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Author(s)	Kuosa, Hannele; Leivo, Markku; Ferreira, Miguel; Piironen, Jukka
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Effect of concrete frost deterioration on chloride penetration and carbonation

M.Sc.(Tech.) Hannele Kuosa
VTT Technical Research Centre of Finland
Structural Performance
P.O. Box 1000, FI - 02044 VTT
Finland
E-mail: hannele.kuosa@vtt.fi

Dr. Markku Leivo
VTT Technical Research Centre of Finland
Advanced Materials
P.O. Box 1000, FI - 02044 VTT
Finland
E-mail: markku.leivo@vtt.fi

Dr. R. Miguel Ferreira
University of Minho, C-TAC - Centre for Territory, Environment and Construction
Campus de Azurém, 4800-058, Guimarães
Portugal,
E-mail: rmf@civil.uminho.pt

M.Sc.(Tech.) Jukka Piironen
Aalto University, Department of Civil and Structural Engineering
P.O. Box 12100
FI - 00076 Aalto
Finland
E-mail: jukka.piironen@aalto.fi

ABSTRACT
Within the Finnish DuraInt research project (Effect of Interacted Deterioration Parameters on Service Life of Concrete Structures in Cold Environments, 2008 – 2011) laboratory studies on the effect of frost deterioration on chloride penetration and carbonation were performed. After frost testing and internal deterioration, samples were exposed to varying levels of chlorides to determination penetration and the chloride migration coefficient, which showed a clear impact due to frost cracking. Field testing is also on-going to evaluate the effect of frost on chloride penetration and carbonation at highway circumstances in the Nordic climate. The final aim is a more accurate estimation of bridge and infrastructure service life.

Key words: Durability, frost deterioration, chloride penetration, carbonation, interacted deterioration, laboratory testing, field testing.

1. INTRODUCTION

For sustainability assessment it is essential to have reliable knowledge on the actual deterioration mechanisms of concrete. This enables accurate modelling of bridge and infrastructure durability with respect to concrete material selection and service life design. In field performance, concrete is affected by simultaneous exposures. For instance frost deterioration causes cracking and results in increased concrete permeability having an effect on service life.

In the laboratory study of the DuraInt project, one aim was to find out if frost deterioration, i.e. cracking, determined as relative dynamic modulus of elasticity (RDM), will have an effect on chloride penetration and the chloride migration coefficient or carbonation /Leivo et al. 2011/. The more specific aim was to determine if it is possible to include these effects as specific factors in service life models. The way of including these interactions in a service life model by the use of interaction factors is not included here. Verification of interacted deterioration should be by field testing. /Vesikari & Ferreira 2011, Vesikari et al. 2012, Kuosa 2011/.

2 MIXES AND TESTING METHODS

Mixes with mainly low frost resistance were used to get varying levels of frost deterioration.
To determine the effect of frost deterioration on chloride penetration (Testing A), i.e. chloride migration coefficient (D_{nssm}), four concretes with cement type CEM II/A-M(S-LL) 42.5 were prepared. Basic information on these mixes is presented in Table 1. Two of these mixes were also used to determine the effect of frost deterioration on carbonation (Testing B). In addition, several mixes with w/b = 0,65 and cement CEM I 52,5N-SR, with or without blast furnace slag, (BFS) were prepared (Table 1). More detailed information on the fresh and hardened mix properties is presented in the DuraInt project report /Leivo et al. 2011/.

Testing 1)	Short code	w/c	Cement [kg/m³]	Water [kg/m³]	Aggregate [kg/m³]	Fresh concrete air content [%]	Compressive strength at 28d [MPa]
A	Y05A2(I)	0,50	333	165	1938	2,7	45,9
A	Y05A3	0,50	333	170	1899	3,0	54,1
A & B	Y05A2(II)	0,50	333	165	1925	1,0	52,0
A & B	Y065A2	0,65	333	210	1808	0,8	32,9
B	6 mixes with different binding materials	Binding material: CEM I 42,5 - SR or CEM I 42,5 - SR + 50 % BFS Water/(Cement + 0,80 x BFS) = 0,60 Fresh concrete air content = 1,5 - 5,4 % Compressive strength at 28 d = 32,7 - 40,5 MPa (100 mm cubes)					

1) A: effect of frost attack on chloride migration (D_{nssm})
B: effect of frost attack on accelerated carbonation

Table 1 - Basic information on the mixes for the studies on the effect of frost deterioration on A) chloride penetration B) and carbonation.

