RESEARCH REPORT

VTT-R-00482-11

Concrete durability field testing
Field and laboratory results 2007 - 2010 in DuraInt-project

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Summary

This research is a part (*Task 2, Long term field test*) of the project DuraInt (*Deterioration Parameters on Service Life of Concrete Structures in Cold Environments (2008 – 10)*. This report includes field testing results from Autumn 2007 – Spring 2010 and related laboratory testing results for concretes casted in this project.

In the DuraInt project the overall objective was to evaluate the effect of interacted deterioration parameters on the service life of concrete structures. In field testing all interacted deterioration is included - e.g. chloride penetration is interacting with carbonation and frost deterioration. Field testing includes e.g. moisture, salt exposure, temperature and solar radiation variations and effects of carbon dioxide and hydration with time. Field testing results were considered necessary to get relevant information on concrete durability in field conditions. A future aim is to continue with field testing for at least 20 years to be able to use more long term results for calibration and verification of durability and service life models.

Studies on chloride penetration, carbonation and freeze-thaw attack with and without salt (highway de-icing) are included. One testing field is a highway near Kotka (HW 7) and one without de-icing salt exposure in Espoo. The mixes represent mainly prevailing common industrial mixes in Finland. The effective water-to-binder ratio was from 0.39 to 0.60. Over half of the mixes were with the w/b ratio close to 0.42. These were mainly air entrained bridge concretes for the highway testing field. The suitable testing field and testing extent for each concrete mix was defined according to the range of use. Field weather data was also collected as well as data on highway salting.

This report does not include any modelling work, which is included in DuraInt Tasks 4 and 5 (*Deterioration models with interaction and Service life models with interaction*). Here some comparisons and common trends are presented between mix design data, laboratory testing results and field testing results.

It was found that it is possible to get accurate numerical data on frost and frost-salt deterioration (internal deterioration/volume change and scaling), chloride penetration and sheltered carbonation at field-locations.

A documentation database is an essential separate appendix to this report. It includes all the numerical data in Excel-files. Former field testing project results (BTB, CONLIFE and YMPBET) updated during DuraInt project with new field measurement results are included.

Confidentiality	Public

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Preface

This research is a part of the project DuraInt (Deterioration Parameters on Service Life of Concrete Structures in Cold Environments), which began in 2008. The on-going Finnish field testing project Durafield (2007–2010) was then included in DuraInt. In DuraInt the objective was to evaluate the effect of interacted deterioration parameters on the service life of concrete structures. Field testing results were considered necessary to get relevant information on concrete durability in field conditions. Results are needed especially for the verification and calibration of deterioration and service life models. The DuraInt project was funded by TEKES (Finnish Funding Agency for Technology and Innovation) together with Finnish organizations and companies.

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1 INTRODUCTION

Field testing has been proven to be essential in getting relevant data on concrete durability properties. Standard laboratory testing is not a reliable enough way to get data for long term service life modelling. Field testing must be with local materials and it must also meet with local environmental actions. Laboratory testing is also needed in concrete quality control. The best possible correlation with field testing is important and laboratory testing and quality control methods should also be developed to find out reliable ways for securing service life.

Studies on chloride penetration, carbonation and freeze-thaw attack with and without salt were included in the project. One testing field is beside Highway 7 near Kotka (HW 7/E 18) and one without de-icing salt exposure is in Otaniemi, Espoo. The suitable testing field and testing extent for each concrete mix was defined according to the range of use, e.g. façade concretes are not tested for chloride penetration.

Chloride penetration studies included studies on the effect of distance from the highway lane. Laboratory testing of frost and frost-salt attack included studies on the effect of ageing with and without carbonation. Microscopic studies with air pore analysis, i.e. spacing factor and specific surface, are included. Some non-EN-standard testing methods were used. They were:

- non steady state chloride diffusion [NT Build 492]
- carbonation in a high precision climatic chamber (EN 13295 with minor modification),
- Air Void Analysis of fresh concrete (AVA) and
- hardened concrete air content at early time of concrete hardening (generation of testing instructions was during the project [VTT-R-03466-11. 2011]).

This report includes field and laboratory testing results for the concretes casted in

- May 2005 (5 concretes, CEM I 42,5 N – SR) – no field testing.
- August - September 2007 (23 concretes),
- March 2008 (4 concretes) and
- September 2009 (5 concretes).

The effective water-binder ratio (w/b = W_{eff}/(Cement + 2 SF + 0.8 BFS + 0.4 FA) ranged from 0.39 to 0.60, with the majority about 0.42. Concretes with 8 different cements or binding materials were included. Tested 28 d compressive strength was 33 – 64 MPa. Some of the concrete specimen for chloride penetration were tested with surface modification. The effect of hydrophobic impregnation (3 products) and the use of form lining (3 products) on chloride penetration was studied. The effect of copper powder as mixed into the concrete or in a mortar layer covering the concrete surface was also studied.

A documentation database is an essential separate appendage to this report. It includes all the numerical data in Excel sheets to be on hand for any further use. Former field testing project results include for instance results form:

- Swedish BTB-project *(Beständighet Tösaltade Betongkonstruktioner, 1996 - 1998),*
- CONLIFE (*EU 5th Framework project: Life-time Prediction of High-Performance Concrete with Respect to Durability, 2001 - 04*) and
- Finnish YMPBET (*Ympäristöystävälliset ja hyvin säilyvät betonit, Environmentally-friendly and durable concretes, 2002 - 04*).

Updated field measurement results obtained during DuraInt are included in this database together with basic information on these former projects and copies and/or list of the delivered project reports. The documentation database will be kept up non-volatile for decades to serve as a basis for future deterioration and service life modeling and normative or directive work.

This report is the result of DuraInt Task 2 (Long term field test). It does not include any further modeling work, which is included in Tasks 4 and 5 reporting (Deterioration models with interaction and Service life models with interaction).

2 TESTING FIELDS

2.1 General information

DuraInt testing fields for concretes casted after 2007 are in southern Finland (Figure 1)

- beside Highway 7 near the town of Kotka (HW 7 field) and
- in the neighbourhood of Otaniemi, in the town of Espoo (Otaniemi field) .

The Otaniemi and Sodankylä fields are also sample locations for the project YMPBET. The Finnish testing field for CONLIFE-project is located in northern Finland in the town of Sodankylä (Sodankylä field). Samples in these fields were also measured during the DuraInt project. These results are included in DuraInt database, together with the former measurement results for these specimens (see Appendix 23).

In autumn 2009 concrete specimen were also delivered to the highway testing field in Borås, Sweden. In all four concretes compositions and eight specimen mainly for chloride penetration studies were placed at Borås testing field beside highway 40 (Figure 15). Information on this field can be found e.g. in [Utgenannt 2004, Vesikari 2004].

Basic information on Finnish field testing areas is presented in Table 1. Testing field location map and field testing area photos are presented in Figures 1 – 4.

The suitable testing field and testing extent for each DuraInt concrete mix was defined according to the range of use, e.g. façade concretes are not tested for chloride penetration.

Figure 1. Testing fields in Finland and Sweden: Otaniemi, Kotka (HW 7), Sodankylä and Borås (Sweden).

Figure 2. DuraInt field exposure site in an environment without salt in southern Finland (Otaniemi, Espoo).

Figure 3. DuraInt field exposure site in an environment without salt in southern Finland (Otaniemi field, Espoo). Carbonation testing sheltered.

Figure 4. DuraInt field exposure at Highway 7 (HW 7 field, Kotka). Large specimens for chloride penetration are placed on wooden stands. Specimen for frost-salt testing are also on wooden stands, but in metal racks.

Table 1. Basic Finnish field testing area information.

Information, research field	Highway 7, Kotka	Otaniemi, Espoo	Sodankylä
Frost - XF3	-	X	X
Frost-salt (de-icing) – XF4	X	-	-
Carbonation:			
- sheltered outdoors – XC3	-	X	-
- not sheltered outdoors – XC4	(X)[1)]	X	(X)[1)]
Chloride penetration, road environment - XD3 (mainly 4.5 m from road line)	X	-	-
Projects and mix designs to date:			
- DuraInt (2007/08 - 11)	32	27	-
- CONLIFE (2001 - 04)	-	-	22
- YMPBETONI (2001 - 04)	-	19	19
Own meteorological station	X	X	-
Concrete temperature and humidity/RH measurements	X	-	-
Location	N 67°22´ E26°39´	N60°11´ 24°48´	N67°24´ E26°35´
Elevation from sea level [m]	about 20	about 20	179

Temperature information (1971-2000):	for Helsinki, Kaisaniemi (elevation 4 m):	Sodankylä:
-Year average [°C]	+6	-1
- January average[°C]	-4	-14
- June average [°C]	+15	+12
Days in a year, when minimum temperature is below 0°C	169	230
Days in a year, when minimum temperature is below -10 °C	40	111
Relative humidity, year average [%]	79	62
Precipitation, year average [mm]	642	507

1) No specific specimen for monitoring, but can be measured later on.

2.2 Highway field salting, weather data and maintenance

Finland is a sparsely populated country where the road network provides access even to the most remote areas of the country. All highways are kept in good condition day and night, throughout the year. De-icing salt (NaCl) has been used in Finland since the 1950s. The amount of salt spread was the highest in the 1990s. Today salting amounts are about one third of the maximum values.

The need for salting depends on weather conditions. If the temperature is low, approximately below -5°C, salt is not used. In general the roads are also less slippery during very cold temperatures compared with near zero temperatures.

Naturally, if the temperature is above zero and there is no packed snow or ice on the roads, then there is no need to use salt unless the temperature is expected to drop or if snowfall or freezing rain is expected.

The conditions when salt is needed most are the temperatures a few degrees below the freezing point. It was found that warmer than normal weather in November and in March and colder than normal weather in December, January and February will decrease salting. Warm midwinter months mean slippery conditions and thus also much salting. [Venäläinen 2000]

Salting

In HW 7 the de-icing salt used has been mainly sodium chloride (NaCl), which is spread as crystals. Also some $CaCl_2$-solution has been used as a preventive measure (ca 6 % of all salt (dry), has been as 32 % liquid). In the future, after autumn 2010, mainly NaCl-solution will be used instead of $CaCl_2$-solution, as also NaCl is delivered today as a water solution. (Information from YIT Rakennus Oy, Mika Blom 1.11.2011)

In Kotka HW 7 de-icing is used normally between October/November and April. For instance in the first DuraInt winter season salt was spread 11.11.07 – 27.3.2008.

Total amount of salt spread on HW 7 (Kotka) and salting occasions are presented in Table 2. There are two lanes in both directions. All the lanes are salted with a 3 m working width.

The daily average number of vehicles on HW 7 is over 27 000, of which ca 13 % are heavy vehicles. [LAM 2008]

Table 2. Total amount of salt spread on HW 7 (Kotka) and number of salting occasions. Winter seasons 2007 – 2010. Width of salting is 3 m/lane. There are two lanes on both directions.

Winter season	2007-08	2008-09	2009-10
Total amount of salt [kg/m^2]	1.27	1.24	ca 0.65
Number of occasions	165	154	ca 65

As a reference data for Table 2 HW 7 salting information, the average yearly value for salting in Borås HW 40 was 2.2 kg/m^2 for the years 1996 – 99 and 1.2 kg/m^2 for the years 2000 – 03. The corresponding average yearly number of salting occasions was 144 for the years 1996 – 99 and 137 for the years 2000 – 03. The reason for the smaller amount of salt spread at the Borås field after year 1999 than before it (years 2000 – 03) was that the salting was performed by using salt solution after year 1999 instead of salt grains. [Utgenannt 2004, Vesikari 2004]

Weather data

Weather data was delivered from weather station ´Kotka HW 7´. This weather station is beside the Highway testing field in Kotka. Weather data was collected in Excel sheets and will be stored in the DuraInt-database for further exploitation, e.g. for durability modeling. This data includes relative humidity data and dew point temperature data as well as road surface temperature data and information on rain. All the measurements are taken every 6 minute intervals.

- Tables on average, minimum and maximum air temperatures and relative humidities for each month from autumn 2007 to autumn 2010 are presented in Appendix 1 (page 1). Corresponding graphs are also presented in Appendix 1 (page 2).
- Weather data graphs are presented in Appendices 2 and 3. These can be found also in Excel sheets if needed.

- Road surface temperature, including air temperature as reference, for the 1st year (August 2007 – September 08) is presented in Appendix 4.

The number of freeze-thaw cycles from +0°C below specified air temperatures and back to +0°C for each winter season is presented in Table 3.

The first winter (2007-08) was mild in Finland, but with many variations around zero Celsius degrees (see Table 3 and Figure 5). The second (2008-09) winter was closer to the average winter. The third winter (2009-10) was colder than it is normally in southern Finland and there was long periods with temperature constantly below +0°C, i.e. with few freeze-thaw cycles (see Table 3).

Figure 5 presents the average temperatures for each month in the years 2007-2010 in the HW 7 field and also the average temperatures for each month based on long term data (1971 – 2000) in Finland , in Helsinki Kaisaniemi (Southern Finland), Jyväskylä (Central Finland) and Sodankylä (Northern Finland). [Finnish metereological institute 2011]

Table 3. Number of freeze-thaw cycles from +0°C below specified air temperatures and back to +0°C at the Highway testing field. Numbers are based on weather station air temperature data (see Appendix 2).

Temperature cycles (°C)	Winter 2007-08	Winter 2008-09	Winter 2009-10
from +0 to -0... -5 and back to +0	83	80	59
from +0 to -5... -10 and back to +0	19	25	14
from +0 to -10...-15 and back to +0	3	9	8
from +0 to -15...-20 and back to +0	-	3	5
from +0 to -20 ... -25 and back to +0	-	1	4
from +0 to -25...-30 and back to +0	-	-	1
from +0 to -30...-35 and back to +0	-	-	-

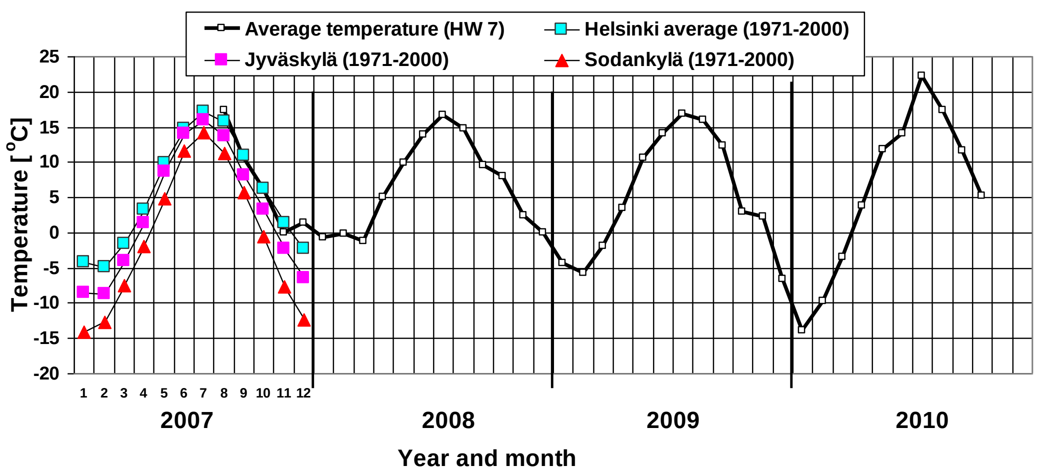


Figure 5. Average temperatures for each month in the years 2007-2010 at HW 7 field and also average temperatures for each month based on long term data (1971 – 2000) in Finland in three different parts of Finland.

Concrete temperature, relative humidity and moisture content

At the HW 7 field there were several concrete specimens for concrete temperature and humidity (RH-%) follow-up (27.6.2008 – 11.8.2010). There are two concrete compositions (w/b-ratio 0.50 and 0.42) and two specimen sizes (300 x 300 x 500 mm^3 and 75 x 150 x 150 mm^3) for these measurements. The data collected in this follow-up is in Excel sheets and will be stored in DuraInt-database for further exploitation. Some general examples are presented in the Appendix 5.

A novel study on the use of optical fibres for measurement of concrete water content profiles (w.-%) and their variation in the concrete specimen with time was also carried out. The results for this study are reported in [Englund 2011]. In this study the same specimen were used as in the concrete temperature and humidity follow-up (see Appendix 5).

HW 7 field maintenance

HW 7 field maintenance was performed to guarantee that salty splash water and water vapour can freely access exposed concrete specimen surfaces. For the frost-salt specimen (150 x 105 x 75 mm^3) it was considered essential that their upper surface was exposed to salt and water. For the chloride penetration specimen (500 x 300 x 300 mm^3) both upper surface and the surface facing to the highway were considered as exposed surfaces and were kept free. Further aim was to avoid water suction through specimen lower surfaces. This was achieved by having all of the specimens on wooden stands. These stands were installed on a gravel bed. In the maintenance it was also considered essential not to damage specimen and their surfaces in anyway.

Main principles in the actual maintenance work were:

- to take care that too much snow did not gather on or beside specimen and their exposed surfaces:
- if specimen were covered by snow, it was removed by careful shovelling and/or brushing to guarantee that no more than 10 mm snow was on the specimen surfaces,
- however, if there was adhered ice on the specimen surfaces it was not hacked off.
- to take care that vegetation does not establish any hindrance for water and salt exposure - mainly this was secured by installing a root carpet and gravel bed under the specimen racks.

Maintenance work was performed by Silta Laksio Oy. This work included reporting of all the maintenance actions and their date. In addition, photographs were delivered from the field at the time of these actions.

2.3 Otaniemi field weather data (2007 – 2010)

The Otaniemi testing field has its own weather station.

All Otaniemi testing field weather data is stored in the DuraInt database. This data includes also data on solar radiation (several solarimeters, also diffuse radiation), air pressure, wind speed. wind direction and daily precipitation.

The Otaniemi testing field was permanently closed January 2011. All the concrete specimen were moved to a new testing field in the neighbourhood of Suomenoja, less than 10 km from Otaniemi and field testing will go on there. This new Southern Finland testing field is also near the Finnish seashore and it is expected that the climate will be essentially identical to the Otaniemi field climate.

3 MATERIALS, CONCRETES AND SPECIMENS

General information

General information on the concretes is presented in Table 4. Detailed concrete composition information on all the concretes together with the casting date and place information is presented in Appendix 6. This information is also in Excel sheets and available in the documentation database.

Concrete mix design, mixing and specimen casting was in three places:

- VTT: VTT - Otaniemi concrete laboratory (18 mixes)
- R: Rudus Oy - Konala concrete mixing plant (15 mixes) and
- P: Parma Oy - Forssa mixing plant for element production (4 mixes).

The mixes represent mainly prevailing common industrial mixes in Finland. The effective water-to-binder ratio (w/b), as defined and presented in Appendix 6 and Figure 6 was from 0.39 to 0.60. Over half of the mixes were with the w/b ratio close to 0.42. These were manly air entrained bridge concretes for the highway testing field. Some of these concretes were intentionally produced without proper air entrainment to study the effect of air entrainment on concrete durability properties. Concretes with higher w/b-ratios were mainly air entrained façade or balcony concretes, or concretes for some specific studies. Fresh concrete air content (measured value) was in all from 1.7 – 7.3 %. About 60 % of the concretes were with 4.0 % – 6.0 % air (Figure 7).

Table 4. Concretes and testing at field and specific testing at laboratory. Concretes cast in 2007 – 2009.

		A	B	C	D	E	G	H	J
		(w/c)eff = Weff/(Cement+2*SF+0,8*BFS+0,4*FA)							
		0,42		**0,50**		**0,60**	"K45" **0.42**	"K50" **0.39**	"K70" **0.43**
Perussementti CEM II/B-S 42,5 N	**1**	i5: Cl+Carb+FS		i5: Cl+Carb+FS		i5: F+Carb			
SR-sementti CEM I 42,5 N - SR	**2**	i5: Cl+Carb+FS							
Yleissementti CEM II/A-M(S-LL) 42,5 N	**3**	i5: Cl+Carb+FS	in all 10 mixes (2 SCC) with different air content: from no air entrainment (2 mixes) to 7% air: Carb(6mixes)+FS(10 mixes)	i5: Cl+Carb+FS	In all 10 cases, i3: Impregnated(1,2&3) & Mould lining(1,2&3) & ref: Cl + Carb & 2009 added mixes (2+one with mortar)	i5: F+Carb			
Valkosementti CEM I 52,5 N	**4**			i5: F+Carb		i5: F+Carb			
Rapidsementti CEM II/A-LL 42,5 R	**5**	i5: Cl+Carb+FS		i5: Cl+Carb+FS+F		i5: F+Carb	i4.5: Cl ("P50")	i 6.8: Cl ("P70")	I2.6: Cl ("P30")
Pikasementti CEM I 52,5 R	**6**	i5: Cl+Carb+FS	i5: Cl+Carb+FS						
Rapid CEM II/A-LL 42,5 R + 50 % Finnsementti SLG KJ400	**7**	i5: Cl+Carb+FS							
Rapid CEM II/A-LL 42,5 R + 24 % FA [EN 450-1. 2005] Fineness N, Class A	**8**	i5: Cl+Carb+FS							
CEM I 42,5 N - SR	**SR1**	i4,5: Cl(lab)							
CEM I 42,5 N - SR	**SR2**			i4,8: Cl(lab)					
CEM I 42,5 N - SR	**SR3**					i6,5: Cl(lab)			
CEM I 42,5 N - SR	**SR4**			i3,5: Cl(lab)					
CEM I 42,5 N - SR +SF	**SR5**			i2,4: Cl(lab)					

Cl: Chloride penetration: Laboratory & Field testing
Carb: Carbonation: Laboratory & Field testing
F: Frost: Laboratory testing (water) + Frost at field
FS: Frost-Salt: Laboratory testing (salt) + Frost-Salt at field

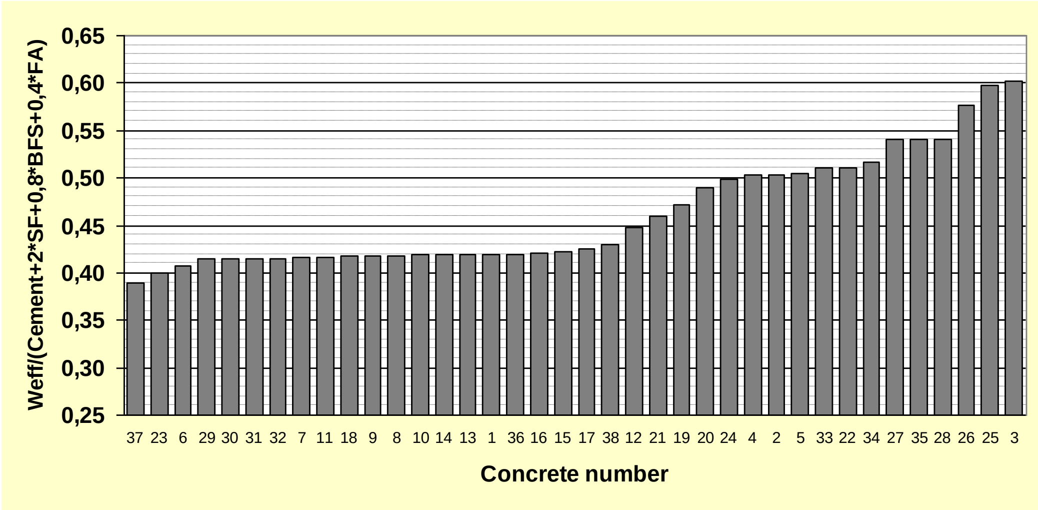


Figure 6. Values for all the DuraInt concrete w/b-ratios.
(w/b =Weff/(Cement+2*SF+0,8*BFS+0,4*FA). More close information is presented in Appendix 6.

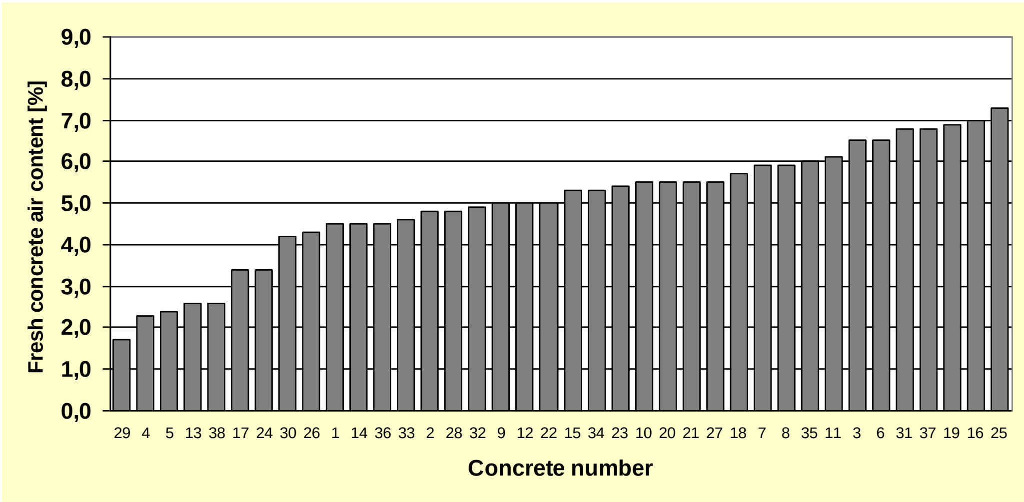


Figure 7. Fresh concrete air content (measured values). More close information is presented in Appendix 6.

