: Determination of air void characteristics in hardened concrete* (2005).

The accelerated freeze-thaw test was carried out according to the reference method of CEN/TS 12390-9: *Testing hardened concrete – Part 9: Freeze-thaw resistance – Scaling* (2006). Two sets of Ø150 mm test specimens were prepared in parallel:

- *standard*: preparation followed exactly the preparation described in CEN/TS 12390-9, including a sample height of 50 mm
- *25+25 mm*: preparation followed CEN/TS 12390-9, except that the 50 mm specimen was cut in half to obtain two 25 mm discs. The discs were assembled by gluing a 3 mm rubber sheet in between (same type of rubber sheet as used on the external surfaces of the test specimen except the test surface). The position of the rubber sheet can be seen in figure 2 (right).

After the freeze-thaw test, one specimen from each series was epoxy impregnated with fluorescent dye to make cracks clearly visible on a plane section of the specimen.

3. RESULTS

3.1 Air void structure

The air void structure of the hardened concrete was examined according to EN 480-11. The results showed a total air content of 1.4% and a spacing factor of 0.74 mm.

3.2 Accelerated freeze-thaw testing

Figure 1 shows the development of scaling during the accelerated freeze-thaw test according to CEN/TS 12390-9. Due to electrical power cuts in the laboratory, there were less than 56 freeze-thaw cycles during the test period. Scaling was registered after 7, 13, 20, 27, 41, and 53 cycles:

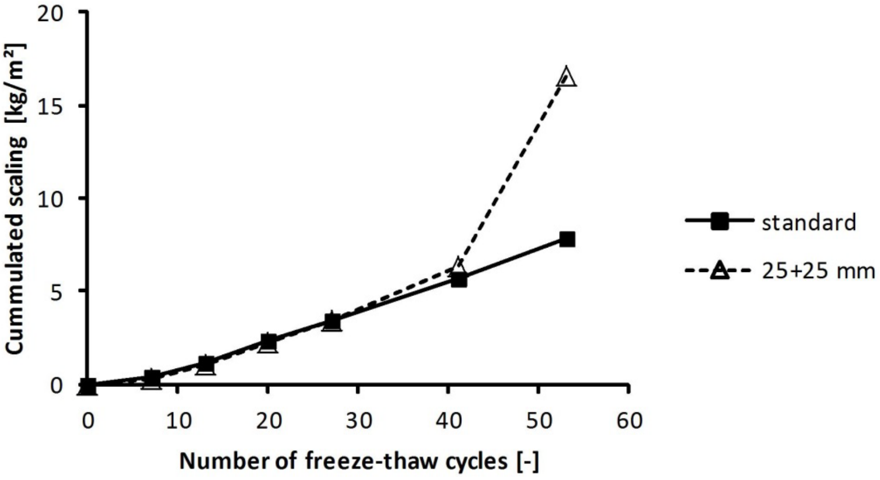

Figure 1 – Development of salt frost scaling.

3.3 Inner frost damage

Figure 2 shows fluorescence impregnated plane sections in UV light of “standard” and “25+25 mm”, respectively:

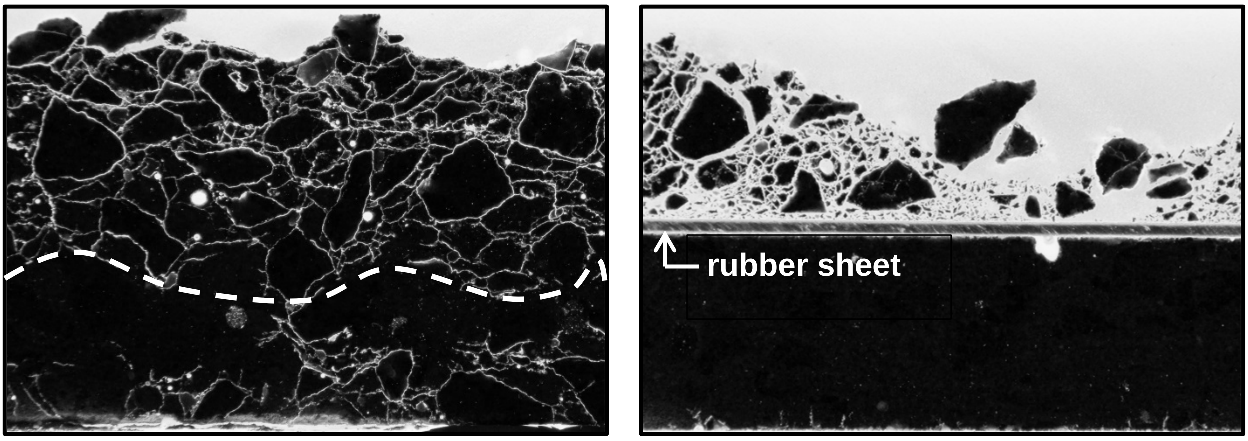

Figure 2 – Fluorescence impregnated specimens of samples after 53 freeze-thaw cycles. The upper edge of each photo corresponds to the original test surfaces before testing, and the height corresponds to the height of the specimen (50 mm) Left: "standard". Right: "25+25 mm".