To introduce different levels of frost deterioration, freeze-thaw testing by the Slab test with water on the specimen surface was used /CEN/TR 15177: 2005/. Internal deterioration was evaluated at certain intervals by RDM as measured by ultrasound. After the desired deterioration level (RDM-value) was reached for a specimen, it was removed from the freeze-thaw testing for further testing (Testing A or B). The aim was to have specimens with RDM-values from less than 30 % to about 95 % for further testing.

When the aim was to determine the effect of frost deterioration on chloride penetration (Testing A), chloride migration testing was started immediately after freeze-thaw testing using the CTH-method /NT Build 492: 1999/. Cores (Ø98 mm; h50 mm) were taken from the freeze-thaw specimens. The upward specimen surface from freeze-thaw testing was selected to be the Cl-side in the chloride migration testing. The migration coefficient (D_{nssm}) was determined for each specimen.

To determine the effect of frost deterioration on carbonation (Testing B), the specimens moved from the freeze-thaw testing to be stored in laboratory conditions at RH 65 % (T= 20 ^{o}C) as long as the weight change was less than 0.2 % in a 24-hour period. The aim was to get an even moisture content in the specimen before the accelerated carbonation at 1 % CO_2 (RH 60 %; T = 20 ^{o}C). Accelerated carbonation was for 56 d. Afterwards the specimen were split and the carbonation depth was determined according to /EN 13295: 2004/. Also some thin sections were prepared to study the effect of the frost deterioration on the near surface cracking and carbonation.

3 TESTING RESULTS AND DISCUSSION

3.1 Effect of frost deterioration on chloride penetration

The chloride migration coefficients (D_{nssm}) for different concretes as a function of RDM are presented in Figure 1. It can be seen that frost deterioration has the tendency to increase D_{nssm}.

For instance, in the case of a high w/c mix (Y065A2; w/c = 0.65), when RDM decreased from 95 % to about 30 %, D_{nssm} increased from 27×10^{-12} m^2/s to 37×10^{-12} m^2/s (37 %). For concrete with some air entrainment (Y05A3; air = 3 %), no frost deterioration was achieved and as expected there was also no increase of D_{nssm}. Though in principle freeze-thaw caused an increase of D_{nssm}, the correlation (R^2) in the testing was not especially high (R^2 = 0.39 – 0.62). This was also expected as RDM was for internal deterioration but for chloride penetration also surface cracking is decisive. The cracking at the surface layer exposed to the chlorides may have been primarily parallel to the surface and thus not so significantly impacting the chloride transport (see Figure 4).

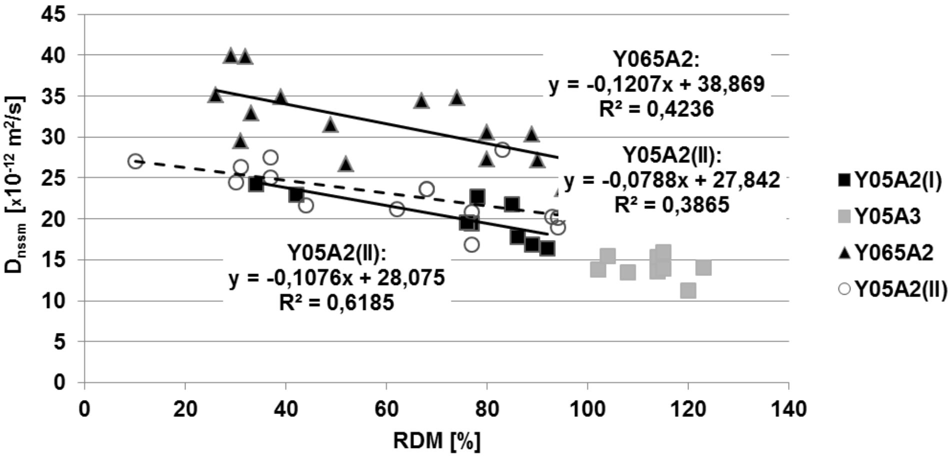


Figure 2 – The effect of internal frost deterioration presented as relative dynamic modulus of elasticity (RDM) on the chloride migration coefficient. /Leivo et. al. 2011/