<u>Cements and additives</u>

Concretes with different binding materials were produced. Common Finnish cements manufactured by Finnsementti Oy, blast furnace slag (SLG) and fly ash (FA) were used. In one mix silica fume was used, but this concrete was with minor testing and without field testing. Information on the used cements and additives is presented in Table 5 and Table 6. This information was supplied by Finnsementti Oy.

<u>Aggregates</u>

At Rudus Oy and Parma Oy aggregates were those used in normal production at the time of mixing and casting. Aggregates used at VTT were delivered from Rudus Oy (see Appendix 7), but were not necessarily the same as used in Rudus Oy concrete production. The aggregates used at VTT were moist, as also aggregates in concrete production in Rudus Oy and Parma Oy. At VTT all the aggregate grades were first homogenized by mixing in a concrete mixer before moisture content measurement and use in concrete production.

The total aggregate moisture content, as well as moisture absorbed by aggregates, was taken in consideration in batching. The effective water content was calculated. It does not include the water absorbed by aggregates. Rough aggregate grading information for the concretes is given in Appendix 6 (Aggregates <0.125 mm, <0.250 mm and < 4 mm as % of total aggregate content in concrete).

Admixtures

Superplasticizer and air-entraining agent was normally used. Only one concrete was without superplasticizer and one concrete without air-entraining agent. Information on the used admixtures is presented in Table 7.

Table 5. Cements and additives. Autumn 2007 materials. Basic information. Supplied by Finnsementti Oy.

Product Name	Cement/Additive	Type	Chemical composition	Setting time at +20 C [min]	Blaine fineness [m²/kg]	Strength [MPa] 1 d	Strength [MPa] 28 d	SLG (Slag) [%]	Silica [%]	FA (Fly ash) [%]	Limestone [%]
CEM II/B-S 42,5 N Finnsementti Perussementti (Lappeenranta)	CEM II/B-S 42,5 N	Normally hardening blended cement	1)	190	380	10	49	27	0	0	2
CEM I 42,5 N - SR Finnsementti SR-sementti (Lappeenranta)	CEM I 42,5 N - SR	Normally hardening sulphate resistant portland cement	1)	200	330	13	54	0	0	0	1
CEM II/A-M(S-LL) 42,5 N Finnsementti Yleissementti (Parainen)	CEM II/A-M(S-LL) 42,5 N	Normally hardening blended cement	1)	170	380	14	49	7	0	0	6
CEM I 52,5 N Finnsementti Valkosementti (Parainen)	CEM I 52,5 N	White portland cement	1)	110	390	21	75	0	0	0	0
CEM II/A-LL 42,5 R Finnsementti Rapidsementti (Parainen)	CEM II/A-LL 42,5 R	Early strength blended cement	1)	160	440	22	54	1	0	0	6
Finnsementti Pikasementti (Lappeenranta)	CEM I 52,5 R	Very early strength portland cement	1)	150	530	30	58	0	0	0	2
Blast furnace Slag Finnsementti Masuunikuonajauhe (SLG) "KJ400"	SLG	Slag (Specific gravity 2980 kg/m³)	1)		400			100	0	0	0
FA - Fly ash	FA	Fly ash (Specific gravity 2200 kg/m³)	[EN 450-1. 2005] Fineness N, Class A		ca 250			0	0	100	0
Finnsementti Silica (S) "Parmix-silika"	SF	Silica fume (Specific gravity 2300 kg/m³)	Basic material: Silicon dioxide					0	100	0	0

1) See separate Table 6 below.

Table 6. Cements, Blast furnace slag (SLG) and Silica (SF). Chemical composition. Autumn 2007 materials. Information supplied by Finnsementti Oy.

Cement/Binding material	CaO [%]	SiO_2 [%]	Al_2O_3 [%]	Fe_2O_3 [%]	MgO [%]	SO_3 [%]	Na_2O/ K_2O [%]	Free lime [%]	Specific gravity [kg/m^3]	LOI (Loss on ignition) [%]	C_3A [%]
	Average clinker composition June - December 2007					cement	cement	clinker	cement	cement	clinker
CEM II/B-S 42,5 N Finnsementti Perussementti (Lappeenranta)	64	21	4,3	3,0	2,9	3,0	?	2,0	3,04	-	6,5
CEM I 42,5 N - SR Finnsementti SR-sementti (Lappeenranta)	63	21	3,3	4,0	2,9	3,1	0,52/0,43	2,5	3,01	2,2	2,0
CEM II/A-M(S-LL) 42,5 N Finnsementti Yleissementti (Parainen)	65	21	5,2	3,1	2,6	3,1	0,31/1,2	1,8	3,12	-	8,5
CEM I 52,5 N Finnsementti Valkosementti (Parainen)	69	25	2,1	0,3	0,7	2,2	0,19/0,04	?	3,19	0,44	5,0
CEM II/A-LL 42,5 R Finnsementti Rapidsementti (Parainen)	65	21	5,2	3,1	2,6	3,7	0,56/1,2	1,8	3,15	-	8,5
Finnsementti Pikasementti (Lappeenranta)	64	21	4,3	3,0	2,9	3,5	0,6/0,53	2,0	3,10	1,7	6,5
Blast furnace Slag Finnsementti Masuunikuonajauhe (SLG) KJ400	40	34	9,3	-	11	-	0,47/0,47		2,97	-	-
Silica (SF) Finnsementti "Parmix-silika"	Basic material: Silicon dioxide	Specific gravity 2300 kg/m^3	BET fineness 15 - 35 m^2/g	Average grain size ca 0.1 µm							

Table 7. Admixtures. General information.

Supplier and product name	Type	Information
Finnsementti Oy, VB-Parmix	Superplasticizer	Polycarboxylate 1)
Finnsementti Oy, Teho-Parmix	Superplasticizer	Melaminsulfonate 1)
Semtu Oy/BASF, Glenium 51	Superplasticizer	Polycarboxsylate Ether 1)
Finnsementti Oy, Ilma-Parmix	Air-entraining agent	Fatty Acid Soap 1)
Semtu Oy/BASF, Mischöl	Air-entraining agent	Vinsolresin 1)

1) CE-marked [EN 934-2]

Specimen

General information on the specimen casted for laboratory and field testing and their purpose of use is presented in Table 8. More detailed information is presented below in connection with the individual testing procedure information (Chapters 5 – 8).

Table 8. General information on the casted specimen.

Purpose of use	Specimen size	Information	Number per case
Compressive strength	150x150x150 mm^3	Plastic cubes [EN 12390-1]	3
Hardened concrete air content	100x100x500 mm^3	Metal moulds (beams)	1
Thin sections 1) (2/mix)	150x150x150 mm^3	Plastic cubes [EN 12390-1]	2
Carbonation (field and laboratory)	100x100x500 mm^3	Metal moulds, beams	3
Field chloride penetration	300x300x500 mm^3	Testing surfaces with wooden mould (or plywood + mould lining) 2)	2
Laboratory chloride migration [NT Build 492] 2)	ø98 mm, h250 mm or cubes 150x150x150 mm^3 or specimen 300x300x500 mm^3	Plastic tubes or plastic cubes [EN 12390-1] or surface modified specimen (300x300x500 mm^3) and coring afterwards	3
Field frost testing (scaling & internal) 3)	150x150x150 mm^3	Plastic cubes [EN 12390-1]	2
Field frost-salt testing (scaling & internal) 3)	150x150x150 mm^3	Plastic cubes [EN 12390-1]	2
Laboratory frost testing (scaling & internal) 3)	150x150x150 mm^3	Plastic cubes [EN 12390-1]	3+3+3
Laboratory frost-salt testing (scaling & internal) 3)	150x150x150 mm^3	Plastic cubes [EN 12390-1]	3+3+3

1) Are prepared from the same cubes as used for freeze-thaw testing or chloride migration testing (if no freeze-thaw testing)
2) Detailed information below (see Chapter 5)
3) Testing with 3 specimen/case, sawing from cubes (see Chapters 7 and 8)

4 FRESH AND HARDENED CONCRETE PROPERTIES

Fresh concrete properties

All the measured fresh concrete properties are presented in Appendix 8. Fresh concrete measurement was normally done immediately after mixing (about 10 minutes after water addition). In three cases it was later on (about 25 min after water addition).

Always measured fresh concrete properties were:

- workability by
  - Slump test [EN 12350-2] or
  - Slump-flow for self-compacting concrete [EN 12350-8] and
- air content by pressure method [EN 12350-7].

In most cases also fresh concrete density was measured [EN 12350-6]. In some cases fresh concrete temperature was measured.

For most concretes, the air void properties, such as spacing factor and specific surface of air voids, were measured by an Air Void Analyzer (AVA). Also the content of air pores in fresh concrete <2 mm and <0.3 mm measured by AVA is included in many cases. [Wang et al. 2008, Petersen 2009]

Hardened concrete basic properties

The measured hardened concrete basic properties are presented in Appendix 12. They are:

- compressive strength - average of three measurements, with cubes (150 x 150 x 150 mm^3),
- hardened concrete air content at early phase of concrete hardening (method of measurement is presented in Appendix 10) [VTT-R-03466-11],
  - which means measurement of concrete air content within a few days after specimen casting. Water pressure is applied to impregnate all the air pores with water
- hardened concrete air void parameters by thin section analysis (method of measurement is presented in Appendix 9) [VTT TEST R003-00] and
- hardened concrete microstructure by thin section analysis.

For hardened concrete microstructure analysis, petrographic thin sections were prepared. A thin section consists of a thin slice of concrete impregnated with fluorescent epoxy, glued to an objective glass and protected by a cover glass. Fluorescent epoxy penetration is achieved through application of a vacuum to assist epoxy impregnation. The thickness required for analysis of cement-based material is ca 25 µm. The final size of a thin section is 35 mm x 55 mm x 25 µm. [NT BUILD 361. 1999] Thin-sections were studied using a Leica DM LP polarization and fluorescence microscope.

Thin section micrographs and some observations are presented in Appendix 11. These photos are only examples, as they represent only a limited area of the whole thin section area (< 0.1%). All the thin sections (2/concrete) are available for more studies when needed. For example, field concrete microstructure after several years exposure (10 – 20 years) can be compared with the initial microstructure.

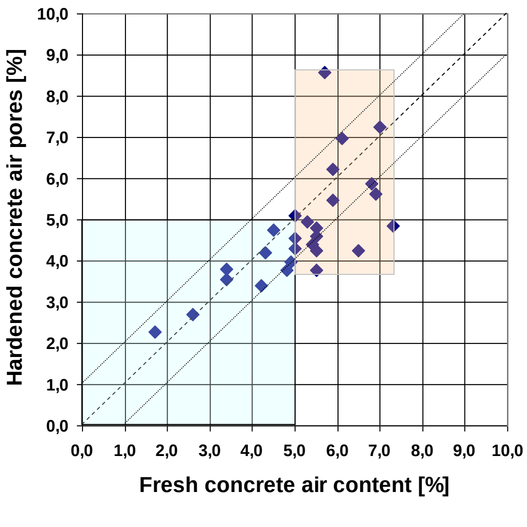
Analysis of air void parameters by thin section is a method to analyse hardened concrete air void parameters for air pores d = 0,020 - 0,800 mm (d = traverse length in thin section analysis plane) as specified in [VTT TEST R003-00]. These results are presented in Appendix 12.

It should be noted here, that ASTM C457 spacing factor is not exactly the same as values presented in this report using the VTT-TEST R003-00 spacing factor. This is because of different limits for the pores in the analysis and calculations. Typically VTT-TEST R003-00 spacing factor is somewhat smaller than ASTM C457 spacing factor, if compaction pores (>0.800 mm) are included in ASTM C457 spacing factor calculation and it is assumed, that pores <0.020 mm do not exist or are not covered. In VTT-TEST R003-00 only air pores 0.020 – 0.800 (linear traverse length) are counted when calculating the spacing factor.

In Figure 8A hardened concrete total air content is presented as a function of fresh concrete air content. Normally the differences are smaller than ±1 % air. If the air content was less than 4 - 5%, there was good correlation. With over 5% air content there were also bigger differences. One reason for this may be differences in compaction. Beams (100 x 100 x 500 mm^3) were prepared for hardened concrete air content measurement. Fresh concrete air content was measured by the pressure method [EN 12350-7]. Especially when the Slump-value was low, fresh concrete air content was higher than hardened concrete air content (see Figure 8B). Perhaps, for low Slump-value concretes, compaction in the air content measurement was not as good as in beam preparation.

In Figure 9 the hardened concrete spacing factor is presented as a function of the AVA spacing factor. In general, spacing factors are relatively high. For instance, if the AVA spacing factor for fresh concrete was <0.25 mm, then the hardened concrete spacing factor was <0.30 mm. If the AVA spacing factor was <0.40 mm, the hardened concrete spacing factor was <0.50 mm.

In Figure 10 AVA (fresh concrete) or thin section (hardened concrete) spacing factor is presented as a function of fresh concrete total air content. In Figure 11 the thin section spacing factor is presented as a function of the fresh or hardened concrete total air content. It can be seen that spacing factor variation was in wide in all cases. It can also be seen that the spacing factor was here in general relatively high compared the with total air content. This means that in some concretes the content of compaction pores was high or protective air pores were relatively big, i.e. the specific surface area was small. In Figure 12 the thin section spacing factor is presented as a function of the specific surface area of the pores (here pores <0.800 mm).



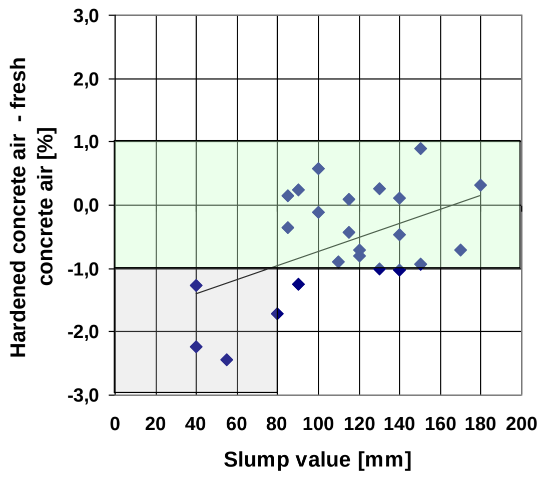


Figure 8. Concretes nos. 6 – 32. A) Hardened concrete total air content as a function of fresh concrete air content. B) Difference in air content for hardened and fresh concrete as a function of Slump-value.

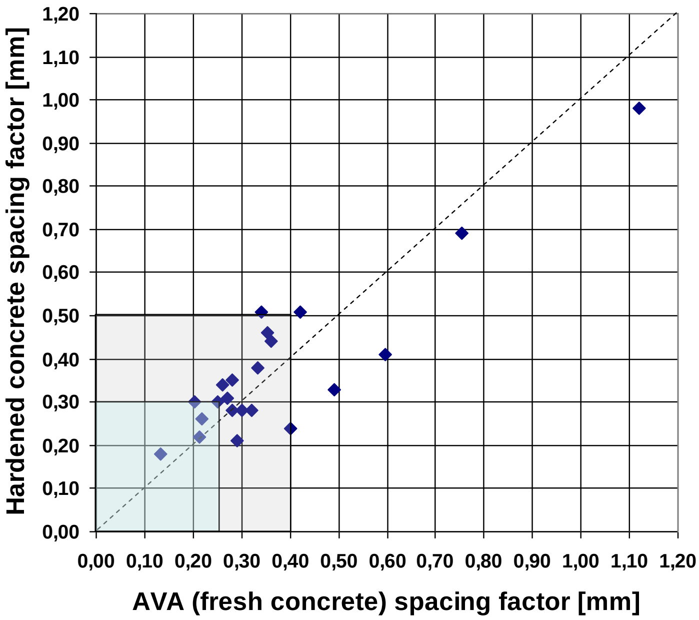


Figure 9. Concretes nos. 6 – 32**.** Hardened concrete spacing factor [VTT TEST R003-00] as a function of fresh concrete AVA spacing factor.

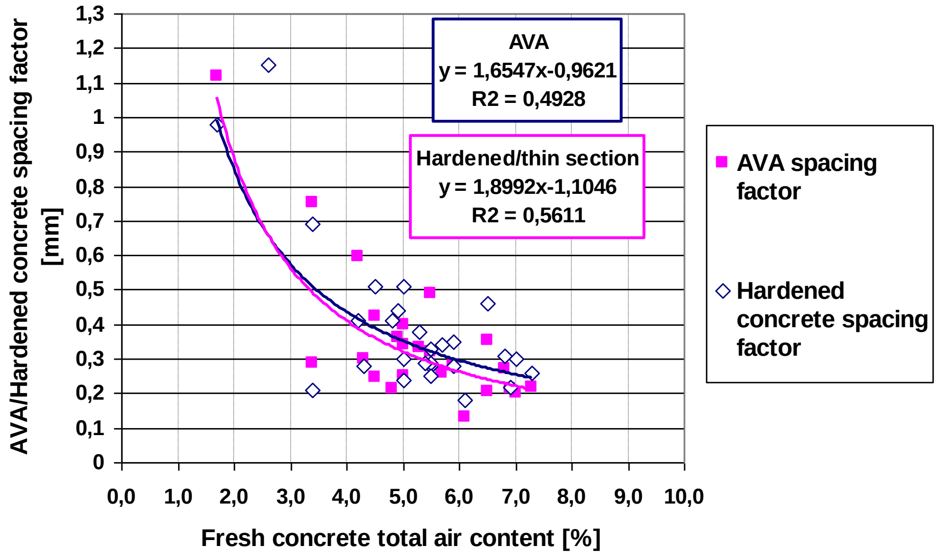


Figure 10. AVA (fresh concrete, pores > 2 mm) or thin section (hardened concrete, pores > 0.800 mm) spacing factor as a function of fresh concrete total air content.

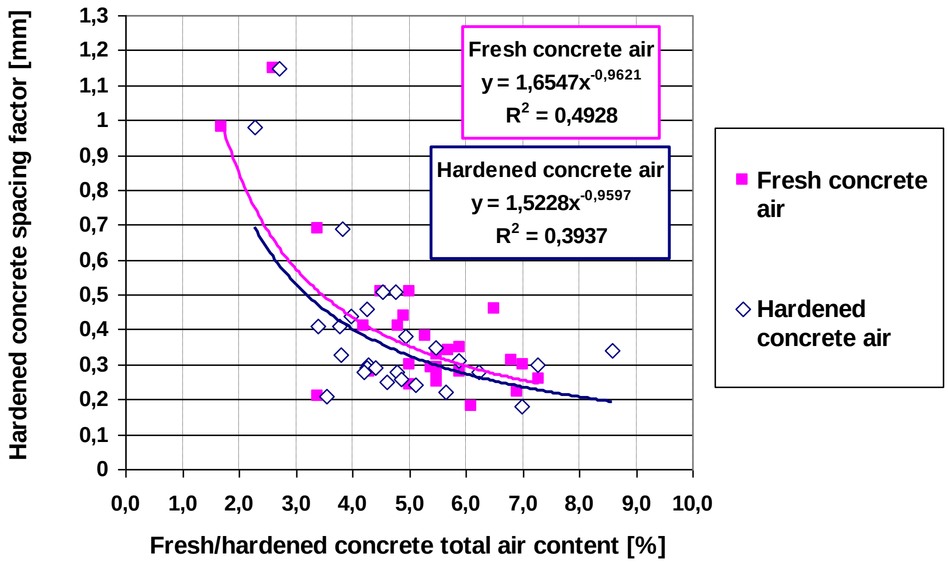


Figure 11. Thin section spacing factor as a function of fresh or hardened concrete total air content.

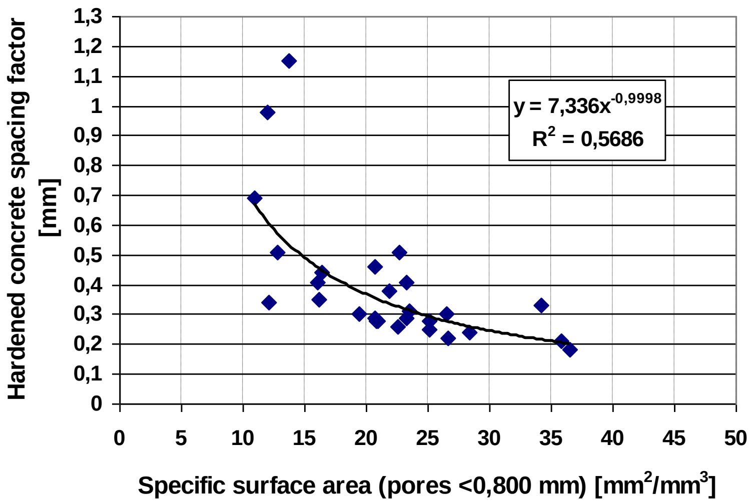


Figure 12. Thin section spacing factor as a function of specific surface area of pores (<0,800 mm).

5 CHLORIDE PENETRATION STUDIES

5.1 General

The aim for the test series was to get field testing data and laboratory testing results on the effect of binding material, w/b ratio, air content and specific concrete surface treatments (impregnation, form lining, Cu-mortar) on the chloride penetration. Also the effect of distance from the road on chloride penetration was studied.

5.2 Testing methods

<u>Field chloride profiles</u>

Field specimen (300 x 300 x 500 mm^3) were cast in an upright position, i.e. one final end surface upwards, as presented in Figure 13. The final testing surfaces, i.e. the surfaces (300 x 500 mm^2) facing to the Highway and upward were normally wooden mould surfaces. When mould lining was used (3 mould linings), these surfaces were plywood surfaces covered by the mould lining. In one case the testing surfaces were covered by a mortar (´Copper-mortar´).

Field specimen for chloride penetration studies are situated at a highway field (Kotka) mainly at a distance of 4.5 m from the road lane on wooden stands (300 x 300 x 500 mm^3, 2/concrete; Figure 14 A). For some parallel specimen (2 concretes) this exposure distance is also 6 m, 8 m and 10 m (Figure 14 B). Four concretes are at the Borås testing field in Sweden (Figure 15).

Field specimens are labelled with an acid-proof steel label. This label includes the concrete ´Short code´ (see Appendix 6) and specimen number. The label is embedded in the casting end surface. This surface is always aligned towards the right hand end surface when looking at the highway behind the specimen. In this way it is ensured that the testing surfaces face towards the highway, and on the other hand the side facing upwards, will remain as the same surfaces.

For chloride analysis cylinders (ø 100 mm, h >100 mm) were cored from the field specimen. Powder samples were taken from these cylinders for chloride content analyses by a profile grinding method and by dry-slicing and by grinding the slices afterwards (Figure 16). Over 6 mm surface layer was always sampled by profile grinding to get small enough steps for Cl-profile at the surface layer. This means, that chloride contents at 0.5 mm, 1.5 mm, 3.0 mm and 5.0 mm are those representing profile grinded powder samples. In 2008 profile grinding was used in many cases also deeper in concrete. The created core holes in field specimen were patched with air entrained concrete before moving them back to the testing field.

Chloride profiles have so far been created after the 1st (2007-08 or 2009-10) and mostly also after the 3rd (2009 – 10) winter season. After the 2nd winter season no profiles were created. The chloride profiles represent the vertical surfaces facing to the highway. Later on it will also be possible to study the surfaces facing upwards. The powder samples´ total chloride content was measured according to [EN 14629]. In some specific cases water soluble chloride content was measured according to [RILEM TC 178-TMC. 2002], but these results are not presented here [VTT:n Tutkimusraportti VTT-R-07974-10, 2010].

<u>Chloride migration coefficient [NT Build 492]</u>

In the laboratory specimens, the chloride migration coefficients (D_{nssm}) were measured at 3 months of age by the so called CTH-method [NT Build 492] (Figure 17). Normally cylinders (ø98 mm, h250 mm) or cubes (150 x 150 x 150 mm^3) were cast for this testing. The final specimen (ø98 mm, h50 mm, 3/case) for chloride migration testing were sawn or cored and sawn according to [NT Build 492]. The surface facing to the Cl-side at the testing cell was normally the original vertical middle plane in the cast specimen. For surface modified specimens, and also for the reference in this case, this surface was the modified surface or the wood mould surface, i.e. the reference surface.

<u>Round Robin testing of rapid chloride migration test</u>

VTT took part in European Round Robin testing of the rapid chloride migration test in 2009. It was led by Joost Gulikers. Centre for Infrastructure, Ministry of Transport, Public Works and Water Management, Utrecht – The Netherlands)In all 23 European laboratories were involved. [Gulikers 2011]

Figure 13. Casting of field specimen for field chloride penetration studies at Rudus Oy.

A B

Figure 14. Specimen for chloride penetration studies at HW 7 field in Southern Finland (Kotka). A) At a distance of 4.5 m from the road lane. B) At a distance of 6 m, 8 m and 10 m from the road lane.

Figure 15. DuraInt specimen in Swedish testing field in Borås (2009).

A

B

Figure 16. A) Profile grinding of a core (ø100 mm), which has been cored from a field specimen. B) Dry-slicing.

Figure 17. Measurement of chloride migration coefficient (D_{nssm}) [NT Build 492].

5.3 Concretes and timing

The casting date and also the date for field testing start-up and the date and age of the first de-icing salting is presented in Appendix 13. The concretes for field chloride penetration studies are listed also below in Table 9. There are some concretes with only laboratory testing of chloride migration coefficient.

Table 9. Casting date, the date for field testing start-up and the date and age for first de-icing salting. This table does not include concretes nos. 1 – 5 with only laboratory testing (see below and Appendix 13).