4. DISCUSSION

The air void analysis reveals that the spacing factor is 0.74 mm >> 0.20 mm, so the concrete cannot be expected to be frost resistant. The results of the accelerated freeze-thaw test confirm this, as the amounts of scaling for both test series exceed the accept limits normally used.

The development of scaling for *standard* specimens and for *25+25mm* specimens is almost identical up to 41 freeze-thaw cycles, and the scaling rate seems to be constant. After 41 cycles, scaling for *standard* specimens continues with the same rate of scaling, whereas scaling accelerates for *25+25 mm* specimens.

The mapping of inner cracking shows somewhat different crack patterns for the two test series. For the *standard* specimen, fine cracks are homogenously distributed in the upper 30 mm of the specimen (above the dotted line in figure 2, left), and there is a distinct front to an un-cracked zone. For the *25+25 mm* specimen, the cracking of the upper 25 mm is more severe than the cracking of the *standard* specimen; both crack density and crack with is higher. Below the moisture barrier (rubber sheet), there are no cracks.

If one imagines that the inner cracking of the *standard* specimen has developed as a front progressing through the specimen at constant rate, then the front has reached the depth of 25 mm after 53·25/30 = approx. 44 freeze-thaw cycles. This coincides with time where scaling in the *25+25 mm* specimen accelerates. This can be explained in the following way: Crack formation starts during the first freeze-thaw cycle at the top surface of the specimen. Between frost periods, moisture is transported via the cracks, so un-cracked concrete in the border zone between cracked and un-cracked becomes critically saturated, and it therefore cracks in the following cycle. Therefore, the front of the cracked zone propagates with almost constant rate. The cracked front also marks a moisture front. The moisture content of the cracked concrete is higher than the moisture content of the un-cracked concrete and the moisture content of cracked concrete remains constant as long as moisture can escape to the un-cracked zone. However, when the moisture front meets a barrier, the cracked zone becomes wetter, and therefore cracking in the paste phase aggravates. This weakens the concrete, and for this reason scaling increases. In fact, the amount of scaling measured at this point is to some extent arbitrary, as the crumbled concrete can almost be brushed of the specimen.

There is also some cracking at the bottom of the *standard* specimen. This may be because some of the sodium chloride solution from the reservoir on top of the specimen has leaked through the specimen and accumulated at the bottom, so a similar process can take place from beneath.

If this sequence of deterioration during testing is a correct interpretation, then it also ought to have implications for how we perform accelerated freeze-thaw tests and evaluate the results. Often, the observation of accelerated scaling (e.g. that the total amount of scaling after 56 cycles is more than twice the amount of scaling after 28 cycles) is included in the evaluation of frost resistance. On one hand, one may argue that the accelerated scaling is due to an artefact of the test method: The moisture front meets a barrier at the bottom of the specimen, which it would not meet in a thicker concrete structure. Therefore it is irrelevant to take acceleration into account during the evaluation of results. On the other hand, one may argue that if acceleration occurs, it is an indirect measure of how prone the concrete is to inner frost damage, as it shows that cracking has reached a depth of 50 mm, and this makes it a relevant evaluation criterion.

At the moment, there is no European test standard for testing susceptibility of hardened concrete to development of inner frost damage. It has been suggested to use measurements of ultrasonic pulse transmission time (UPTT) during the scaling test for this purpose /Setzer et al., 2004/. However, if inner damage is not homogenously distributed in the specimen - in fact there are separate zones of cracked and un-cracked concrete - then it is difficult to differentiate the degree of damage by using UPTT measurements. For practical reasons, e.g. the size of the sender and receiver of the UPTT equipment, measuring heads have to be placed some distance from the test surface. If they are placed so their centres are 25 mm below the test surface, then the upper 25 mm of the concrete can be cracked, before a change in UPTT is registered, and this extent of cracking may be more than what is acceptable to categorise concrete as frost resistant.

ACKNOWLEDGEMENT

The experimental work presented in this paper was performed by Jens Hedegaard and Anton Kleiter. Their effort during the project is highly appreciated. Fluorescence impregnated plane sections are prepared by Pelcon A/S, and the project has been financially supported by the Larsen & Nielsen Foundation. This is greatly acknowledged.

REFERENCES

Hedegaard, J., & Kleiter, A. 2013
”Undersøgelse af luftporestrukturens indvirkning på fryse/tø-mekanismer og isdannelse i cementpasta” (in Danish), BSc report, Technical University of Denmark, Lyngby, 2013.
Pigeon, M., & Pleau, R., 1995
“Durability of concrete in cold climates”, E & FN Spon, London, 1995.
Valenza, J.J., & Scherer, G.W., 2007
“A review of salt frost scaling: II. Mechansisms”, Cement and Concrete Research, vol. 37, 2007, pp. 1022-1034.
Setzer, M.J., et al., 2004
”Test methods of frost resistance of concrete: CIF-test: Capillary suction, internal damage and freeze thaw test – Reference method and alternative methods A and B”, Materials and Structures, vol. 37, 2004, pp. 743-753.