3.2 Effect of frost deterioration on carbonation

Carbonation depths for different mixes as a function of RDM are presented in Figure 3. It can be seen that frost deterioration can potentially increase carbonation. There was also some correlation (R^2 = 0.58 – 0.74) between RDM and carbonation degree as determined after the frost testing for the mixes with high enough w/b ratio (0.60 – 0.65). For instance when RDM decreased from 95 % to 30 %, surface carbonation increased by 60 % (from 3.5 mm to about 5.5 mm; Y065A2). When there was heavy frost deterioration (RDM < 10 %; w/b = 0.60), also carbonation after frost attack was especially high (increase from about 5 mm to 14 mm).

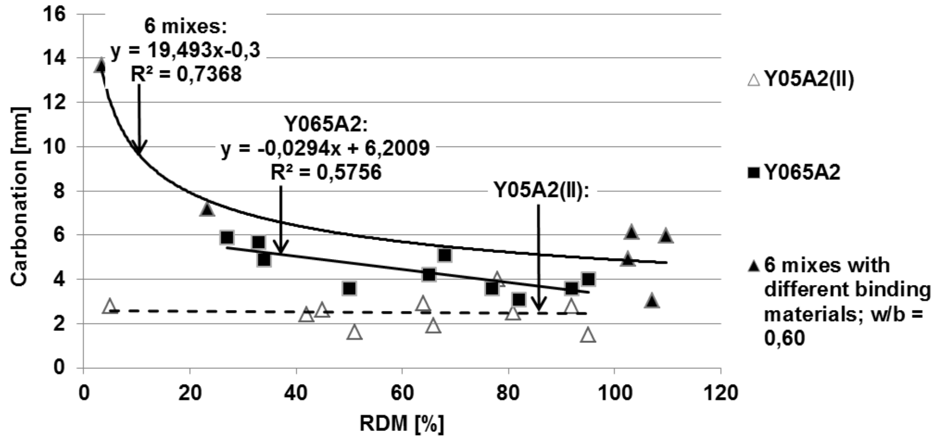
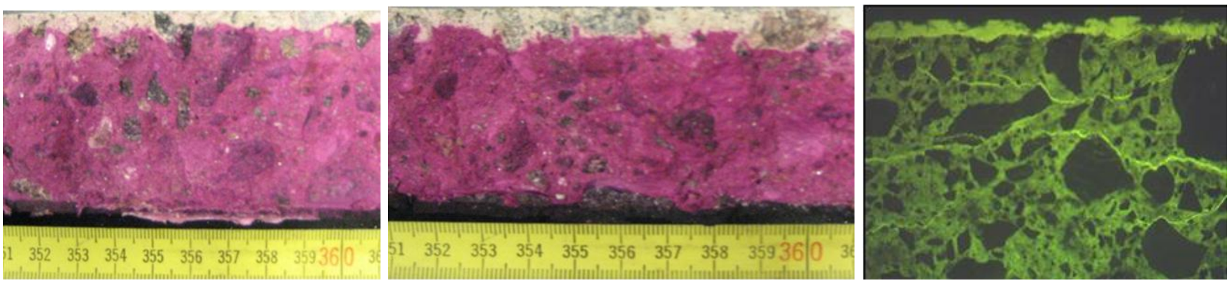


Figure 3 - The effect of internal frost deterioration (measured by RDM) on the depth of carbonation.

Based on the thin section studies, there was surface cracking associated with the measured internal deterioration (RDM) and cracking (Figure 4). This was mainly parallel with the surface. Especially with low w/c mixtures, the effect of this kind of cracking on carbonation is not necessarily heavy. For instance the effect of very low RDM caused by freeze-thaw cracking in the case of mix Y05A2(II) with w/c = 0.50 was not at all detected (Figure 2).



a) b) c)

Figure 4 - Concrete with interacted frost and carbonation attack. Concrete surface is upwards. a) Split concrete specimen; RDM= 0.95 and average carbonation depth after frost attack 4 mm; b) Split concrete specimen; RDM= 0.27 and average carbonation depth after frost attack 6 mm. c) Thin section photo representing about 2.5 mm thick concrete surface layer. Parallel surface cracking is visible in UV-light.

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