Number	Casting place	Casting date	Short code	Cement/Binding material type	Weff/(Cement+2*SF+0,8*BFS+0,4*FA)	Specimen (300x300x500 mm^3)		1st salting	
						Demoulding and to field/outdoors	Surface treatment	Date	Age about [months]
6	VTT	12.9.07	1A	CEM II/B-S 42,5 N	0,41	10.10.07		11.11.07	2,0
7	R	16.8.07	2A	CEM I 42,5 N - SR	0,42	6.9.07		11.11.07	2,9
8	R	14.8.07	3A	CEM II/A-M(S-LL) 42,5 N	0,42	6.9.09		11.11.07	3,0
9	R	14.8.07	5A	CEM II/A-LL 42,5 R	0,42	6.9.09		11.11.07	3,0
10	VTT	20.8.07	6A	CEM I 52,5 R	0,42	13.9.07		11.11.07	2,8
11	VTT	11.9.07	7A	CEM II/A-LL 42,5 R & Finnsementti SLG KJ400	0,42	10.10.07		11.11.07	2,0
12	R	6.9.07	8A	CEM II/A-LL 42,5 R & FA [EN 450-1. 2005] Fineness N, Class A	0,45	27.9.07		11.11.07	2,2
19	VTT	13.9.07	1C	CEM II/A-M(S-LL) 42,5 N	0,42	10.10.07		11.11.07	2,0
20	R	23.8.07	3C	CEM II/A-M(S-LL) 42,5 N	0,42	13.9.07		11.11.07	2,7
22	R	28.8.07	5C	CEM II/A-LL 42,5 R	0,51	20.9.07		11.11.07	2,5
23	P	18.9.07	6C	CEM I 52,5 R	0,40	10.10.07		11.11.07	1,8
24	R	24.8.07	3D	CEM II/A-M(S-LL) 42,5 N	0,50	13.9.07	24.9.07	11.11.07	2,6
33	VTT	16.9.09	3Db-REF	CEM II/A-M(S-LL) 42,5 N	0,51	28.11.09			1,9
34	VTT	17.9.09	3Db -Cu	CEM II/A-M(S-LL) 42,5 N	0,52	28.11.09			1,8
35	VTT	2.10.09	Cu-mortar	CEM II/A-M(S-LL) 42,5 N	0,54	28.11.09			1,0
36	R	22.9.09	5G	CEM II/A-LL 42,5 R	0,42	28.11.09			1,7
37	R	22.9.09	5H	CEM II/A-LL 42,5 R	0,39	28.11.09			1,7
38	R	22.9.09	5J	CEM II/A-LL 42,5 R	0,43	28.11.09			1,7

Below the concretes/binding materials are listed according to the w/b ratio and with some additional information on the testing. The w/b here is the planned w/b, but this can be somewhat different, especially for factory produced mixes, than the final w/b, which is based on the factory weighing report. The final w/b can be found e.g. in Appendix 6 and is used later on, if e.g. testing results are compared with w/b.

<u>Binding materials and concretes with about w/b 0.42:</u>

- Perussementti CEM II/B-S 42,5 N (No. 6)
- SR-sementti CEM I 42,5 N – SR (only testing at laboratory) (No. 7)
- Yleissementti CEM II/A-M(S-LL) 42,5 N (No. 8)
    - also specimen with different distances from road side
- Rapidsementti CEM II/A-LL 42,5 R (No. 9)
    - also specimen with different distances from road side
- Pikasementti CEM I 52,5 R (2 different mixes/different producers) (Nos 10 and 23)
- Rapid CEM II/A-LL 42,5 R + 50 % Finnsementti SLG KJ400 (No. 11)
- Rapid CEM II/A-LL 42,5 R + 24 % FA [EN 450-1. 2005] Fineness N, Class A (No. 12)
- CEM I 42,5 N – SR (only testing at laboratory) (No. 1)

With Rapidsementti CEM II/A-LL 42,5 R three (3) concretes (year 2009)

- with w/b: 0.42, 0.39 and 0.43 and with air content: 4.5 %, 6.8 % and 2.6 % (Nos 36, 37 and 38)

All of these three concretes were delivered also to the Borås testing field (Sweden, year 2009).

Binding materials and concretes with about w/b 0.50 (one with w/b 0.60) are:

- Perussementti CEM II/B-S 42,5 N (No. 19)
- Yleissementti CEM II/A-M(S-LL) 42,5 N (No. 20)
- Rapidsementti CEM II/A-LL 42,5 R (No. 22)
- SR-sementti CEM I 42,5 N – SR (only testing at laboratory):
    - air 4.8 % (No. 2)
    - w/b 0.60, air 6.5 % (No. 3)
    - air 3.5 % (No. 4)
    - with SF, air 2.4 % (No. 5)
- With Yleissementti CEM II/A-M(S-LL) 42,5 N also field specimen and laboratory studies with 3 form liners and with 3 impregnations and reference were made. One concrete batch (No. 24) was made at Rudus Oy for these studies and specimen.
- With Yleissementti CEM II/A-M(S-LL) 42,5 N two more concretes were prepared in autumn 2009 for a ´Cu-study´. In this study the goal was to determine, if copper powder can diminish chloride penetration in field by reacting with it. One concrete was produced with fine copper powder and one was without (i.e. reference). Also, the reference concrete without copper powder was used in a field specimen as a separate Cu-mortar layer:
  (No. 33 (ref))
  (No. 34 (Cu-concrete))
  (No. 35 (with Cu-mortar))
    - reference concrete (No. 33) was delivered also to the Borås testing field (Sweden, year 2009)

5.4 Results

Results for chloride migration coefficients (D_{nssm}, laboratory specimen, age 3 months, [NT Build 492]) are presented in Table 10. Field chloride contents after 1 and 3 winter seasons at selected depths (1.5 mm, 5.0 mm and after 3 winters also 7.3 mm) from the specimen surfaces are also presented. For the specimen with 3 winter seasons also the depths for chloride content 0.2 % of cement and 0.3 % of cement are presented, if the specified chloride level has been reached (see also Figure 32).

All the chloride contents are presented in Appendices 14 and 15. These values are the measured values [% of concrete] and the calculated values [% of cement/binding material].

In the calculation the values [% of cement] it is expected, that water amount included in at 105 ^{o}C dried cement gel is 25 % of cement weight. All weights and ingredient amounts (aggregate, cement/binding material and total effective water) are taken to be as in 1 m^3 of mixed concrete (see Appendix 8). Hydration degree is here estimated to be mainly 90 %, but 85 % for concretes including separately added slag (SLG) or fly ash (FA), i.e. mixes nos. 11 and 12. Here hydration degree is estimated to be the same at after ca 1 year and ca 3 year hydration. This means, that hydration degree does not play any role in the calculation of chloride content [% of cement] based on the measured chloride content [% of concrete].

Concrete dry weight is calculated to be:

$$G = A + C + 0.25\ H\ C \tag{1}$$

where G is concrete dry weight (105 °C) [kg/m^3],
A is aggregate amount [kg/m^3],
C is cement amount (or binding material amount) [kg/m^3],
H is hydration degree and
0.25 H C is the non evaporable (105 °C) water content in cement gel.

When [Cl] is the measured chloride content [% of concrete], the below equation must be fulfilled, when X is the chloride content [% of cement]:

$$([Cl]/100)\ (A+C+0.25\ H\ C)=(X/100)\ C \tag{2}$$

Then the chloride content [% of cement] is:

$$X = [Cl](A+C+0.25\ H\ C)/C \tag{3}$$

Thus, to get the chloride content [% of cement], the chloride content [% of concrete] is here multiplied by (A+C+0.25 H C)/C.

Chloride content [% of cement] can also be calculated based on the binding material content and average concrete dry density (e.g. 2400 kg/m^3). Chloride contents [% of concrete] are presented in Appendices 14 and 15. By this way chloride content as % of cement will be 4 – 10 % higher (average 7 %).

Figure 18 shows the chloride migration coefficient (D_{nssm}) [NT Build 492] measured at 3 months age for concretes with different cements and binding materials, when w/b ratio is 0.42 - 0.45 (mainly about 0.42). Figure 19 shows the migration coefficient when the w/b ratio is 0.47 – 0.60. Figure 20 shows the migration coefficient for 2009 cast concretes with w/b 0.39 – 0.43. Figure 21 shows the chloride migration coefficient (D_{nssm}) [NT Build 492] for 2009 cast reference concrete with w/b 0.51 and a concrete with copper powder and a mortar with copper powder.

Figures 18 – 21 also include information on w/b ratio and fresh concrete air content.

Figure 22 shows the surface treated specimens and reference specimen right after coring of three smaller specimens (ø98 mm) per each for laboratory measurement of migration coefficients. In this study the surface was the Cl-solution side during testing [NT Build 492].

Figure 23 shows the chloride migration coefficient (D_{nssm}) [NT Build 492] measured at 3 months age for the surface treated specimen (impregnation or form lining) at 3 months age. The value for the reference specimen is also included.

In Figures 24 – 31 the chloride ingress is presented as chloride profiles after one (2007-08 or 2009-10) and for the most cases (2007 casted specimen) also after three (2007-10) winter seasons. Numerical values for all the chloride profiles [% of cement] are presented in Appendices 14 and 15.

The chloride profiles with different binding materials and w/b ratios are presented in Figures 24 and 25). Calculated average base chloride content and standard variation for it are also presented (red lines and dash lines).

Profiles for field specimen with impregnations (3 different cases/impregnations) or with the use of form lining (3 cases) including reference for these are presented in Figures 26 and 27.

In Figures 28 and 29 are the chloride profiles for specimen with varying distance from road line side (4 distances, 2 mixes).

In Figure 30 are the results for the specimen cast in year 2009 with w/b 0.42, 0.39 and 0.43. These mixes have different air contents (4.5 %, 6.8 % and 2.6 %). Results after the first winter season 2007-08 for two mixes (nos 9 and 22) with the same cement and with w/b 0.42 and 0.50, both with 5.0 % air content, are also included in this Figure 30.

In Figure 31 are chloride profiles for year 2009 cast special cases with added Cu-powder, with Cu-mortar layer and reference.

Reference concrete (no 33), and also in 2009 cast three concretes with w/b 0.39 – 0.42 (nos 36 – 38) in Figure 30, were delivered 2009 also to Borås testing field in Sweden, but have not yet been tested. The idea is to compare results obtained at the Finnish and Swedish highway testing fields after some years.

In Figure 31, results after the first winter season 2007-08 for the reference mix (no 24, 3D) with the same cement and with about the same w/b (0.50 vs. 0.51) as for year 2009 reference (no. 33, 3Db), are also included. Air content is slightly lower for the year 2007 reference than for the year 2009 reference (3.4 % vs. 4.6 %).

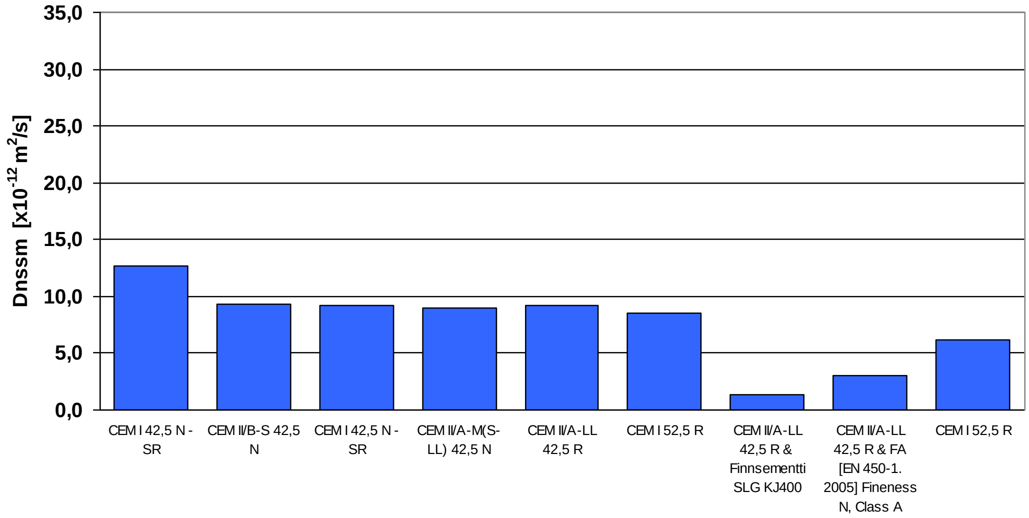
The standard deviation for chloride content [% of cement] was ca 0.017 %. The base chloride content was ca 0.076 % of cement in year 2007 and ca 0.056 % of cement when tested in year 2010. The reason for this small difference is unknown (see Figures 20 and 21). This difference was in spite of the testing being calibrated as usual.

In Figure 32 the chloride penetration depths for chloride content 0.2 % of cement and 0.3 % of cement is presented after 3 winter seasons. These chloride contents were selected just to get penetration depths for this comparison (no critical depth/value). If there is no value, it means that chloride content was below the specified value at all depths.

Table 10. Chloride migration coefficients (D_{nssm}, laboratory specimen, age 3 months, [NT Build 492]) and field specimen chloride contents at selected depths from the specimen surface after the 1st and 3rd winter season. For the specimen with 3 winter seasons also the depth for chloride content 0.2 % of cement and 0.3 % of cement is presented, if this chloride level has been reached (Figure 32 and Figures 24 – 27).

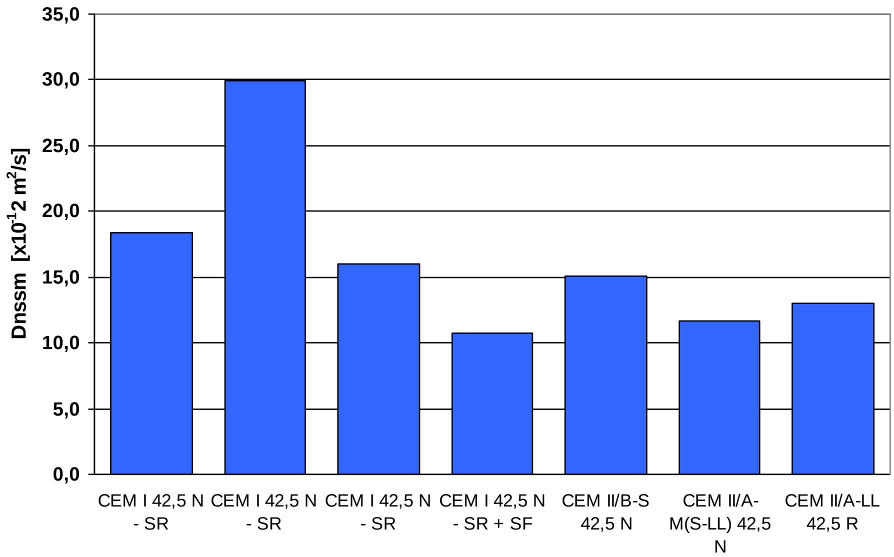
									Cl-content [w.-% of cement]					Depth [mm]	
						Chloride migration coefficient [NT Build 492]			After 1st winter season (2007-08)		After 3rd winter season (2009-10)				
w/b	Number	Casting place	Casting date	Short code[1]	Cement/Binding material type	Age [month]	Dnssm average[x10-12 m2/s]	Dnssm stdev	at 1.5 mm, 1 winter, 2007-08	at 5.0 mm, 1 winter, 2007-08	at 1.5 mm, 3 winters, 2007-10	at 5.0 mm, 3 winters, 2007-10	at ca 7.3 mm, 3 winters, 2007-10	Depth [mm] for Cl = 0,2 % of cement	Depth [mm] for for Cl = 0,3 % of cement
0,42	1	VTT	25.5.07	SR1	CEM I 42,5 N - SR	3,2	12,7	1,3	No field specimen						
0,50	2	VTT	25.5.07	SR2	CEM I 42,5 N - SR	3,1	18,4	0,8							
0,60	3	VTT	28.5.07	SR3	CEM I 42,5 N - SR	3,0	29,9	0,0							
0,50	4	VTT	28.5.07	SR4	CEM I 42,5 N - SR	3,1	16,0	1,8							
0,50	5	VTT	28.5.07	SR5	CEM I 42,5 N - SR + SF	3,2	10,7	1,3							
0,41	6	VTT	12.9.07	1A	CEM II/B-S 42,5 N	3,1	9,3	0,7	0,290	0,168	0,266	0,122	0,073	3,50	1,20
0,42	7	R	16.8.07	2A	CEM I 42,5 N - SR	3,2	9,2	0,0	0,264	0,147	0,264	0,188	0,110	4,80	
0,42	8	R	14.8.07	3A - 4.5 m	CEM II/A-M(S-LL) 42,5 N	3,1	8,9	0,4	0,185	0,145	0,277	0,136	0,083	2,80	
				3A 3 - 6 m					0,138	0,080	0,042	0,037	0,055		
				3A 5 - 8 m					0,080	0,084	0,083	0,083	0,054		
				3A 7 - 10 m					0,079	0,065	0,042	0,031	0,053		
0,42	9	R	14.8.07	5A (4.5 m)	CEM II/A-LL 42,5 R	3,1	9,2	0,0	0,215	0,171	0,226	0,183	0,114	4,50	
				5A3 - 6 m					0,072	0,104	0,066	0,077	0,083		
				5A 5 - 8 m					0,094	0,096	0,072	0,033	0,068		
				5A 7 - 10 m					0,100	0,073	0,061	0,028	0,075		
0,42	10	VTT	20.8.07	6A	CEM I 52,5 R	3,1	8,5	0,3	0,286	0,124	0,254	0,135	0,091	2,40	
0,42	11	VTT	11.9.07	7A	CEM II/A-LL 42,5 R & Finnsementti SLG KJ400	3,1	1,4	0,2	0,317	0,109	0,462	0,171	0,110	4,60	3,40
0,45	12	R	6.9.07	8A	CEM II/A-LL 42,5 R & FA [EN 450-1. 2005] Fineness N, Class A	3,2	3,0	0,2	0,230	0,136	0,395	0,200	0,130	5,20	3,30
0,47	19	VTT	13.9.07	1C	CEM II/B-S 42,5 N	3,2	15,1	1,0	0,349	0,195	0,453	0,328	0,116	6,70	4,50
0,49	20	R	23.8.07	3C	CEM II/A-M(S-LL) 42,5 N	3,0	11,7	0,5	0,257	0,226	0,298	0,298	0,202	7,20	
0,51	22	R	28.8.07	5C	CEM II/A-LL 42,5 R	3,5	13,0	1,1	0,354	0,221	0,400	0,227	0,134	5,70	3,00
0,40	23	P	18.9.07	6C	CEM I 52,5 R	3,0	6,2	0,5	0,252	0,130	0,303	0,207	0,119	5,20	1,70
0,50	24	R	24.8.07	3D 3 - impregnation		3,1	11,0	0,6	0,111	0,067	0,187	0,048	0,053	1,50	0,70
0,50				3D 6 - impregnation		3,2	12,2	0,5	0,126	0,106	0,104	0,062	0,058		
0,50				3D 9 - impregnation		3,2	12,7	0,5	0,138	0,116	0,118	0,062	0,058		
0,50				3D 12 - form lining		3,2	12,7	0,0	0,187	0,163	0,214	0,097	0,094	1,70	
0,50				3D 15 - form lining		3,4	13,0	1,8	0,193	0,126	0,325	0,221	0,108	5,50	3,00
0,50				3D 18 - form lining		3,4	14,2	1,3	0,241	0,131	0,249	0,145	0,117	2,20	0,80
0,50				3D reference	CEM II/A-M(S-LL) 42,5 N	3,0	20,2	1,0	0,246	0,222	0,367	0,318	0,214	8,50	6,00
									After 1st winter season (2009-10)						
									at 1.5 mm, 1 winter, 2009-10	at 5.0 mm, 1 winter, 2009-10					
0,51	33	VTT	16.9.09	3Db-REF	CEM II/A-M(S-LL) 42,5 N	2,8	13,8	1,4	0,183	0,251	No results yet after 1st winter season (2009-10) results				
0,52	34	VTT	17.9.09	3Db -Cu	CEM II/A-M(S-LL) 42,5 N	2,8	12,5	1,0	0,094	0,189					
0,54	35	VTT	2.10.09	Cu-mortar	CEM II/A-M(S-LL) 42,5 N	3,4	13,6	1,2	0,000	0,182					
0,42	36	R	22.9.09	5G	CEM II/A-LL 42,5 R	2,8	7,9	1,2	0,167	0,113					
0,39	37	R	22.9.09	5H	CEM II/A-LL 42,5 R	2,8	7,3	0,9	0,165	0,110					
0,43	38	R	22.9.09	5J	CEM II/A-LL 42,5 R	2,8	8,0	0,1	0,205	0,146					

1) Distance from road line is normally 4.5. m (for 3A and 5A there are 3 additional distances)



w/b = 0.42 0.41 0.42 0.42 0.42 0.42 0.42 0.45 0.40
air = 4.5 % 6.5 % 5.9 % 5.9 % 5.0 % 5.5 % 6.1 % 5.0 % 5.4 %

Figure 18. Chloride migration coefficient [NT Build 492] measured after 3 months at RH 95 % humidity room (for concretes with different cements and binding materials, when w/b ratio is 0.42 - 0.45 (mainly about 0.42).



w/b = 0.50 0.60 0.50 0.50 0.47 0.49 0.51
air = 4.8 % 6.5 % 2.3 % 2.4 % 6.9 % 5.5 % 5.0 %

Figure 19. Chloride migration coefficient [NT Build 492] measured after 3 months at RH 95 % humidity room for concretes with different cements and binding materials, when w/b ratio is 0.47 – 0.60.

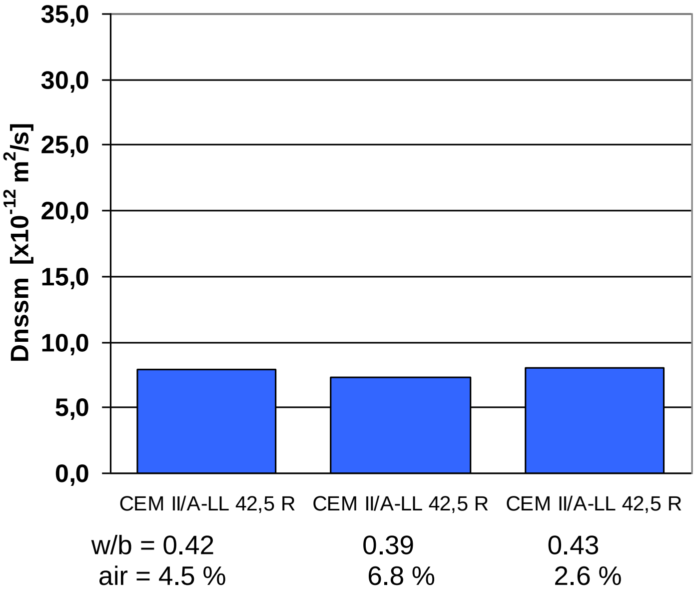


Figure 20. Chloride migration coefficient [NT Build 492] measured after 3 months at RH 95 % humidity room at 3 months age for 2009 casted concretes with w/b 0.39 – 0.43.

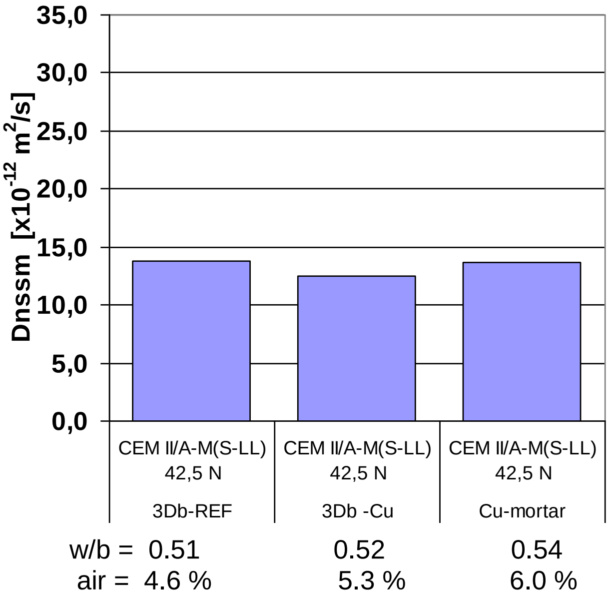


Figure 21. Chloride migration coefficient [NT Build 492] measured after 3 months at RH 95 % humidity room at 3 months age for 2009 casted reference with w/b 0.51 and a concrete with copper powder and a mortar with copper powder.

Figure 22. Surface treated specimens and reference specimen right after coring of three smaller specimens (ø98 mm) per each specimen for laboratory measurement of migration coefficient (D_{nssm}).

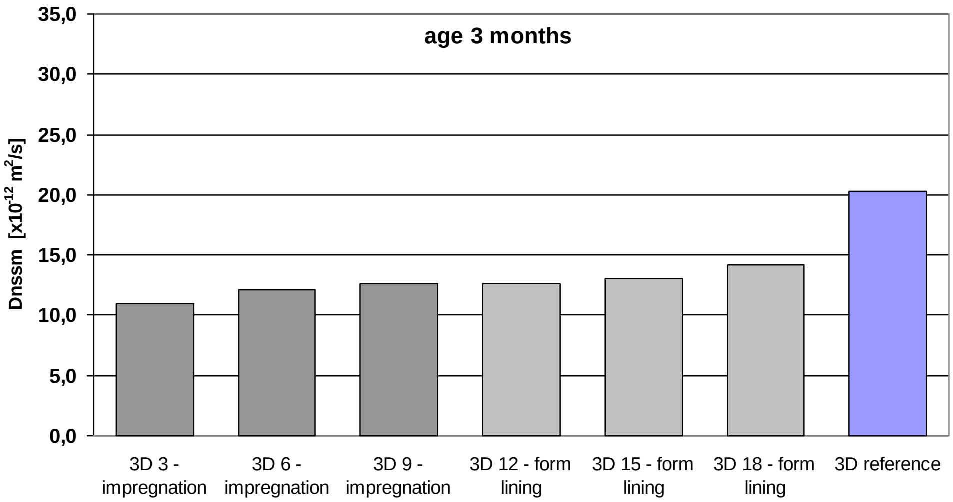


Figure 23. Migration coefficient (D_{nssm}) measured for surface treated specimen after 3 months at RH 95 % humidity room. Value for reference specimen is also included.

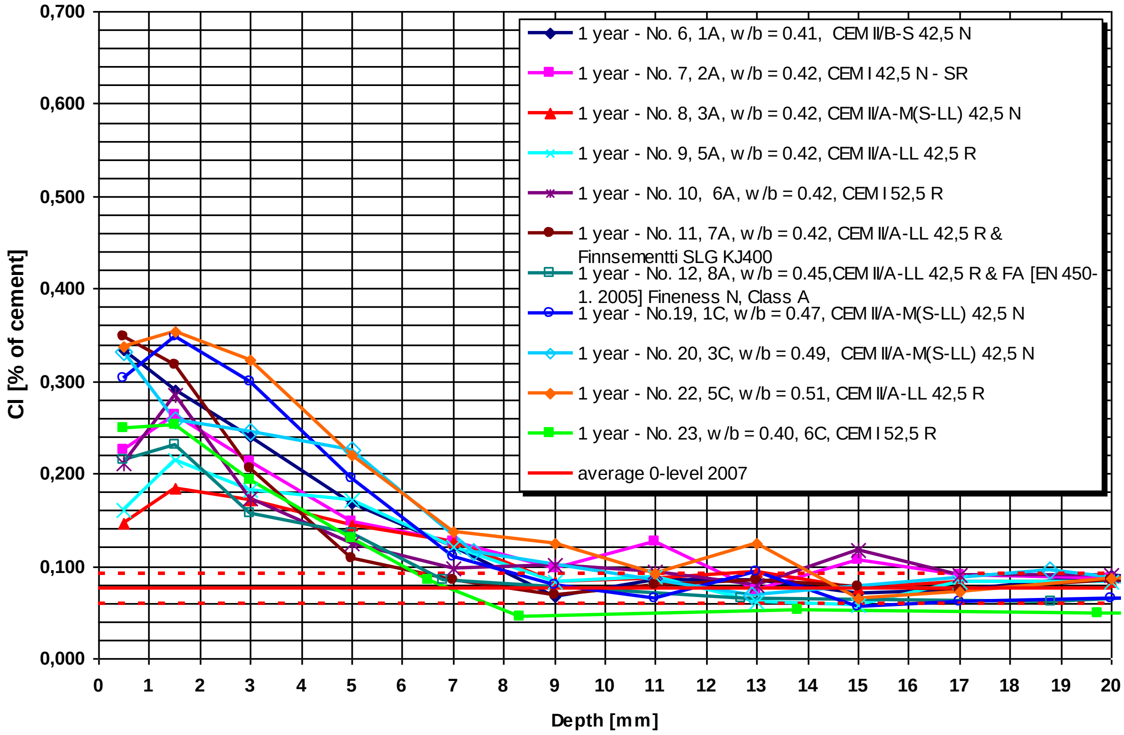


Figure 24. Chloride ingress profiles after the 1st winter season (2007-08) for specimen with different binding materials and w/b ratios. All specimens are at 4.5 m from the highway lane.

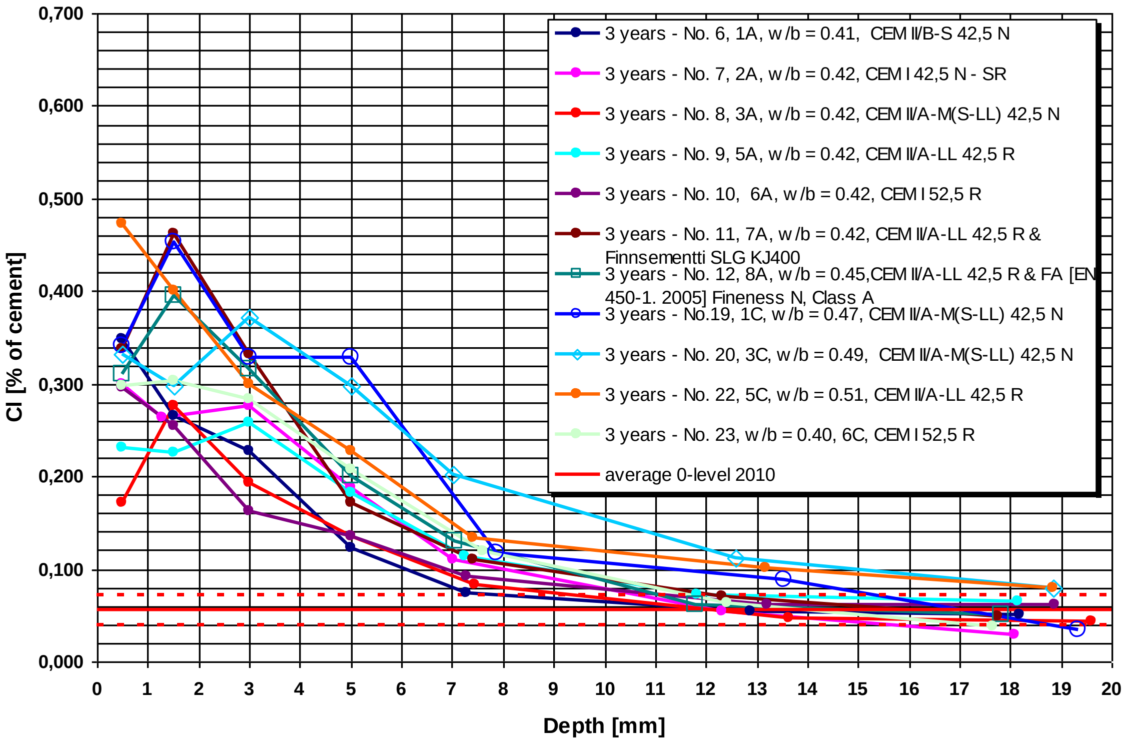
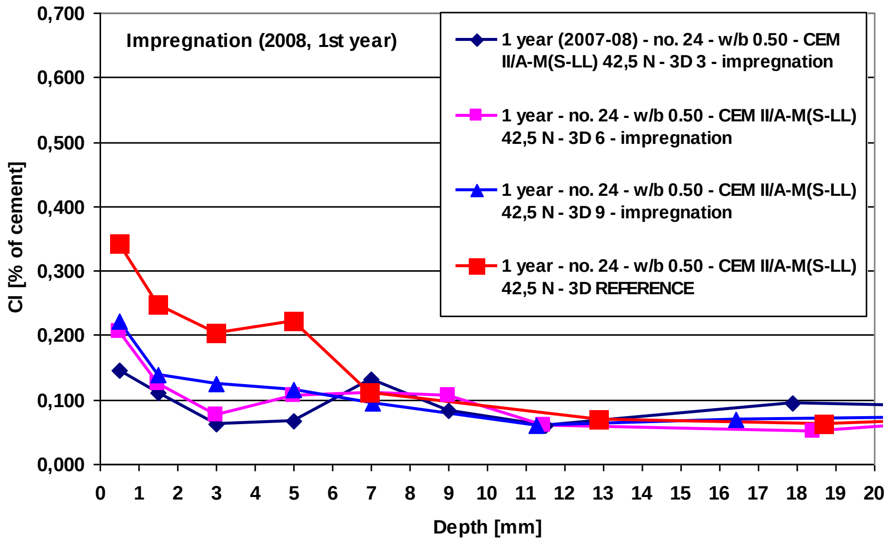


Figure 25. Chloride ingress profiles after the 3rd winter (2009-10) season for specimen with different binding materials and w/b ratios. All specimens are at 4.5 m from the highway lane.



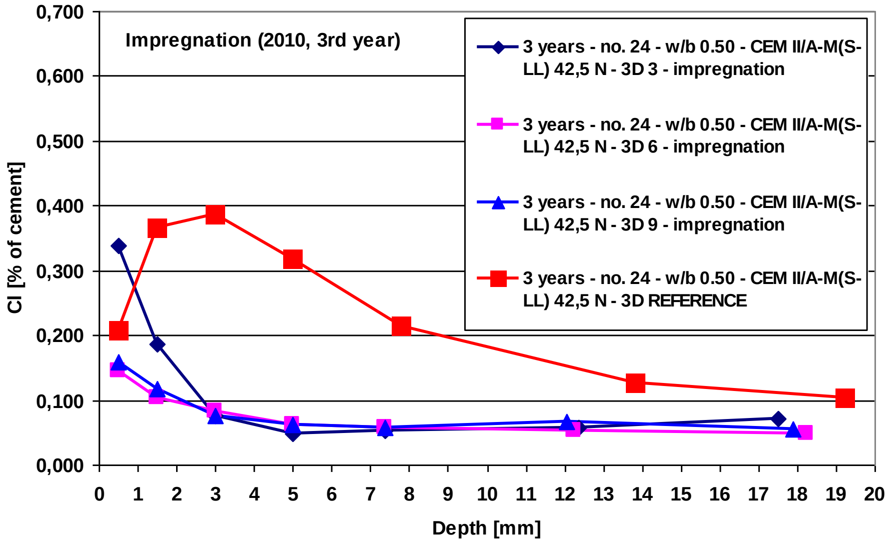
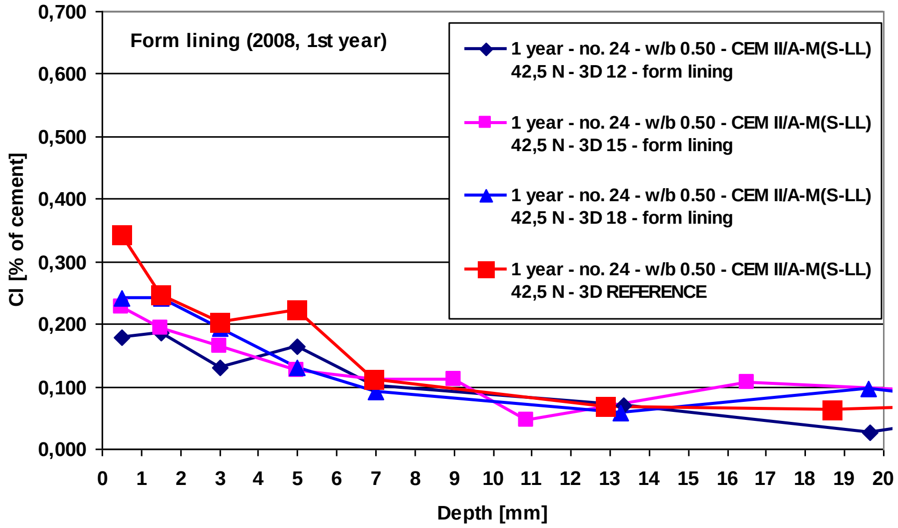


Figure 26. Chloride ingress profiles after the 1st and 3rd winter season for the specimen with 3 different impregnations (3D3, 3D6 and 3D9) and for the reference concrete. All the specimens are made with a wooden mould surface. All the specimens are at 4.5 m from the Highway lane.



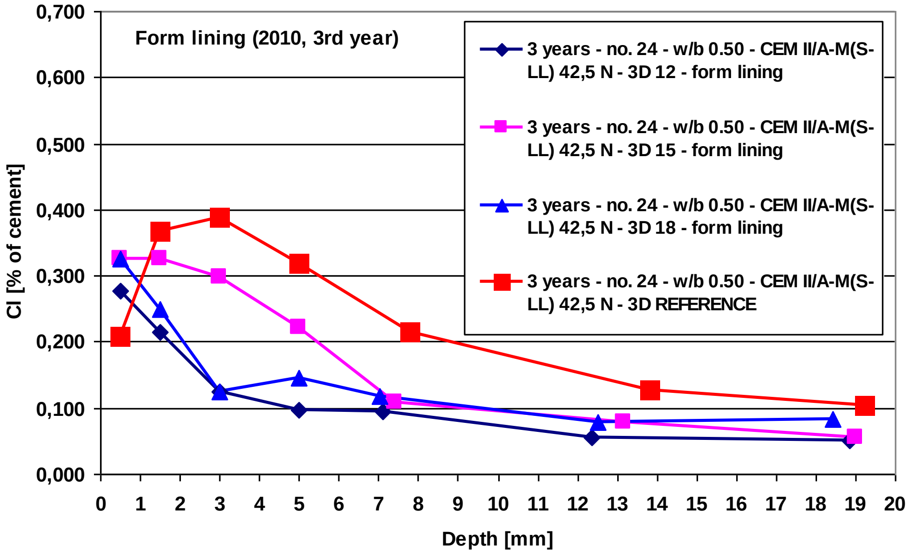
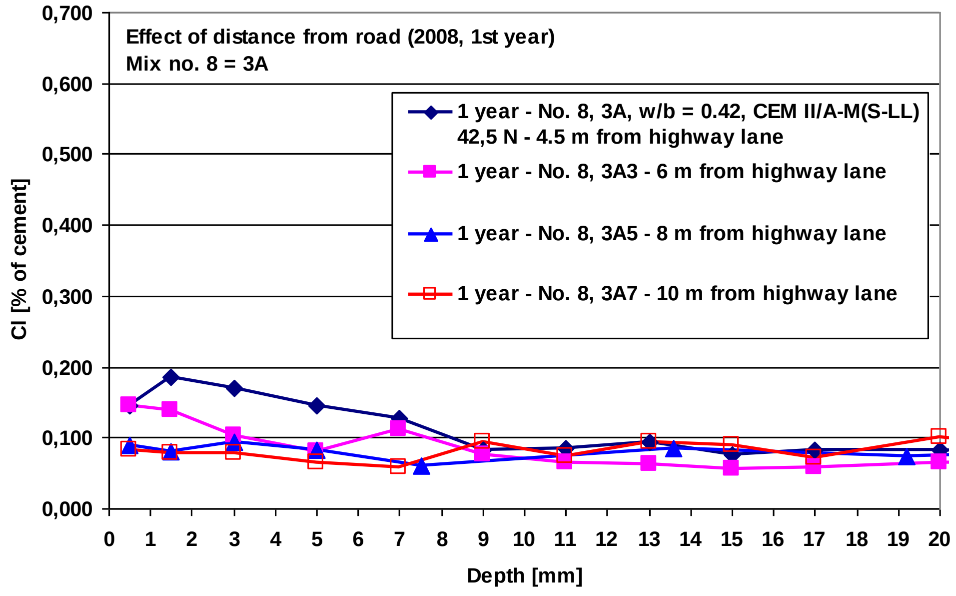


Figure 27. Chloride ingress profiles after the 1st and 3rd winter season for the specimen made with 3 different form linings (3D12, 3D15 and 3D18) and for the reference concrete with wooden mould surface. All the specimens are at 4.5 m from the Highway lane.



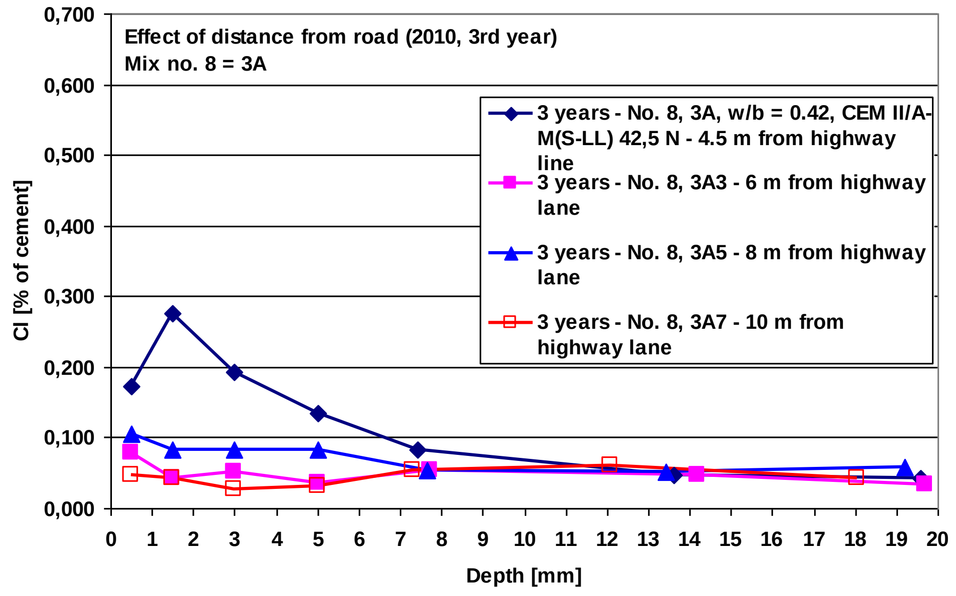
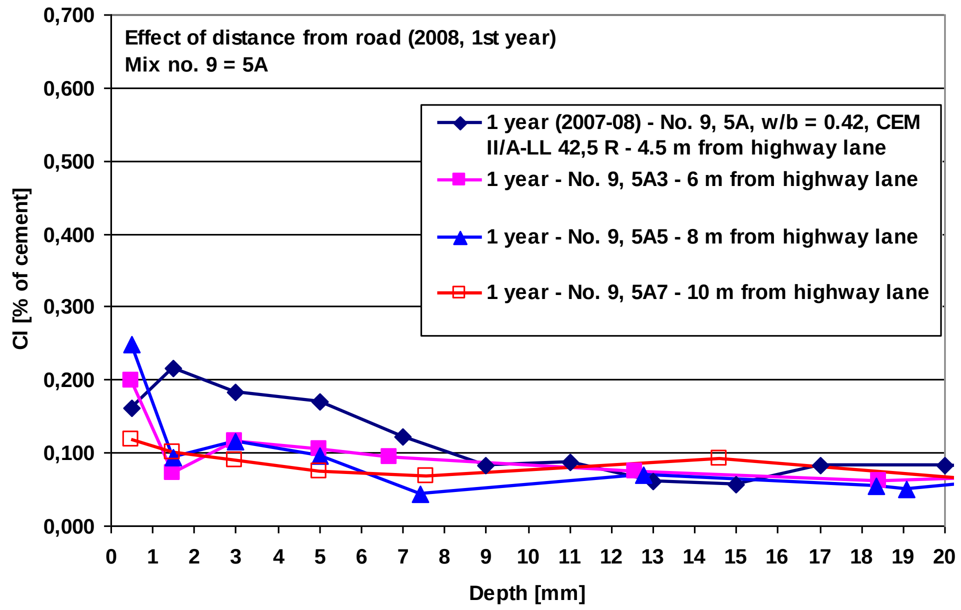


Figure 28. Chloride ingress profiles after the 1st and 3rd winter season for specimen at four distances from the Highway lane (4.5 m, 6.0 m, 8.0 m and 10.0 m). Concrete no. 8 (3A) with w/b = 0.42.



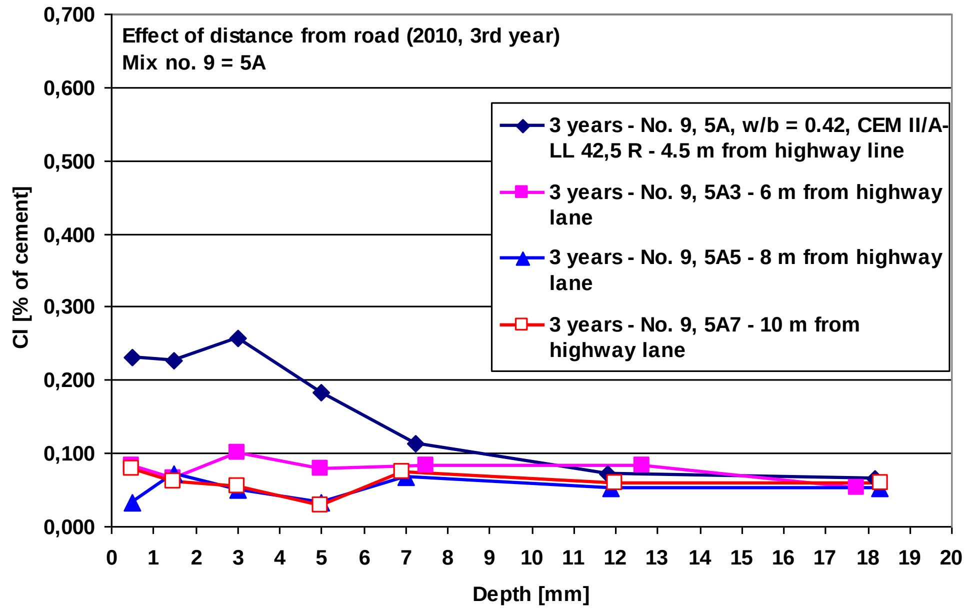


Figure 29. Chloride ingress profiles after the 1st and 3rd winter season for specimen at four distances from the Highway lane (4.5 m, 6.0 m, 8.0 m and 10.0 m). Concrete no. 9 (5A) with w/b = 0.42.

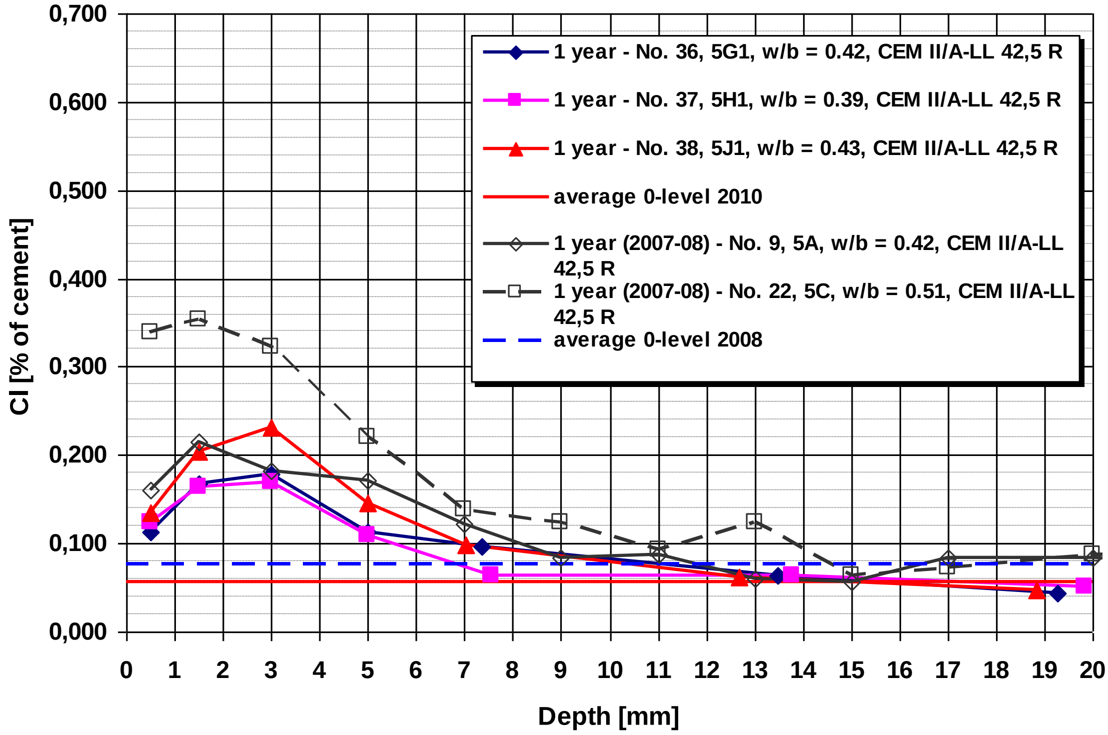


Figure 30. Chloride ingress profiles after one winter season 2009-10 for three (3) specimen with w/b 0.39 – 0.43, which were cast in year 2009. These mixes have different air contents (4.5 %, 6.8 % and 2.6 %). Results after the first winter season 2007-08 for two mixes (nos 9 and 22) with the same cement and with w/b 0.42 and 0.50, both with 5.0 % air content, are also included.

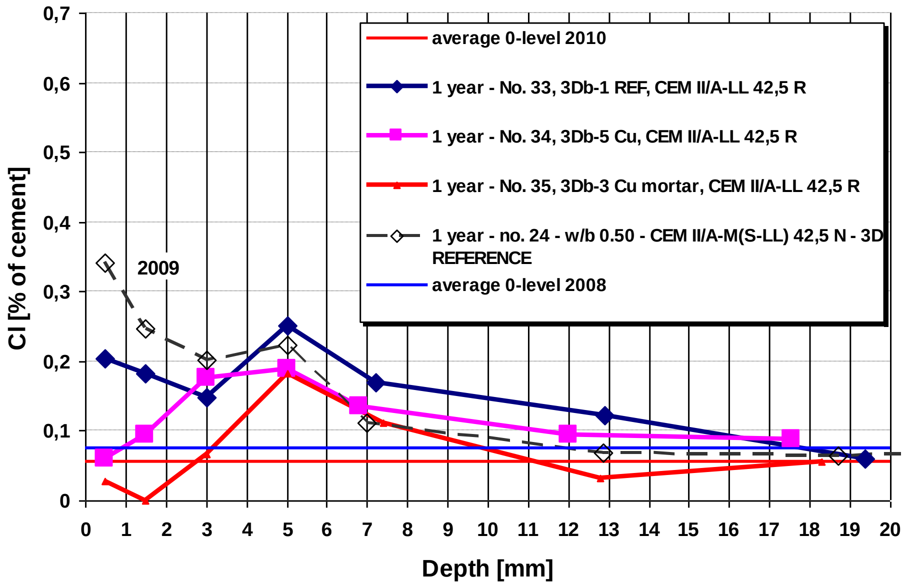


Figure 31. Chloride ingress profiles after one winter season 2009-10 for in year 2009 casted special cases with Cu (no. 34) or Cu-mortar (no. 35) and reference (no. 33). Results after the first winter season 2007-08 for the mix (no. 24) with the same cement and with about the same w/b (0.50 vs. 0.51) are also included. Air content is slightly lower for the year 2007 mix (no. 33) than for the year 2009 mix (no. 24), i.e 3.4 % vs. 4.6 %.

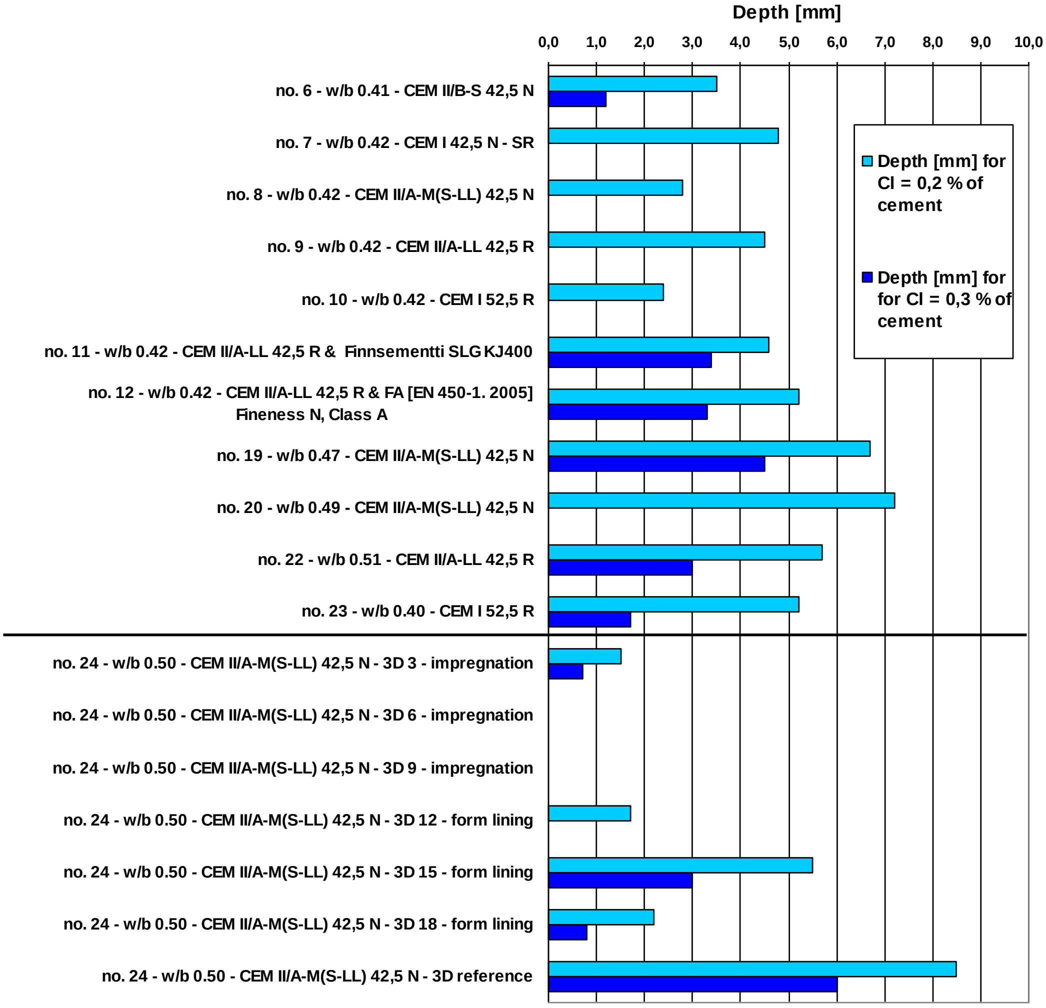


Figure 32. Chloride penetration depths for chloride content 0.2 % of cement and 0.3 % of cement (less than expected critical chloride content, 0.4 % of cement). Results after 3 winter seasons (2007-10) for the specimen located 4.5 m from highway lane side. Includes results for 3 different impregnations (3D3, 3D6, and 3D9) and 3 different form linings (3D12, 3D15 and 3D18).

In Figures 33 and 34 the migration coefficient (D_{nssm}, at 3 months age, [NT Build 492]) is presented as a function of w/b ratio for different cements and binding materials. Figure 33 includes also the results with varying form surfaces (impregnations and with the use of form linings) in the D_{nssm}-testing.

In Figure 35 the chloride content in specimens at field after the 1st and 3rd winter season at 5.0 mm depth is presented. In Figures 36 the chloride content in specimens at 5.0 mm and 7.5 mm is presented as a function of w/b.

In Figures 37 and 38 the field chloride contents at 5.0 mm depth is presented as a function of chloride migration coefficient. In Figure 37 the surface facing to the chloride side in D_{nssm}-testing was the sawed specimen´s middle surface, but in Figure 38 it was from the wooden form face with impregnation, from form surface with the use of mould lining or the reference surface (from the wooden form surface).

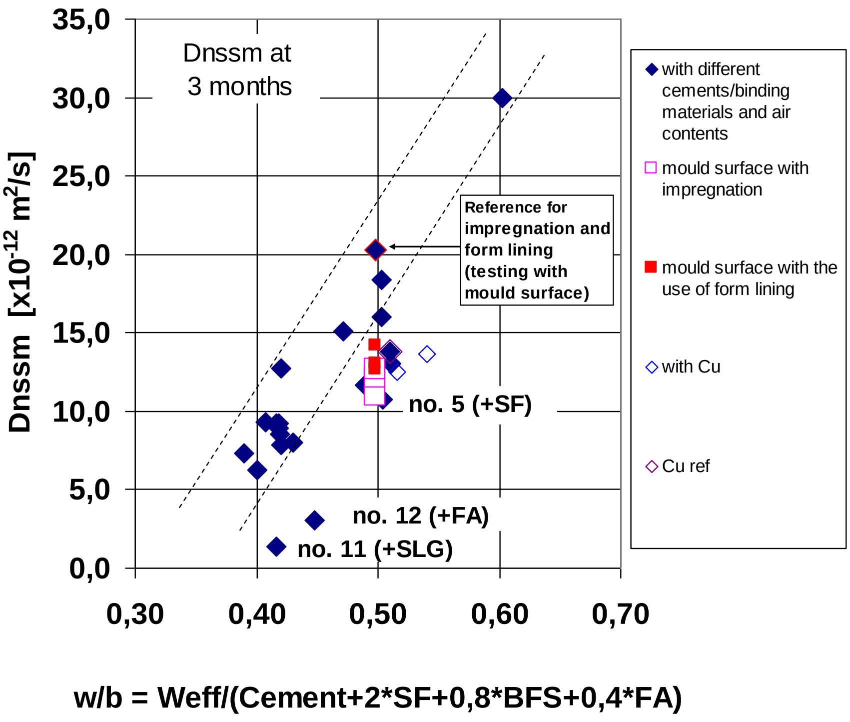


Figure 33. Migration coefficient (D_{nssm}, at 3 months age [NT Build 492]) as a function of w/b ratio. Includes also the results with form surface in D_{nssm}-testing (with impregnations or with the use of form linings).

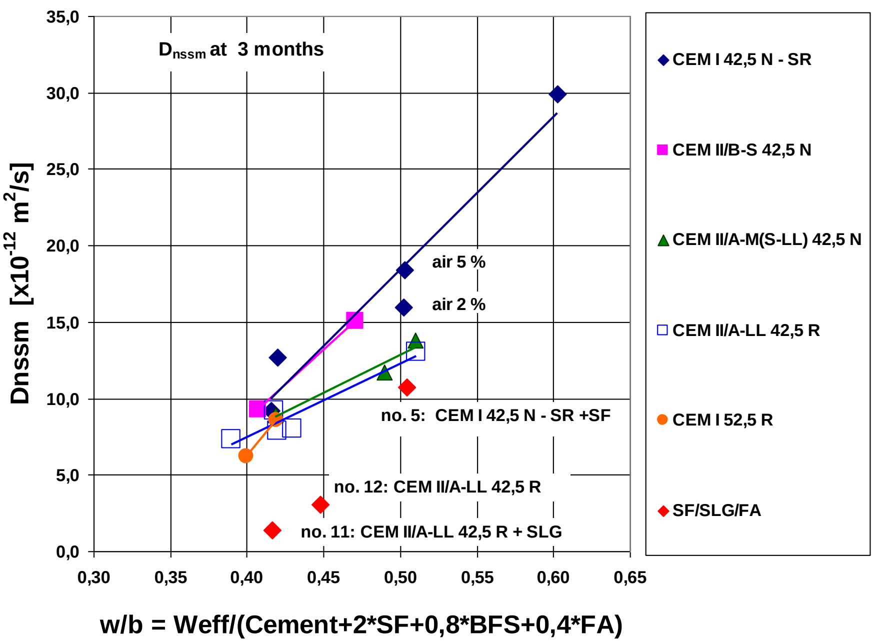


Figure 34. Migration coefficient (D_{nssm}, at 3 months age [NT Build 492]) as a function of w/b ratio for different cements and binding materials.

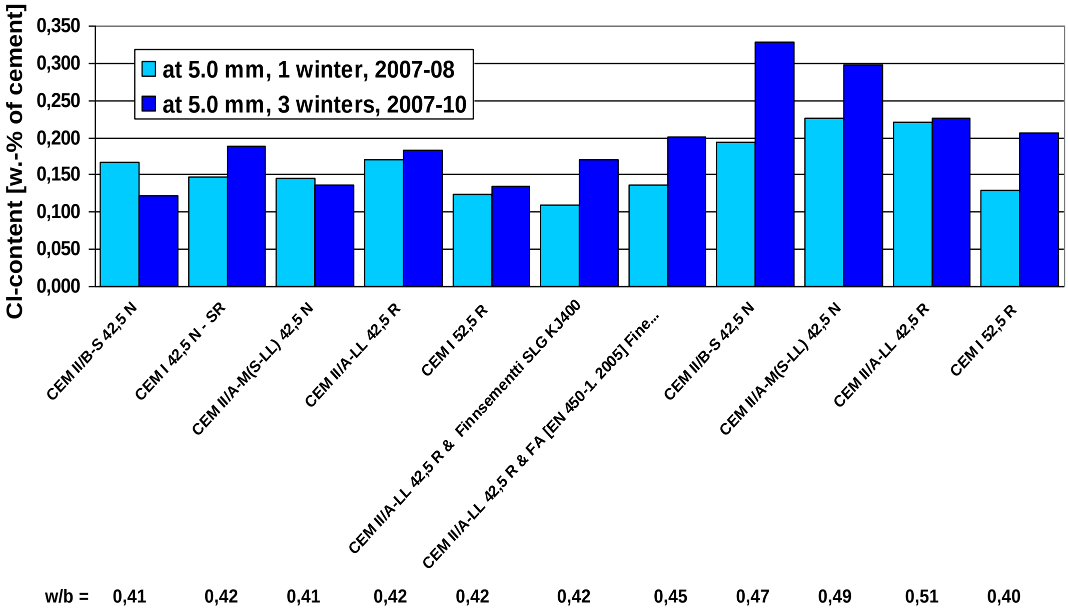


Figure 35. Chloride content at field at 5.0 mm from the specimens surface after the 1st and 3rd winter season (w/b = Weff/(Cement+2*SF+0.8*BFS+0.4*FA)).

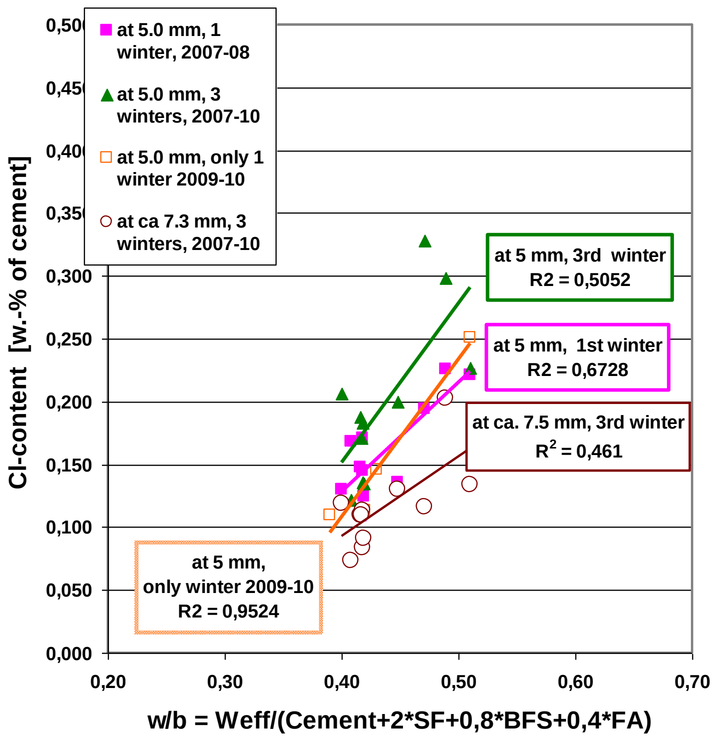


Figure 36. Chloride content at field at 5.0 mm from the specimens surface after the 1st and 3rd winter season, and also at 7.5 mm after the 3rd winter season, as a function of w/b ratio (Weff/ (Cement+2*SF+0,8*BFS+0,4*FA)).

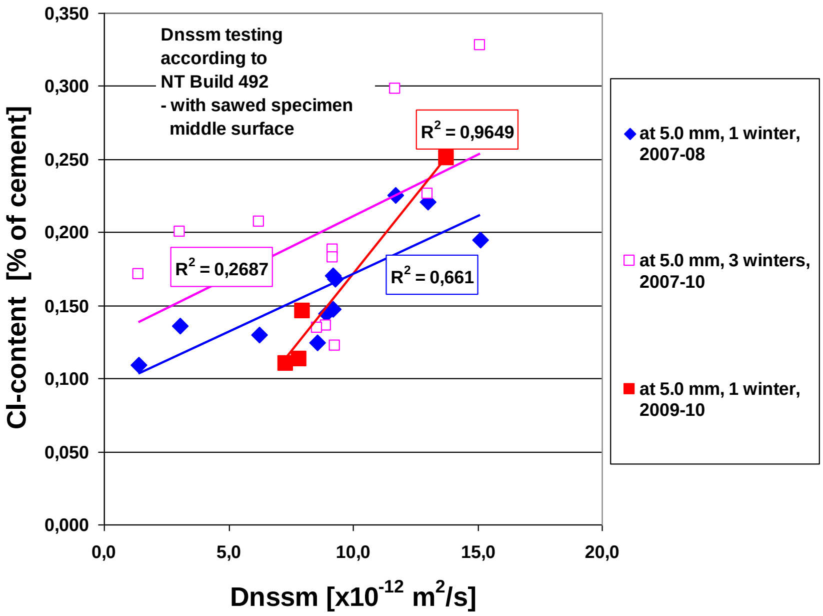


Figure 37. Chloride content at field at 5 mm depth as a function of chloride migration coefficient (D_{nssm}, at 3 months age). Results after 1st and 3rd winter season. In testing D_{nssm} [NT Build 492] the surface facing to the chloride side was the sawn specimen´s middle surface.

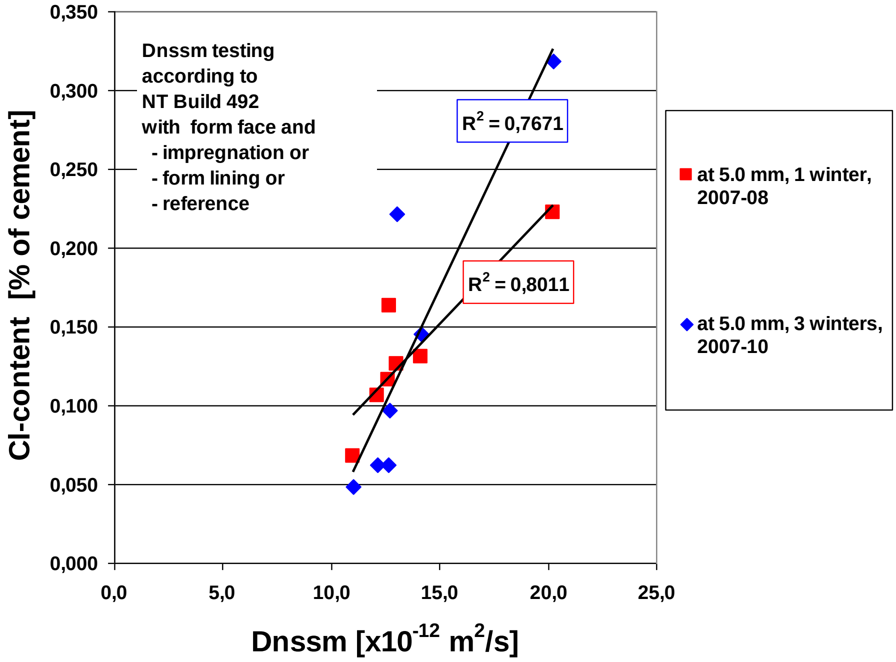


Figure 38. Chloride content at field at 5 mm depth as a function of chloride migration coefficient (D_{nssm}, at 3 months age). Results after 1st and 3rd winter season. In testing D_{nssm} [NT Build 492] the surface facing to the chloride side was from the wooden form face and with impregnation, form face with the use of the mould lining or the reference from the wooden form face. Highest values are for the reference.

6 CARBONATION STUDIES

6.1 General

The aim of these test series was to get field testing data and also both accelerated and non-accelerated laboratory testing results on the effect of binding material, w/b ratio and air content on concrete carbonation.

Field testing of carbonation was in southern Finland outdoor sheltered conditions, i.e. under a roof on wooden racks (Otaniemi) (see Figures 2 and 39). CO_2-concentration at Otaniemi was measured 4.4.2011 and it was then 376 ppm. Year average temperature can be expected to be +6^{o}C and year average relative humidity can be expected to be 79 %. (see Table 1: year average values for Helsinki, Kaisaniemi, 1971 – 2000. Kaisaniemi is 6 km from Otaniemi).

Carbonation at the highway field in unsheltered conditions, i.e. with interacted carbonation, salt and frost action, has not been studied yet. It can be studied later on when carbonation has progressed to measurable depths.

One aim was to compare laboratory accelerated carbonation, which was in a cabinet with 1 % CO_2, RH 60 % and T = 21 ^{o}C (28 d and 56 d), with field sheltered carbonation and also with carbonation in the laboratory at constant humidity (RH 65 %). CO_2-concentration in RH 65 % room was measured 4.4.2011 and it was then 419 ppm.

An additional study on the effect of mould vs. casted surface on carbonation (steel moulds) is also included as this information was available.

6.2 Testing methods

All the specimens for carbonation studies were cast in steel moulds (100 x 100 x 500 mm^3). Mould release agent was always used. After de-moulding at 1 d the specimens were cured in water. At 7 d they were moved to laboratory climatic room with RH 65 % (T = 20 ^{o}C).

Testing at the field and in the laboratory after began 7 d age and was as presented below:

- Carbonation continued in laboratory climatic room with RH 65 % (T = 20 ^{o}C)
- Field carbonation sheltered was started at about concrete age 28 d (25 – 32 d, see Appendix 13). There are 2 beams (100 x 100 x 500 mm^3) per one concrete.
- Laboratory accelerated carbonation in a sealed cabinet with 1 % CO_2, RH 60 % and T = 21^{o}C was started at concrete age 28 d (accidentally for concretes nos. 7, 8 and 9 at age 33 d, 35 d and 35 d).

So far there have been two measurement times for field carbonation depths. The average field carbonation times are 268 days (September 2007 - May 2008) and 772 days (September 2007 – autumn 2009). The coefficients for carbonation (k-values at field sheltered) were calculated based on the individual exact carbonation time at field for each concrete.

The coefficients for carbonation (k) were calculated based on a common equation:

$$\text{Carbonation [mm]} = k\sqrt{t} \qquad (4)$$

where t is carbonation time [d] and
k coefficient of carbonation [mm/d$^{0.5}$].

Accelerated carbonation at 1 % CO_2 was otherwise done according to [EN 13295], but curing before the start of carbonation was as presented above. This means, that the test specimens were not dry conditioned after 28 d to constant weight but dry conditioning at RH 65 % was started already at 7 d and testing at 1% CO_2 was started right after that at 28 d concrete age.

The cabinet (see Figure 40) for carbonation was modified with a gas inlet and outlets such that a uniform flow of CO_2 reached all parts of the cabinet. The relative humidity was also closely controlled to compensate for e.g. extra moisture liberated by carbonation. The precision of the cabinet was at least as high as demanded in [EN 13295].

The measurement of carbonation depth for accelerated carbonation (1 % CO_2) exposed samples was mainly done as in [EN 13295]. However, it was both after 28 d and 56 d. For non-accelerated carbonation exposure (at field and at lab RH 65 %), duplicate broken faces were not used, but the measurement was made on one broken face (100 x 100 mm^2). For each concrete and at every measurement time, there were 40 measurement points for accelerated carbonation exposed sample and 20 measurement points for non-accelerated carbonation samples.

The coefficient for carbonation (k) was calculated for the accelerated carbonation samples in the same way as for the non-accelerated carbonation samples (see Equation (1) above). In this case the coefficient for carbonation (k) is for the accelerated carbonation exposure (1 % CO_2, RH 60 % and T = 21 ^oC).

It was also recorded if the carbonation depth was measured from the casting surface, bottom surface or side surface of the specimen. Average value and standard deviation was calculated for all the surfaces. The average values were also calculated for the individual surfaces, but these values (rounded to 0.5 mm) were not used for the calculation of the final carbonation depth (as in [EN 13295]). Instead, the average carbonation depth of each surface type (casting, bottom and side) was compared with the average carbonation depth for all the surfaces.

Figure 39. Specimen (beams 100x100x500 mm^3) in field sheltered carbonation exposure.

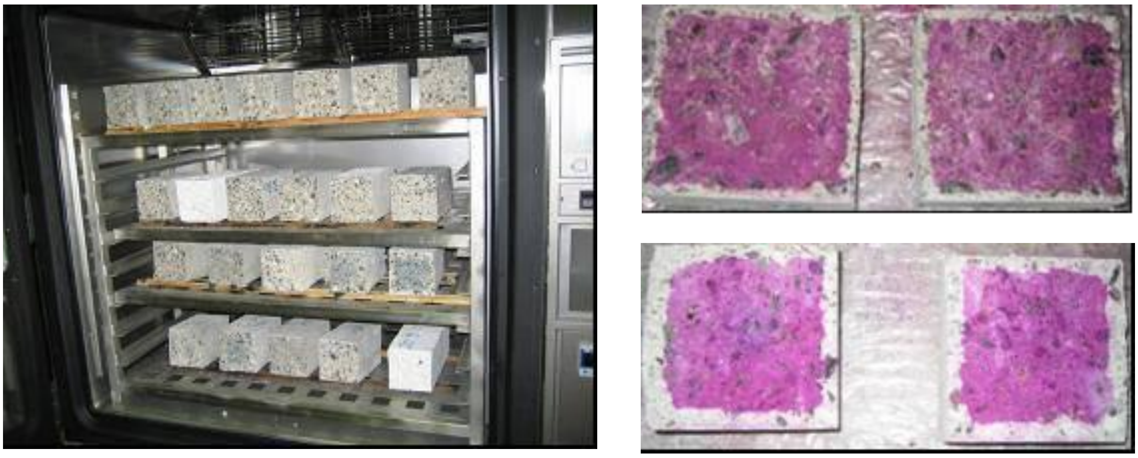


Figure 40. Cabinet for accelerated carbonation exposure and broken specimen faces (100x 100 mm^2) after phenolphthalein solution treatment.

6.3 Concretes and timing

There were in all 22 concretes for the carbonation studies. These are concretes nos. 6 – 28 in Appendices 6 (mix design), 8 (fresh concrete properties), 12 (hardened concrete properties) and 13 (timing for field specimen casting, curing and start of field testing).

Below the concretes/binding materials are listed according to the w/b ratio and with some additional information. The w/b here is the planned w/b, but this can be somewhat different, especially for factory produced mixes, than the final w/b, which is based on the factory weighing report. The final w/b can be found e.g. in Appendix 6 and is used later on, if e.g. testing results are compared with w/b.

<u>Binding materials with about w/b 0.42 are:</u>

- Perussementti CEM II/B-S 42,5 N (No. 6)
- SR-sementti CEM I 42,5 N – SR (No. 7)
- Yleissementti CEM II/A-M(S-LL) 42,5 N (No. 8)

    - with Yleissementti CEM II/A-M(S-LL) 42,5 N also an additional testing series with different air contents – in all 6 concretes (Nos. 13 – 18)
        - includes 2 SCC-mixes,
        - from no air entrainment to 7 % air.
- Rapidsementti CEM II/A-LL 42,5 R (No. 9)
- Pikasementti CEM I 52,5 R (2 different mixes/different producers) (No. 10 and No. 23)
- Rapid CEM II/A-LL 42,5 R + 50 % Finnsementti SLG KJ400 (No. 11)
- Rapid CEM II/A-LL 42,5 R + 24 % FA [EN 450-1. 2005] Fineness N, Class A (No. 12)

Binding materials with about w/b 0.50 are:
- Perussementti CEM II/B-S 42,5 N (No. 19)
- Yleissementti CEM II/A-M(S-LL) 42,5 N (Nos. 20 and 24)
    - 2 mixes with different air contents (5.5 % and 3.4 %)
- Valkosementti CEM I 52,5 N (No. 21)
- Rapidsementti CEM II/A-LL 42,5 R (No. 22)

Binding materials with about w/b 0.60 are:
- Perussementti CEM II/B-S 42,5 N (No. 25)
- Yleissementti CEM II/A-M(S-LL) 42,5 N (No. 26)
- Valkosementti CEM I 52,5 N (No. 27)
- Rapidsementti CEM II/A-LL 42,5 R (No. 28)

6.4 Results

All the carbonation measurement data is presented in Appendices 16 - 18. This data includes the average values, values for standard deviation and calculated k-values.

The values for accelerated carbonation at 1 % CO_2 are presented in Appendix 16. The average carbonation depth for all the concretes
- after 28 d was 3.6 mm and
- after 56 d was 5.2 mm.

For concretes with about w/b 0.42 these values were
- 3.2 mm (28 d) and
- 4.8 mm (56 d).

For concretes with w/b 0.46 – 0.60 (about 0.52) these values were
- 4.3 mm (28 d) and
- 5.9 mm (56 d).

Laboratory accelerated carbonation is presented as a function of square root of time in Figure 41. Comparison of carbonation after 28 d with carbonation after 56 d at 1 % CO_2 is presented in Figure 42, where it is seen that there is good correlation (R^2 = 0.938). This means, that good information on carbonation is possible to get already after 28 d testing time. Anyway, especially for concretes with high carbonation resistance (high strength concrete, not included here) it is good to have a long enough carbonation time to be able to make accurate measurements. In Figure 43 (A and B) the standard deviation and coefficient of variation [%] is presented as a function of 28 d and 56 d carbonation time at accelerated carbonation (1% CO_2). The average value of the standard deviation was 0.6 mm after 28 d carbonation and 0.7 mm after 56 d carbonation. Average value for the coefficient of variation was 15 % after 28 d carbonation and 17 % after 56 d carbonation.

The field specimen carbonation depths after about 8.9 and 25.7 months are presented in Appendix 17, as well as results for carbonation at RH 65 % laboratory climatic room after about 8.9 months carbonation.

The field carbonation is presented as a function of square root of time for each concrete in Figure 44 and in Figure 45 as average values (for all w/b ratios and separately for ca. w/b 0.42 and for w/b 0.46 – 0.60 (about 0.52). To date after 27 moths, the field carbonation is mainly less than 2 mm.

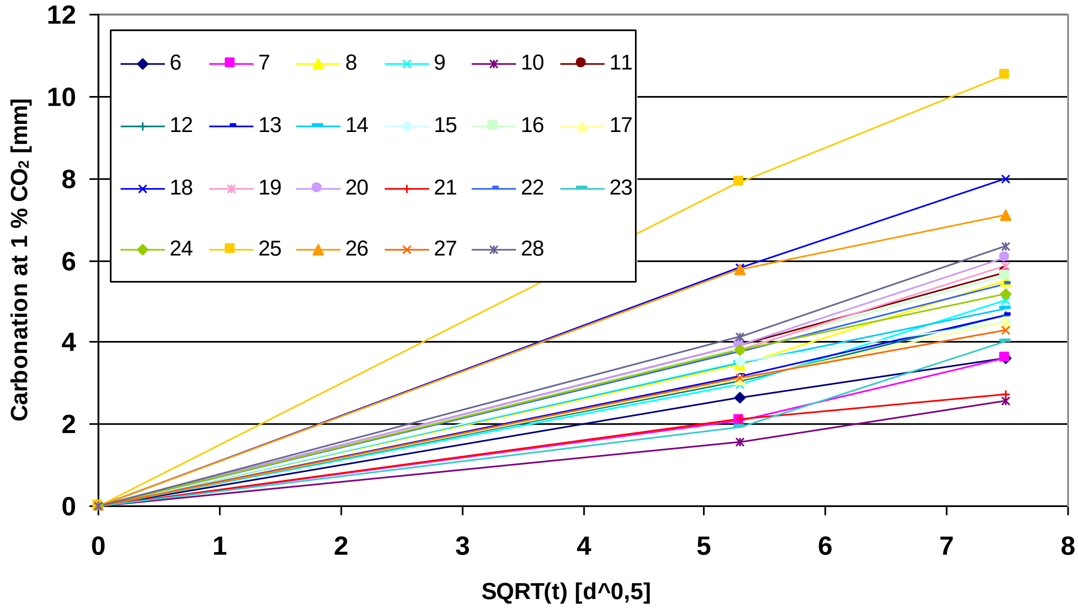


Figure 41. Accelerated laboratory carbonation at 1 % CO_2 (measurement at 28 d and 56 d). Curing before carbonation was 7 d in water and 21 d at RH 65 %. Concrete (nos. 6 – 28) composition as binding material and w/b is presented in Appendix 6.

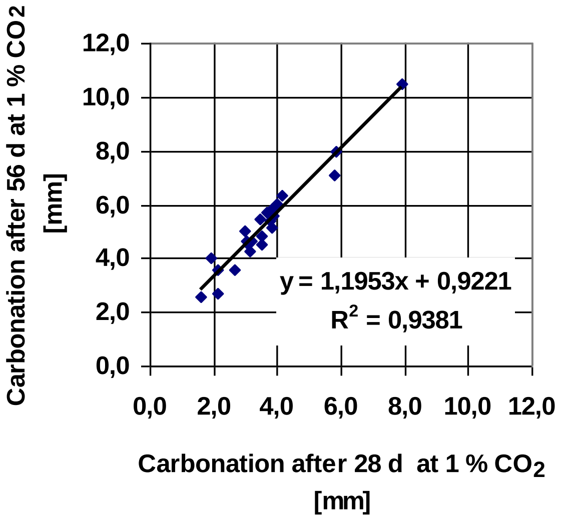
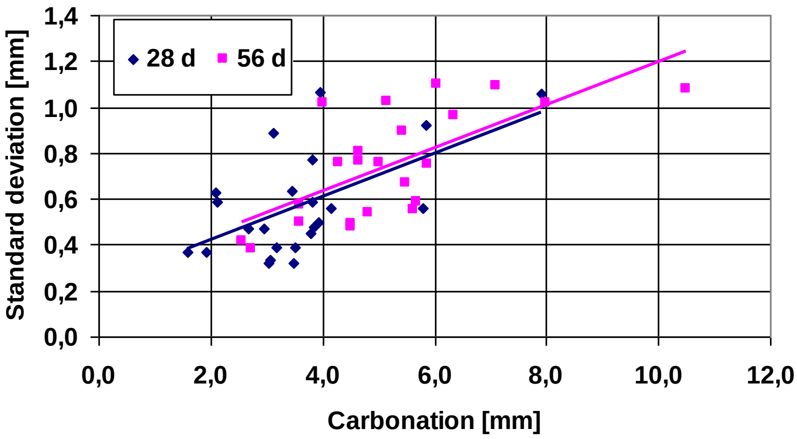
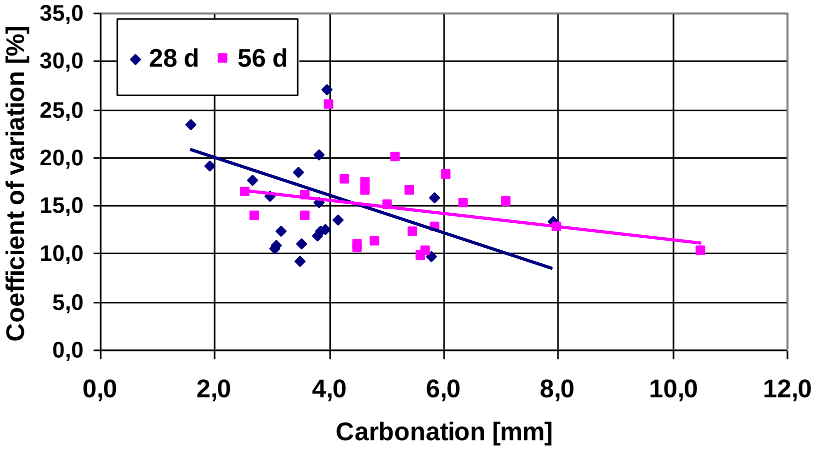


Figure 42. Accelerated lab carbonation after 56 d at 1 % CO_2 as a function of carbonation after 28 d at 1 % CO_2.



A



B

Figure 43. Standard deviation (A) and coefficient of variation (B) for carbonation as a function of carbonation depth. Accelerated lab carbonation at 1 % CO_2.

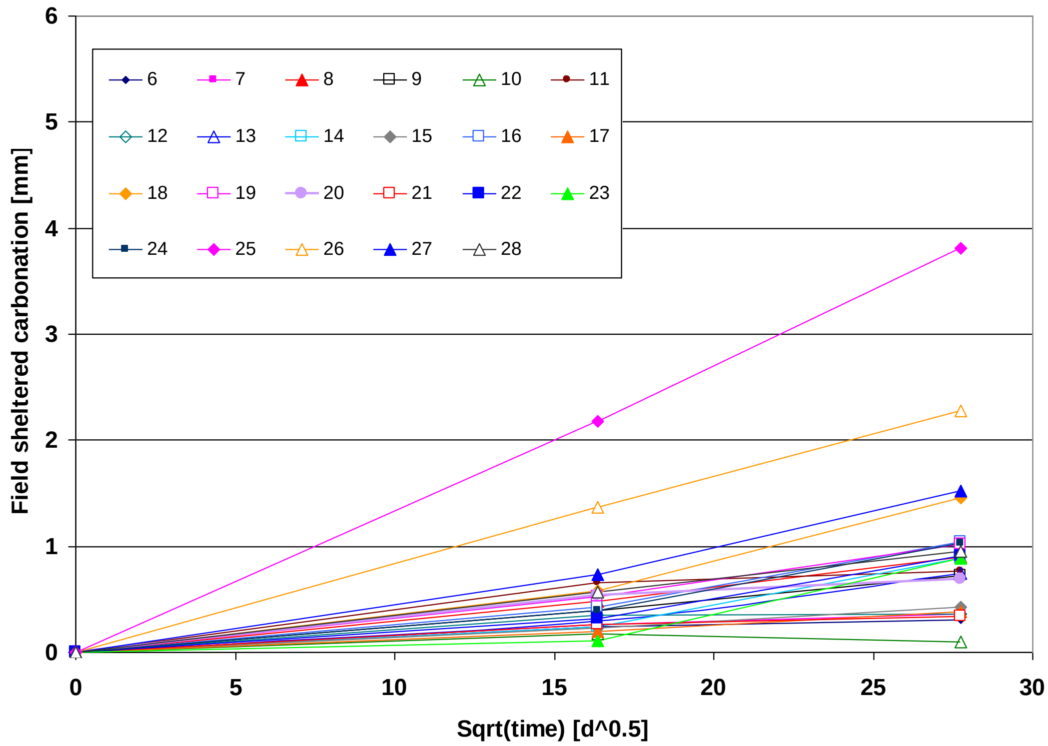


Figure 44. Field sheltered carbonation as a function of square root of time. Concrete (nos. 6 – 28) composition as binding material and w/b is presented in Appendix 6.

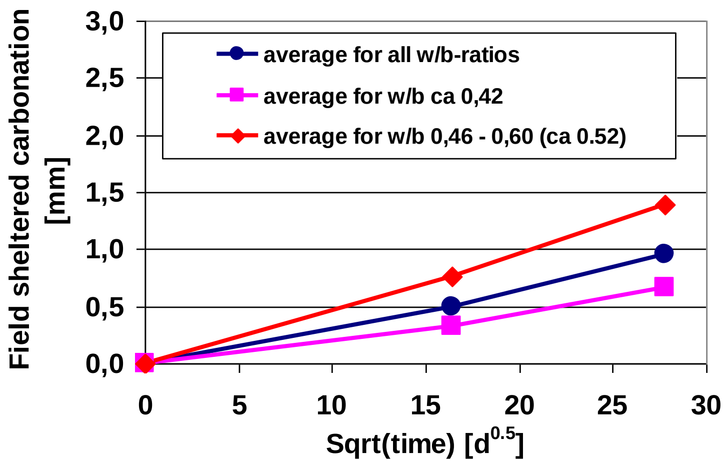


Figure 45. Average field carbonation for all w/b ratios and separately for ca. w/b 0.42 and w/b 0.46 – 0.60 (ca. 0.52) as a function of square root of time, at sheltered conditions.

In Figure 46 carbonation for field specimen and for specimen at laboratory storage at RH 65 % is presented as a function of accelerated laboratory carbonation at 1 % CO_2 (56 d).

In Figure 47 the average, the minimum and the maximum carbonation depths at different carbonation circumstances and after different carbonation times are presented. These values are presented separately for concretes with w/b about 0.42

and for concretes with w/b about 0.52 (0.46 – 0.60). It can be seen that on average w/b has an effect on carbonation depth. There is also high variation between different concretes/binding materials, i.e. differences between minimum and maximum carbonation depths. For instance the average carbonation depth for w/b 0.42 is always more than the minimum carbonation depth for w/b 0.46 – 0.60.

In Figure 48 the coefficient for carbonation (k) for field specimens and for specimen at laboratory storage at RH 65 % is presented as a function of accelerated laboratory carbonation at 1 % CO_2 (56 d). It can be seen that the correlation is best between accelerated carbonation at 1 % CO_2 and carbonation at laboratory at RH 65 % (R^2 = 0.95). Correlation coefficient between accelerated carbonation and field sheltered carbonation is R^2 = 0.69 after 0.75 years field carbonation and R^2 = 0.73 after 2.1 years field carbonation.

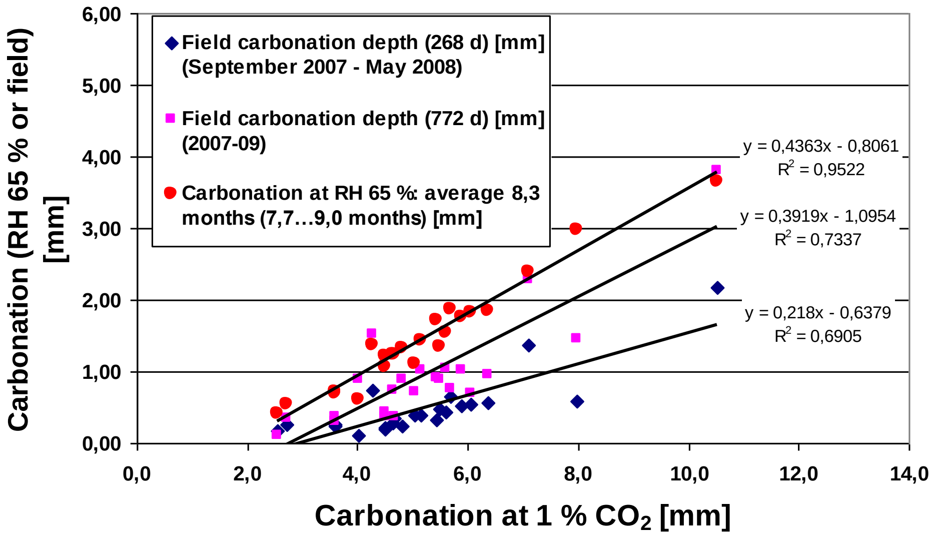


Figure 46. Carbonation depth for naturally carbonated field specimen and for lab specimen at RH 65 % as a function of carbonation depth at accelerated 1 % CO_2 exposure (56 d).

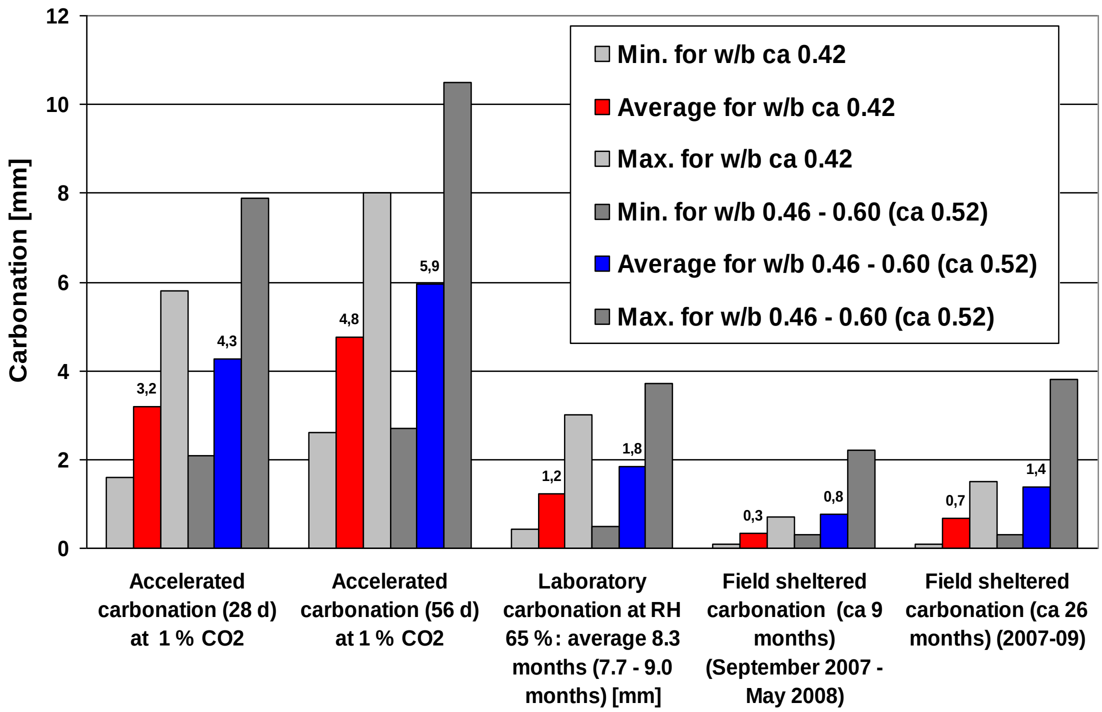


Figure 47. Average, minimum and maximum values for carbonation, when w/b is ca 0.42 and ca. 0.52 at different carbonation circumstances and after different carbonation times.

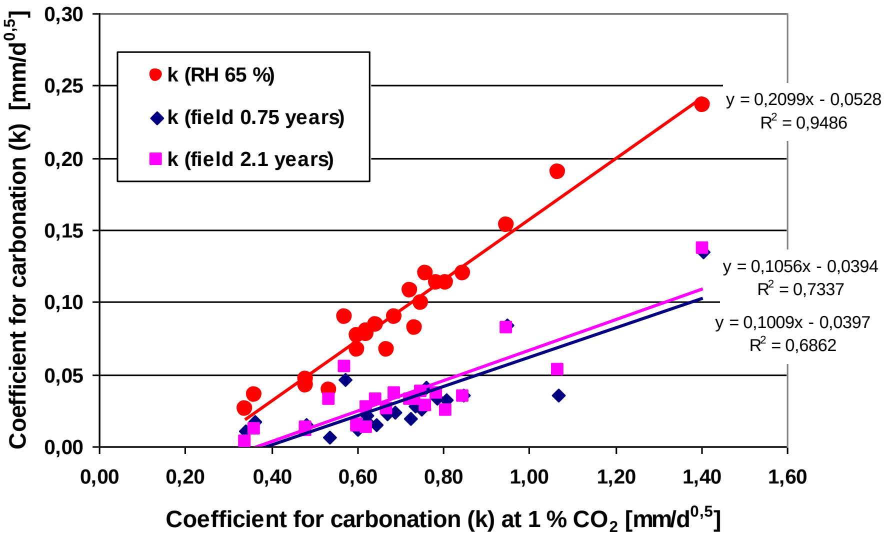


Figure 48. Coefficient for carbonation (k) for field specimen and for specimen at RH 65 % as a function of k-value in lab accelerated carbonation at 1 % CO_2 (56 d).

In Figure 49 the coefficient for carbonation (k) is presented as a function of w/b (= W_{eff}/(Cement+0.8*BFS+0.4*FA) and in Figure 50 as a function of 28 d compressive strength. The correlation of w/b with carbonation is not good (R^2 is 0.26 for accelerated carbonation and 0.36 for field carbonation). On the other hand, the correlation of compressive strength and carbonation is far better (R^2 > 0.60 for accelerated carbonation and R^2 > 0.70 for field carbonation). In all, the coefficient of carbonation depends on the permeability of concrete, type of cement, possible cement replacements and environmental conditions, moisture conditions and atmospheric CO_2 content.

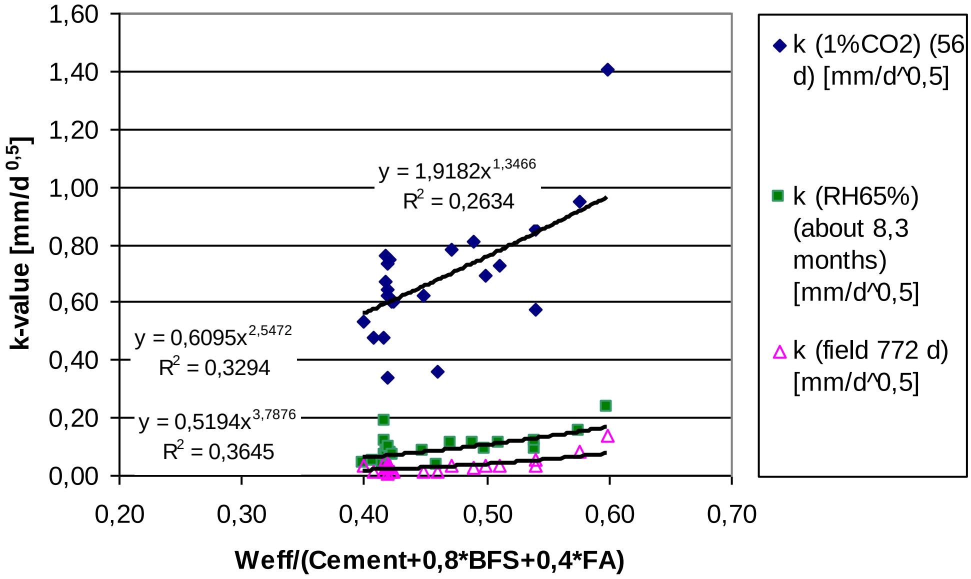


Figure 49. Coefficient for carbonation as a function of w/b (= Weff/(Cement+0,8*BFS+0,4*FA).

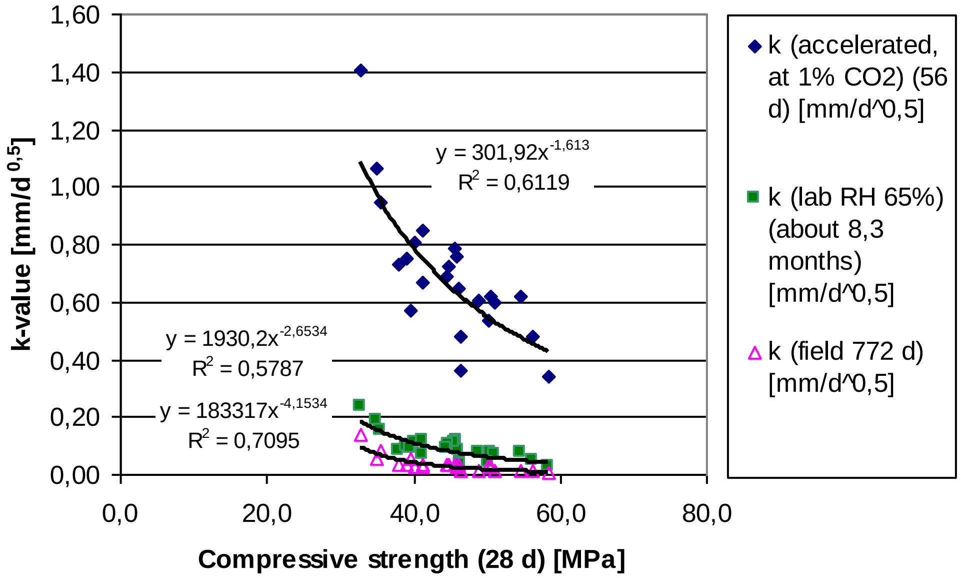


Figure 50. Coefficient for carbonation as a function of 28 d compressive strength.

For 6 concretes (Nos. 13 – 18) the binding material was CEM II/A-M(S-LL) 42.5 N (Yleissementti) and w/b was exactly 0.42. For these concretes the air content ranged from no air entrainment to high air content. Hardened concrete air content was from 2.7 % to 8.6 %. In Figure 51 the carbonation of these concretes is presented as a function of hardened concrete air content. It can be seen that with air content more than 5 %, and especially >7 %, there will be increased carbonation both for accelerated and non-accelerated carbonation exposure. With especially high air content, the carbonation was about two times higher than the carbonation for non-air entrained concrete.

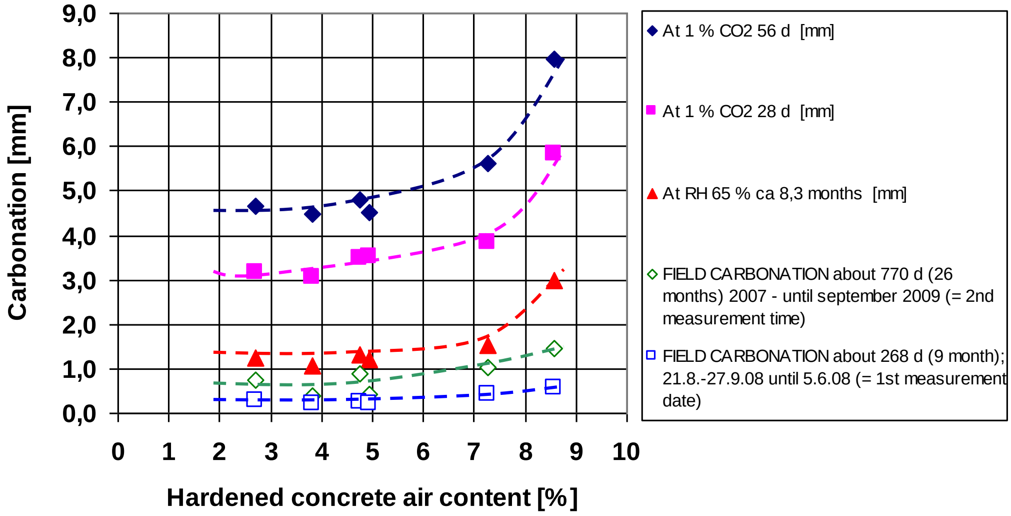


Figure 51. Carbonation of concretes with CEM II/A-M(S-LL) 42.5 N and w/b 0.42 (concretes Nos 13 – 18) as a function of hardened concrete air content.

The carbonation of concretes with different binding materials and with different w/b ranges is presented in Figures 52 - 54. Carbonation depth is sorted by carbonation at 1 % CO_2 (56 d). Carbonation of concretes

- with about w/b 0.42 (0.40 – 0.45) is presented in Figure 52,
- with about w/b 0.50 (0.46 – 0.51) is presented in Figure 53,
- with w/b 0.46 – 0.60 is presented in Figure 54.

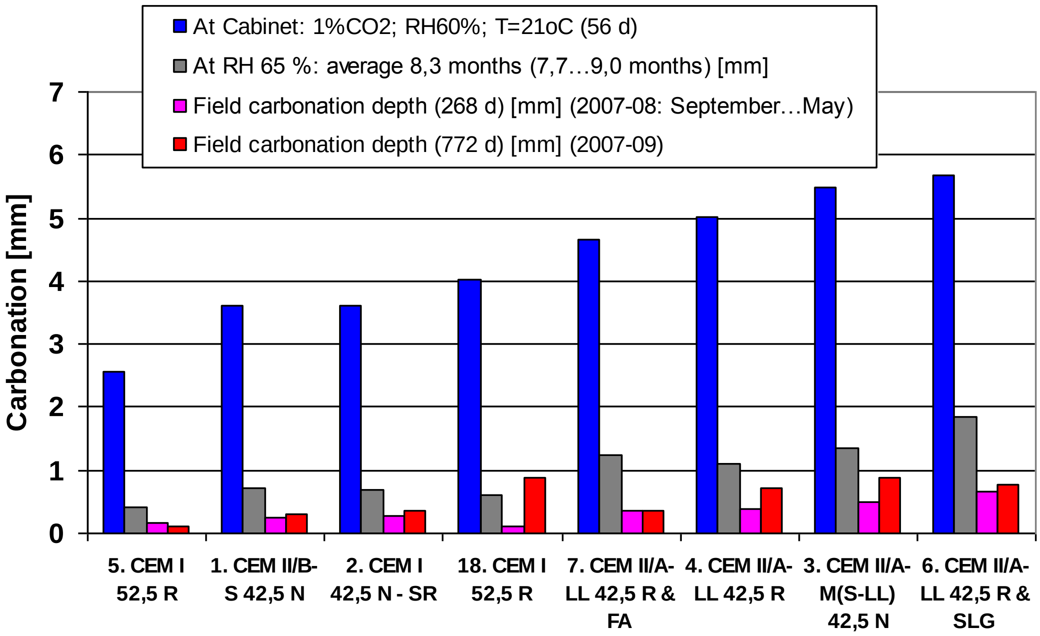


Figure 52. Carbonation of concretes with different binding materials and with w/b 0.40 – 0.45. Carbonation depth is sorted by carbonation value when stored at 1 % CO_2 (56 d).

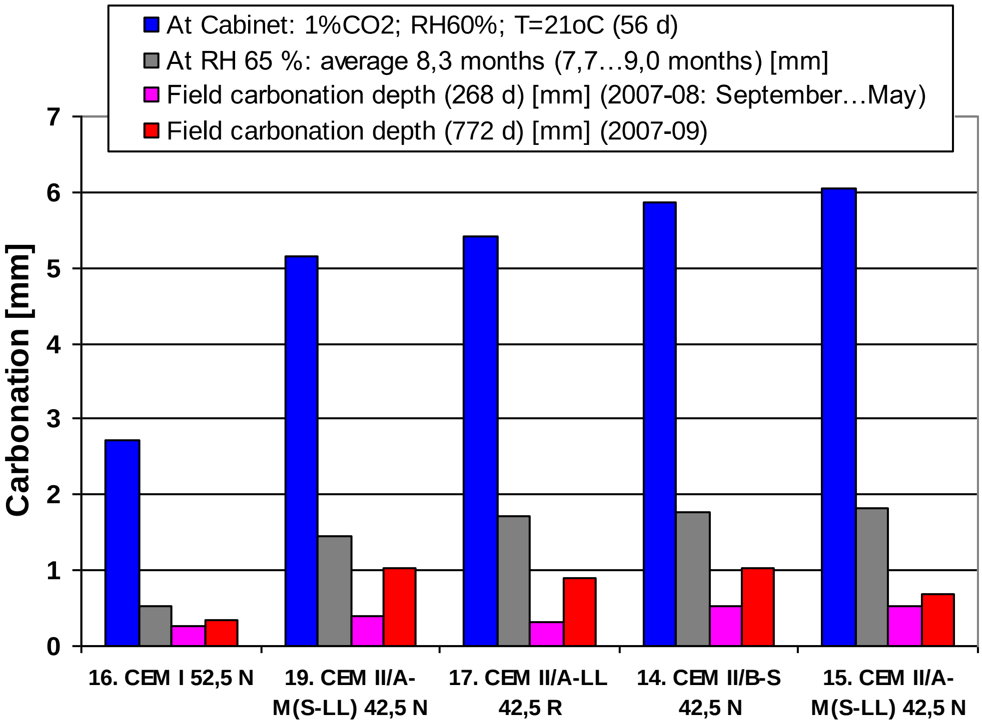


Figure 53. Carbonation of concretes with different binding materials and with w/b 0.46 – 0.51. Carbonation depth is sorted by carbonation value when stored at 1 % CO_2 (56 d).

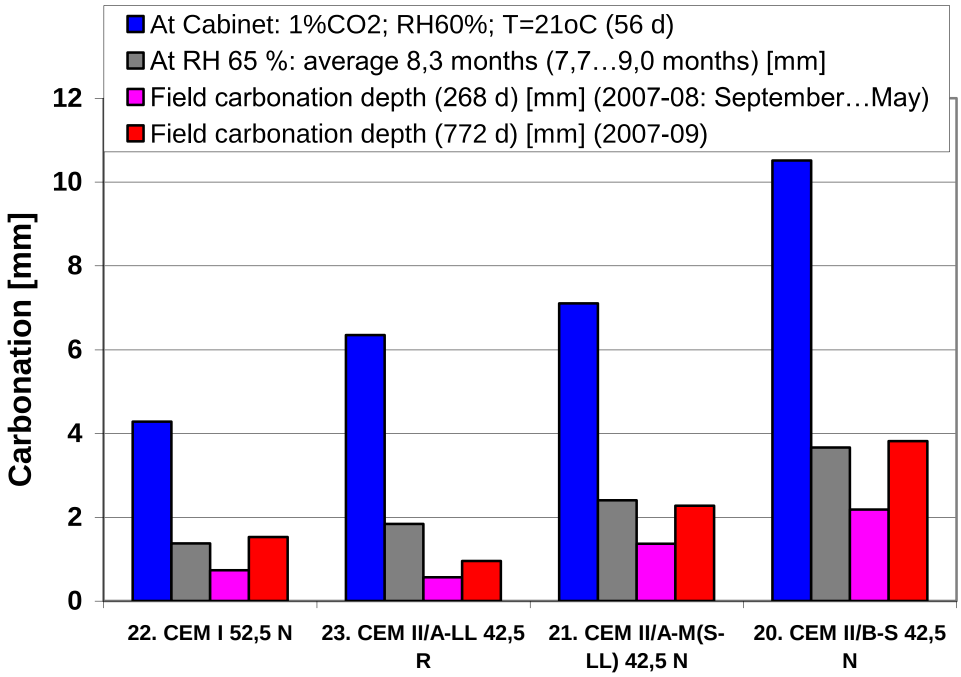


Figure 54. Carbonation of concretes with different binding materials and with w/b 0.54 – 0.60. Carbonation depth is sorted by carbonation value when stored at 1 % CO_2 (56 d).

Data on the average carbonation depth of each surface type (casting, bottom and side) is presented in Appendix 18. The average values are calculated for all the concretes and separately for concretes with w/b about 0.42 and for concretes with w/b 0.46 – 0.60 (about 0.52) (See also Figures 55 - 57 below). There are no big differences for concretes with w/b about 0.42 in Figure 56. For concretes with w/b 0.46 – 0.60 in Figure 55 the casting surface has on an average carbonated the most and the bottom surface the least. Casting surface carbonation as a function of the bottom surface carbonation is presented in Figure 57 for all the concretes and all the carbonation cases.

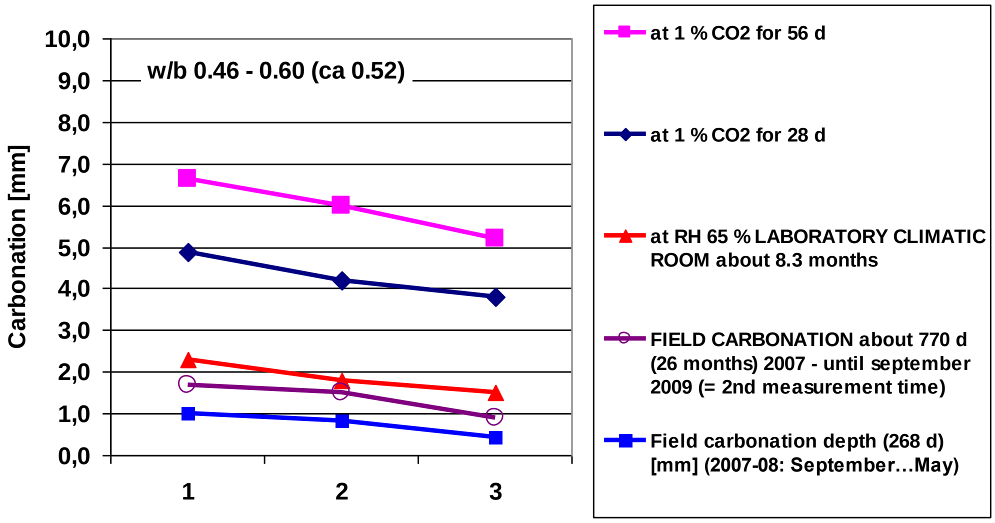


Figure 55. Average carbonation for each specimen surface, when w/b is 0.46 – 0.60 (about 0.52)

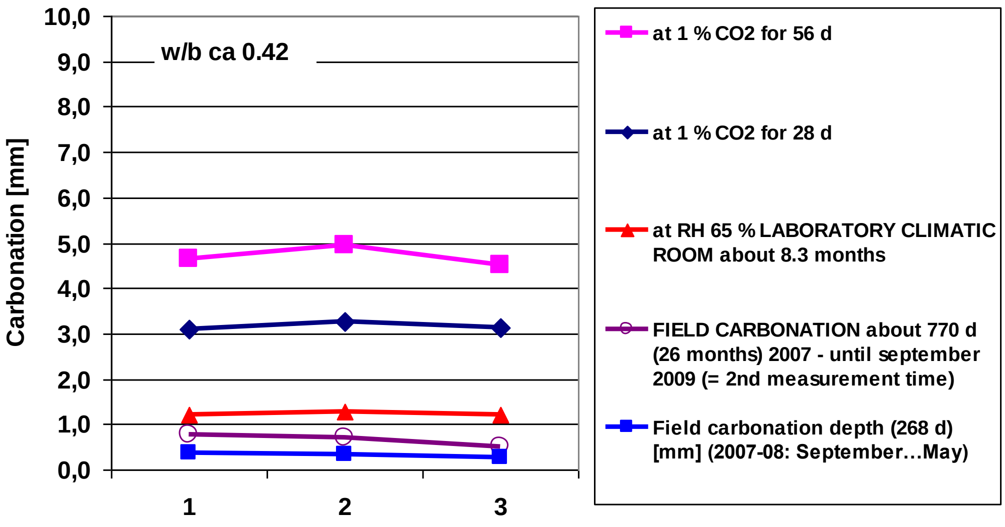


Figure 56. Average carbonation for each specimen surface, when w/b is about 0.42.

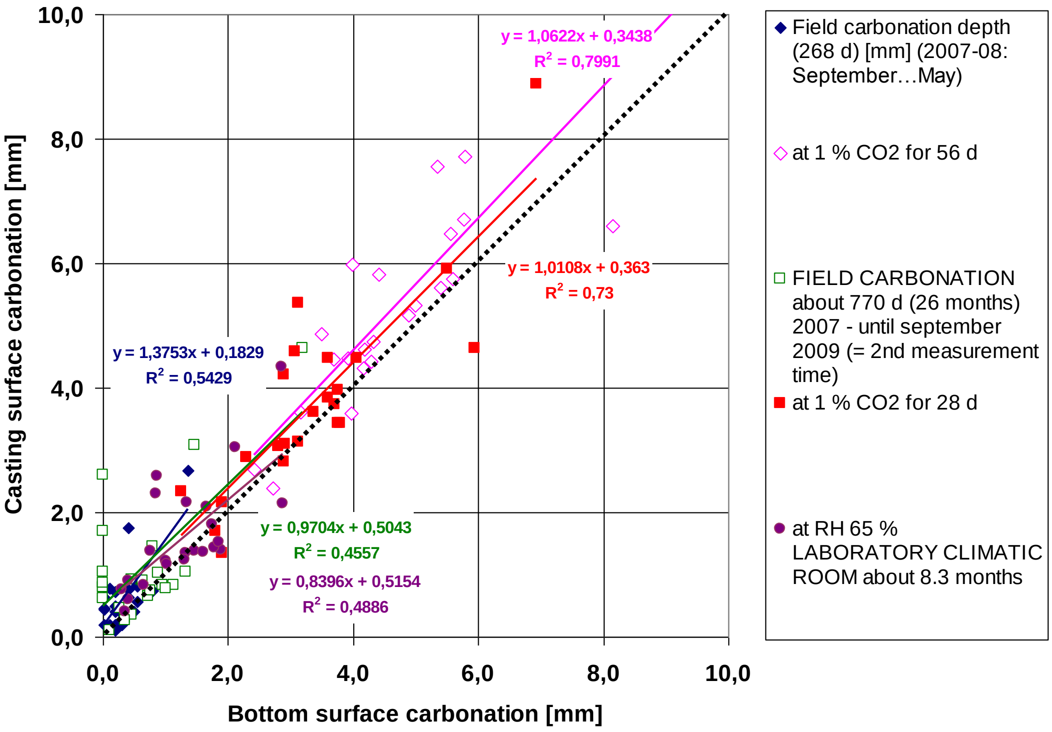


Figure 57. Casting surface carbonation as a function of bottom surface carbonation for all the concretes and all the carbonation cases: lab accelerated at 1% CO_2 after 28 d and 56 d, field after about 8.9 months and 25.7 months and lab storage at RH 65 % after about 8.3 months.

7 FREEZE-THAW STUDIES WITHOUT DE-ICING SALT (FROST)

7.1 General

The aim of these series was to get field testing data and also laboratory testing results on the effect of binding material, w/b ratio, air content and air pore structure on freeze-thaw durability. Laboratory frost testing was done three times for each concrete. It was done both after a normal curing period (28 d) and also after ageing with two methods (see Chapter 7.2).

Laboratory testing results will serve as reference for field testing results. They are also a part in DuraInt Task 3 (Laboratory test with interaction).

7.2 Testing methods

Field specimen (75x150x150 mm^3), (3+1)/concrete) were situated in wooden stands at the Otaniemi-field station with no salt exposure. Frost scaling (volume change) and internal deterioration (RDM by ultrasound and fundamental frequency) was monitored for 3 specimens per each concrete. There is an extra field specimen for future optical thin section studies, e.g. studies on cracking, scaling and carbonation. Thin section studies on field specimens were not included, but can be performed later on, e.g. after 5 - 10 years.

In laboratory accelerated conditions frost scaling and internal deterioration was studied on additional samples by the Slab test with de-ionized water [CEN/TR 15177]. Both internal deterioration by ultrasound and scaling were measured. The total number of freeze-thaw cycles was 56.

Laboratory exposure testing of frost scaling and internal deterioration was studied in all three times:

1. By the standard method and procedure, starting at 28 d with the re-saturation of the specimens [CEN/TR 15177].
2. For most concretes, also as ´aged and carbonated´ after about 1 year of storage at RH 65%. This included the surface drying at RH 65 % (at about 20 ^oC). Testing was started by normal re-saturation of the specimens.
3. For most concretes, frost testing was also performed with ´aged but not carbonated´ specimen. In this case a 10 mm surface layer was sawn off to remove the carbonated layer resulting from the 65 % RH storage. Sawing off the surface layer means also, that testing surface drying degree was also smaller than in testing case 2 above. Testing was started by normal re-saturation of the specimens as soon as possible after the sawing and rubber sheet gluing. Re-saturation was started at the same time for all the specimens. For practical reasons this meant that the specimens had to wait for the re-saturation. Because of that minor surface carbonation (< 2 days at RH 65 %, T = 20 ^oC) was possible.

The idea in the above three-phase testing procedure was to find out the effects of ageing and hydration, and in addition especially to evaluate the relations between surface carbonation and drying on scaling. This three-phase testing was performed for frost attack alone, i.e. with de-ionised water on the surface of the specimen. This testing procedure is similar to the frost-salt scaling studies (see Chapter 8).

7.3 Concretes and timing

There were in all 6 concretes for frost studies. These are concretes nos. 21 – 22 and nos. 25 – 28 in Appendices 6 (mix design), 8 (fresh concrete properties), 12 (hardened concrete properties) and 13 (timing for field specimen casting, curing and start of field testing).

Below the concretes/binding materials are listed according to the w/b ratio. The w/b here is the planned w/b, but this can be somewhat different, especially for factory produced mixes, than the final w/b, which is based on the factory weighing report. The final w/b can be found e.g. in Appendix 6 and is used later on, if e.g. testing results are compared with w/b.

Binding materials with about w/b 0.50 are:

- Valkosementti CEM I 52,5 N (No. 21)
- Rapid cement CEM II/A-LL 42,5 R (No. 22)

Binding materials with about w/b 0.60 are:

- Perussementti CEM II/B-S 42,5 N (No. 25)
- Yleissementti CEM II/A-M(S-LL) 42,5 N (No. 26)
- Valkosementti CEM I 52,5 N (No. 27)
- Rapidsementti CEM II/A-LL 42,5 R (No. 28)

7.4 Results

7.4.1 Laboratory testing results

Laboratory frost testing results are presented in Appendix 19. Information on fresh concrete air content and hardened concrete air pore structure (spacing factor and air pores < 0.300 mm [%] is included. Results are presented graphically in Figures 58 – 62.

The relative dynamic modulus of elasticity (RDM) after frost testing (56 cycles) with three different testing methods (standard and with 2 ageing methods before testing, see Chapter 7.2) is presented in Figure 58. It can be seen, that there is no decrease in RDM in frost testing (after 56 cycles RDM > 1). It can also be seen, that after ageing (ca 1 year) the increase of RDM is normally somewhat higher (6 – 7 % higher) during the initial early age frost testing (56 cycles).

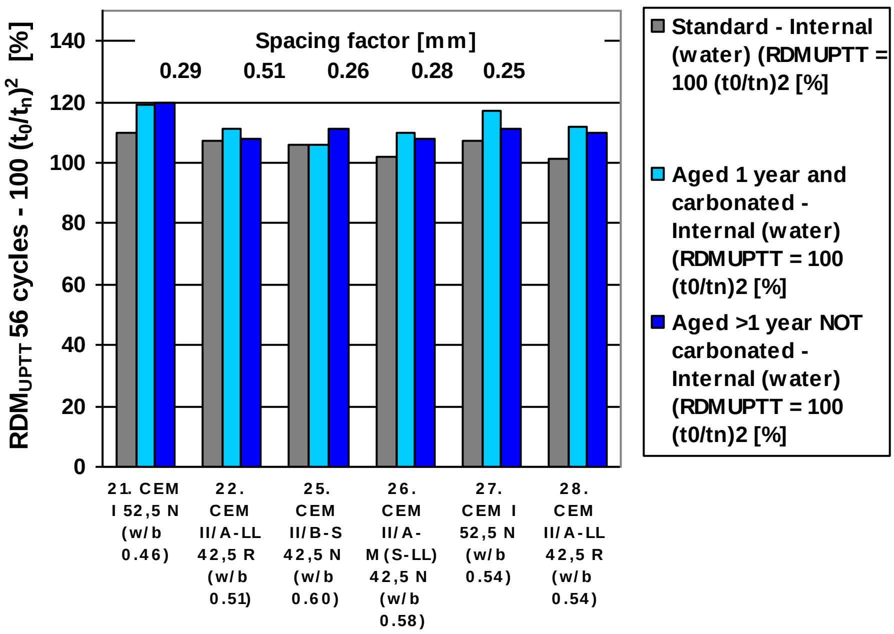


Figure 58. Relative dynamic modulus of elasticity (RDM) after frost testing (56 cycles) with three different testing methods (standard and with 2 ageing methods before testing, see Chapter 7.2 above).

Frost scaling after frost testing (56 cycles) with three different testing methods (standard and with 2 ageing methods before testing, see Chapter 7.2) is presented in Figure 59. It can be seen, that in this case there is clearly increased scaling in three cases (0,259, 0,404 and 0,406 kg/m^2). This scaling was in spite of having de-ionized water on the testing slab surface.

Binding material, w/b, air pore content and structure and also surface ageing do determine when scaling is started (see also Figures 60 – 62, where scaling is presented as a function of the number of frost cycles and Figures 64 – 67, where scaling is presented as a function of different air pore quality parameters). Surface ageing, e.g. hydration, carbonation and drying, does matter as it can change concrete surface layer properties.

In the case of ageing (ca 1 year) without surface carbonation and with a lower drying degree, there was always only small scaling (<0,056 kg/m^2; see Figure 62). The mixes with the lowest content of small air pores (pores < 0,300 mm: 1,4 – 1,6 %) and usually the highest spacing factor (0,28 – 0,51 mm) started to scale earliest. When there was enough small pores (pores < 0,300 mm: 2,4 – 3,1 %) with a small enough spacing factor (0,25 – 0,29 mm) there was always only minimal scaling.

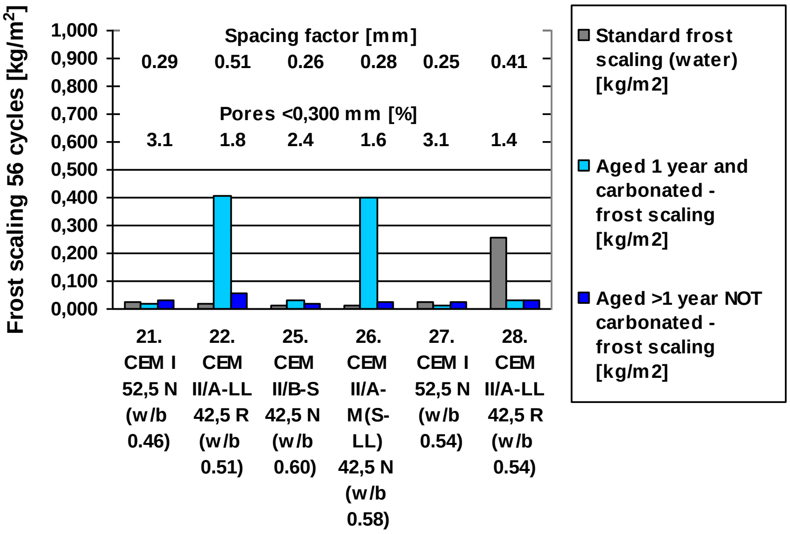


Figure 59. Frost scaling after frost testing (56 cycles) with three different testing methods (standard and with 2 ageing methods before testing, see Chapter 7.2).

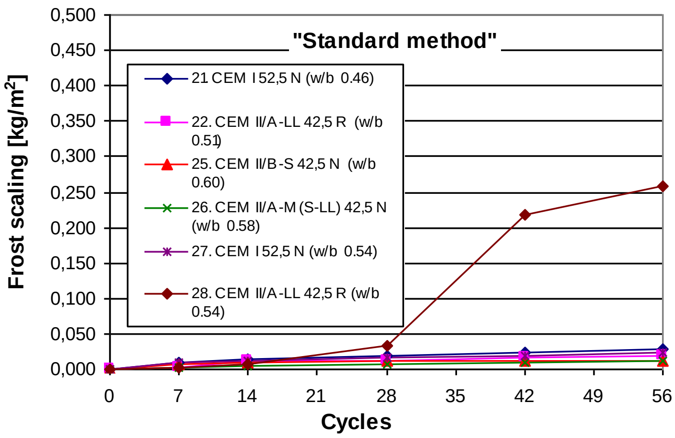


Figure 60. Frost testing by the standard method and procedure [CEN/TR 15177]. Scaling as a function of the number of frost cycles.

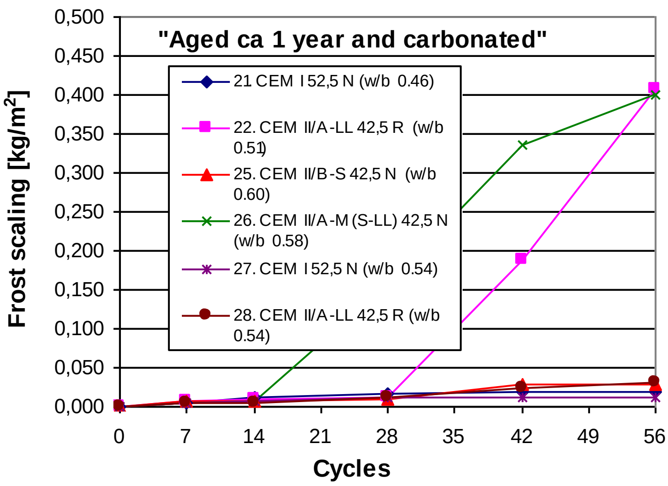


Figure 61. Frost testing as "aged and carbonated" after about 1 year at RH 65%, i.e. including also surface drying at RH 65 % (see Chapter 7.2). Scaling as a function of the number of frost cycles

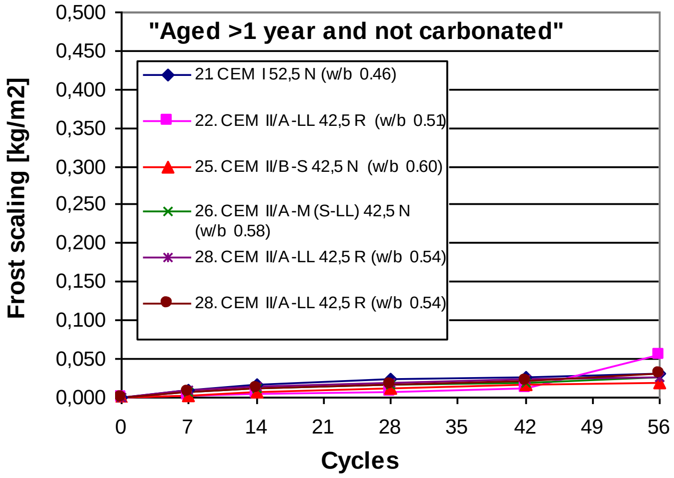


Figure 62. Frost testing as “aged but not carbonated”. In this case the 10 mm surface including at RH 65 % carbonated surface layer was sawn off before testing (see Chapter 7.2). Scaling as a function of the number of frost cycles.

In Figure 63 frost scaling is presented as a function of internal RDM. In Figure 64 RDM is presented as a function of air pore spacing factor measured from thin sections.

In Figure 65 frost scaling is presented as a function of fresh concrete total air content and in Figure 66 as a function of air pores < 0,300 mm in hardened concrete. In Figure 67 frost scaling is presented as a function of spacing factor.

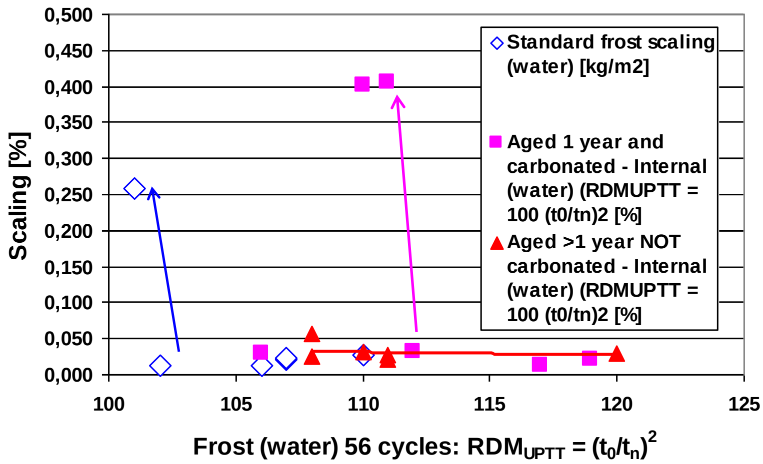


Figure 63. Frost scaling as a function of internal relative dynamic modulus (RDM). Three testing/ageing methods (see Chapter 7.2).

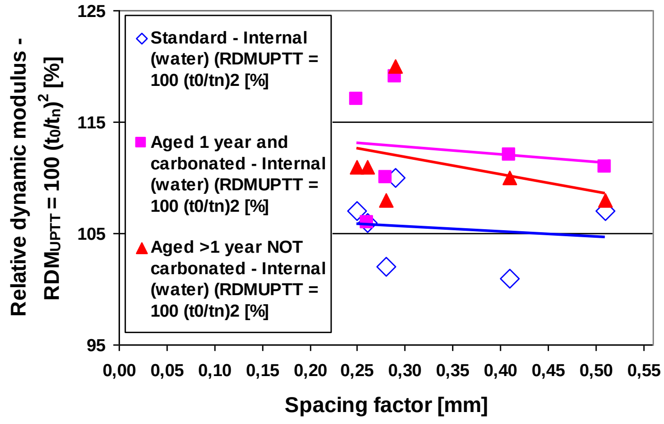


Figure 64. Frost testing (3 methods, see Chapter 7.2). Internal deterioration, i.e. RDM, as a function of spacing factor.

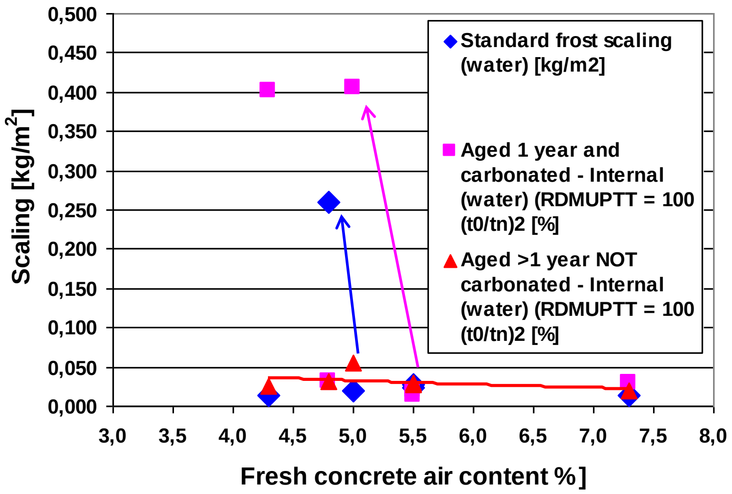


Figure 65. Frost testing (3 methods, see Chapter 7.2). Scaling as a function of fresh concrete air content.

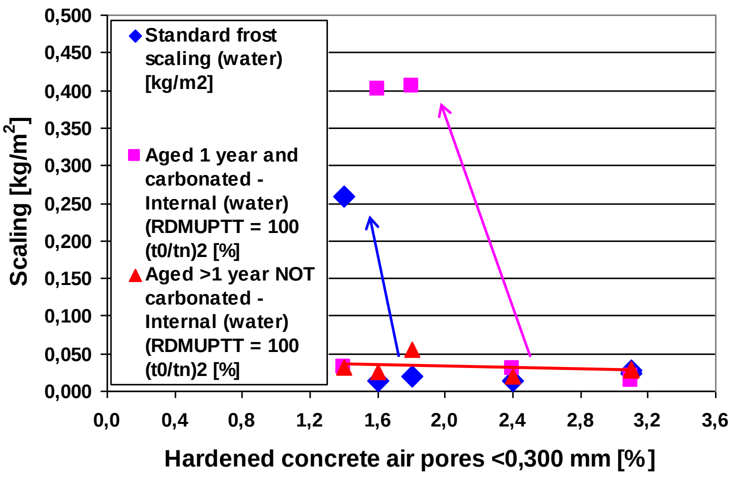


Figure 66. Frost testing (3 methods, see Chapter 7.2). Scaling as a function of air pores < 0.300 mm in hardened concrete.

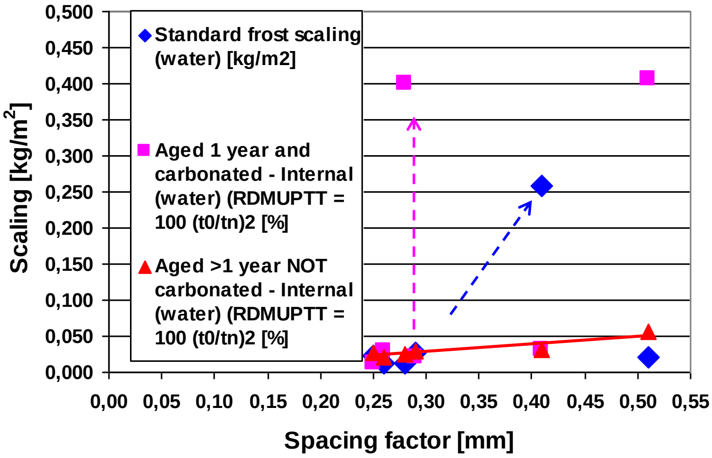


Figure 67. Frost testing (3 methods, see Chapter 7.2). Scaling as a function of spacing factor.

7.4.2 Field testing results (frost, Otaniemi field)

<u>Field testing results (frost, Otaniemi field)</u>

Field testing results are presented in Appendix 20 and Figures 68 – 71.

The relative dynamic modulus of elasticity (RDM, in %) determined by using fundamental frequency (FF) of the specimen after the 1st, 2nd and 3rd winter, and also after the first summer period, is presented in Figure 68. It can be seen for 3 concretes RDM has mainly increased in the field during 2007-10, but for 2 mixes there are no big changes. Increase of RDM is presumably because of strength gain and it also may be because of some increase in moisture content or some other changes. Before every measurement time, all the specimen were maintained 1 d in water and 6 days in RH 65 %, to get as similar as possible moisture content for each measurement time.

A linear correlation was also found between compressive strength (28 d) and fundamental frequency (FF) as well as with ultrasonic pulse transit time (UPTT) (see Figure 70). In this comparison FF and UPPT were measured before the specimen (150 x 150 x 75 mm^3) were moved to the field 2007.

The average standard deviation for RDM in % determined by FF was 1.1 %. There are 3 field specimen/concrete for these measurements. When RDM was measured by ultrasound (ultrasonic pulse transit time, UPTT) average standard deviation for RDM was 1.8 %. These average standard deviation values are based on all the measurements made for field specimen 2007 – 2010.

The average specimen volume change [%] after the 1st, 2nd and 3rd winter, and also after the first summer period, is presented in Figure 69.

Some volume changes are always caused by specimen shrinkage or swelling. Weight and density changes may also be caused by some moisture content variation, in spite of 1 d water uptake before every measurement time. Also carbonation can change the specimen weight. Average densities for the specimen are presented in Figure 71. Weight measurement alone does not give reliable information on the volume change, when it is small and when e.g. cracking causes both volume changes and also weight changes, when the cracks are filled with water.

The average standard deviation for specimen volume change was 0.519 cm^3 (in all from 0.035 to 2.022 cm^3). There are 3 field specimen/concrete for these measurements and the size of each specimen is ca 15 x 15 x 7,5 cm^3. Based on this field specimen size the average calculated standard deviation for volume change in % is ca 0.03 % (in all from 0.00 % to 0.12 %). These average standard deviation values are based on all the measurements made for field specimen 2007 – 2010.

After 3 winter (spring 2010) relative dynamic modulus of elasticity for field frost specimen (150x150x75 mm^3) was in all 97 % - 106 % (6 air entrained concretes). Volume degrease was in all 0.27 – 0.49 % and there was no clear scaling detected.

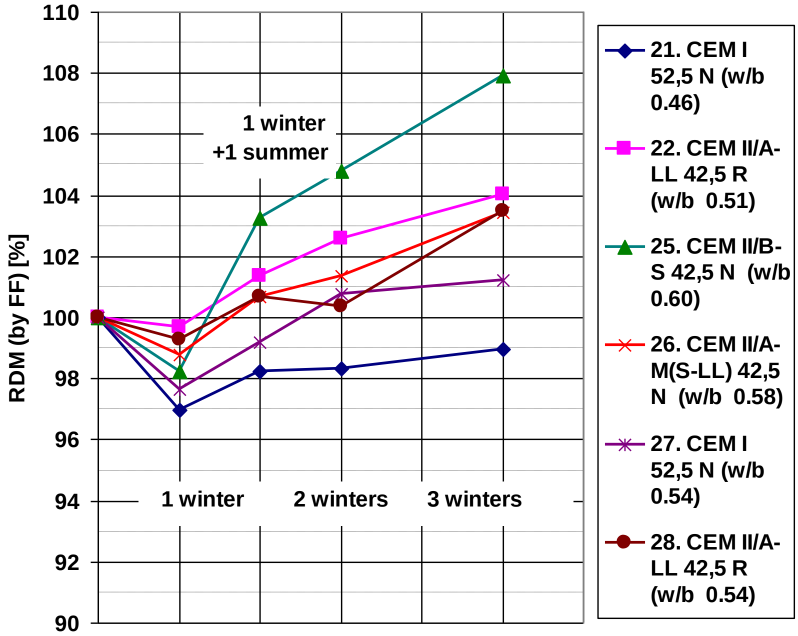


Figure 68. Otaniemi field for freeze-thaw without salt (frost, 2007 - 2010). Relative dynamic modulus (RDM) by FF of the specimen after the 1^{st}, 2^{nd} and 3^{rd} winter, and also after the first summer period (1 winter + 1 summer). Averge standard deviation for FF is 1.1 %.

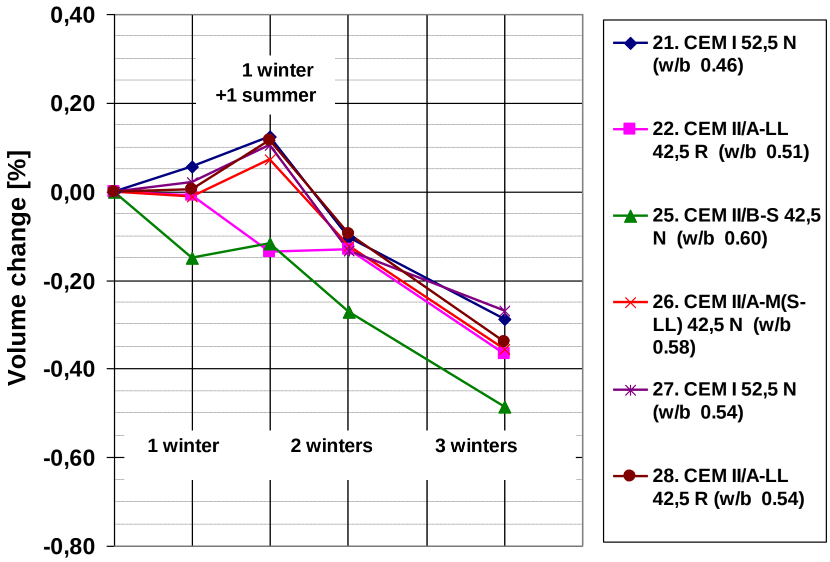


Figure 69. Otaniemi field for freeze-thaw without salt (frost, 2007 - 2010). Volume change after the 1st, 2nd and 3rd winter, and also after the first summer period (1 winter + 1 summer). First measurement when delivered to field Autumn 2007. Volume increase is positive (+).

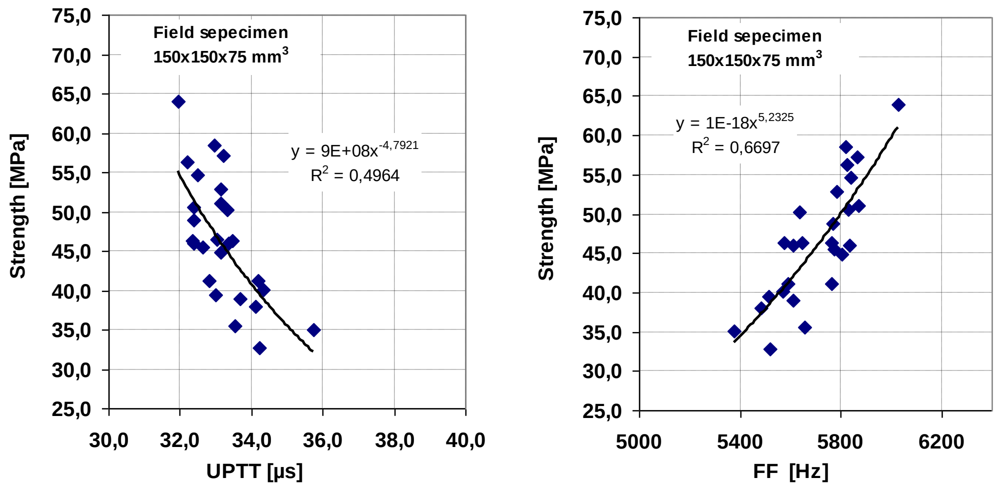


Figure 70. Ultrasonic pulse transit time (UPTT) and fundamental frequency (FF) as a function of 28 d compressive strength. UPPT and FF results for field specimen (average values autumn 2007, 3 specimen/concrete). All frost and frost-salt specimen are included.

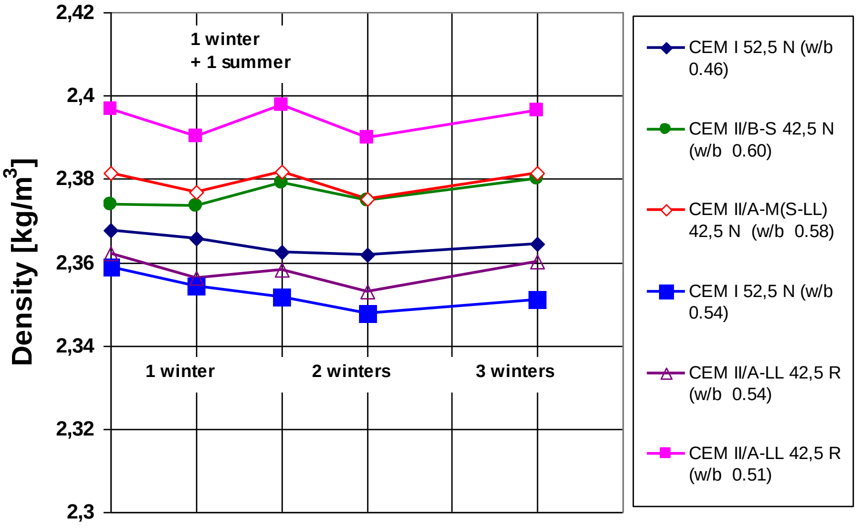


Figure 71. Otaniemi field for freeze-thaw without salt (frost, 2007 - 2010). Specimen densities 2007 – 2010. First measurement when delivered to field Autumn 2007.

8 FREEZE-THAW STUDIES WITH DE-ICING SALT (FROST-SALT)

8.1 General

The aim of these test series was to get field testing data and also laboratory testing results on the effect of binding material, w/b ratio, air content and air pore structure on freeze-thaw durability with de-icing salt, i.e. frost-salt resistance. Laboratory freeze-thaw testing was done three times for each concrete, as it was done in the case of frost testing (see Chapter 7). It was done both after a normal curing period (28 d) and also after ageing with two methods (see Chapter 8.2).

Laboratory testing results will serve as reference for field testing results. They are also a part in DuraInt Task 3 (Laboratory test with interaction).

8.2 Testing methods

The field specimen (75x150x150 mm^3), (3+1)/concrete) were situated in wooden stands on HW 7 field with salt exposure. Frost scaling (volume change) and internal deterioration (RDM by ultrasound and fundamental frequency) was monitored for 3 specimens per each concrete. There is an extra field specimen for future optical thin section studies, e.g. studies on cracking, scaling and carbonation. Thin section studies are not included here, but can be performed later on, e.g. after 5 - 10 years.

In the laboratory frost-salt scaling and internal deterioration were studied by the Slab test with 3 % salt (NaCl) solution [CEN/TS 12390-9]. Both internal deterioration by ultrasound and scaling were measured. The total number of cycles was 56.

In the laboratory frost-salt scaling and internal deterioration were studied in all three times:

1. By the standard method and procedure starting at 28 d with the re-saturation of the specimens [CEN/TS 12390-9].
2. For most concretes also as ´aged and carbonated´ after about 1 year at RH 65%, i.e. including also surface drying at RH 65 % (at about 20 ^{o}C). Testing was started normally by re-saturation of the specimens.
3. For most concretes, frost testing was also performed with ´aged but not carbonated´ specimen. In this case a 10 mm surface layer was sawn off to remove the carbonated layer resulting from the 65 % RH storage. Sawing off the surface layer means also, that testing surface drying degree was also smaller than in testing case 2 above. Testing was started by normal re-saturation of the specimens as soon as possible after the sawing and rubber sheet gluing. Re-saturation was started at the same time for all the specimens. For practical reasons this meant that the specimens had to wait for the re-saturation. Because of that minor surface carbonation (< 2 days at RH 65 %, T = 20 ^{o}C) was possible.

In the testing case 2, i.e. with carbonation, it was studied if the carbonation depth was more than the scaling depth after carbonation. This study included measurement of carbonation of the sawn testing surface (or actually corresponding surfaces carbonated at the same place, i.e. at RH 65 %, as frost-salt specimen surfaces). In addition after frost-salt testing scaling depth was measured by point-count method for 20 specimens. A correlation of the scaling depth and scaling degree in terms of kg/m^2 was established and used for all the concretes.

For the four (4) concretes cast in spring 2008 and including the separate Yleissementti CEM II/A-M(S-LL) 42.5 N testing series (see below), frost-salt testing was done with only the standard method [CEN/TS 12390-9].

The idea in the above three-phase testing procedure was to find out the effects of ageing and hydration, and in addition especially identify the influence of surface carbonation and drying on scaling. One future aim is to find if the correlation of laboratory testing with field testing is improved when aged specimen surfaces are used in the testing. Here the ageing was quite long term (ca. one year at RH 65 %), but could also be somehow accelerated. Anyway, it was considered here useful to have results with this non-accelerated ageing method.

8.3 Concretes and timing

There were in all 21 concretes for frost-salt studies. These are concretes nos. 6 – 20, 22, 23 and 29 – 32 in Appendices 6 (mix design), 8 (fresh concrete properties), 12 (hardened concrete properties) and 13 (timing for field specimen casting, curing and start of field testing).

Below the concretes/binding materials are listed according to the w/b ratio. The w/b reported here is the planned w/b, but this can be somewhat different, especially for factory produced mixes, than the final w/b, which is based on the factory weighing report. The final w/b can be found e.g. in Appendix 6 and is used later on, if e.g. testing results are compared with w/b.

<u>Binding materials with about w/b 0.42 are:</u>

- Perussementti CEM II/B-S 42.5 N (No. 6)
- SR-sementti CEM I 42.5 N - SR (No. 7)
- Yleissementti CEM II/A-M(S-LL) 42.5 N (No. 8)
    - with Yleissementti CEM II/A-M(S-LL) 42.5 N also an additional year 2007 testing series with different air contents – in all 6 concretes (Nos. 13 – 18)
        - includes 2 SCC-mixes,
        - from no air entrainment to 7.0 % air.
    - with Yleissementti CEM II/A-M(S-LL) 42.5 N also an additional year 2008 testing series with different air contents – in all 4 concretes (Nos. 29 – 32)
        - from no air entrainment to 6.8 % air
- Rapidsementti CEM II/A-LL 42.5 R (No. 9)
- Pikasementti CEM I 52.5 R (No. 10)
- Rapidsementti CEM II/A-LL 42.5 R + 50 % Finnsementti SLG KJ400 (No. 11)

- Rapidsementti CEM II/A-LL 42.5 R
  + 24 % FA [EN 450-1. 2005] Fineness N, Class A (No. 12)

Binding materials with about w/b 0.50 are:

- Perussementti CEM II/B-S 42.5 N (No. 19)
- Yleissementti CEM II/A-M(S-LL) 42.5 N (No. 20)
- Rapidsementti CEM II/A-LL 42.5 R (No. 22)

8.4 Results

8.4.1 Laboratory testing results

The laboratory frost-salt testing results are presented in Appendix 21. Information on fresh concrete air content and hardened concrete spacing factor measured by thin sections is included. The results are presented graphically in Figures 72 – 82. Some simple correlations are presented in Figures 83 – 90.

Different binding materials, w/b 0.41 – 0.51, with air entrainment (ca. 5.7 %)

The relative dynamic modulus of elasticity (RDM) after frost salt testing (56 cycles) with three different testing methods (standard and with 2 ageing methods before testing, see Chapter 7.2) for air entrained concretes (nos. 6 – 12, 19, 20, 22 and 23) with different binding materials and w/b-values (0.40 - 0.42 or 0.50) is presented in Figure 72. It can be seen that there was normally no decrease in RDM in frost-salt testing (after 56 cycles RDM > 1). It can also be seen, that after ageing (ca 1 year) the increase of RDM was normally somewhat higher (average 5 %) during the frost salt testing (56 cycles).

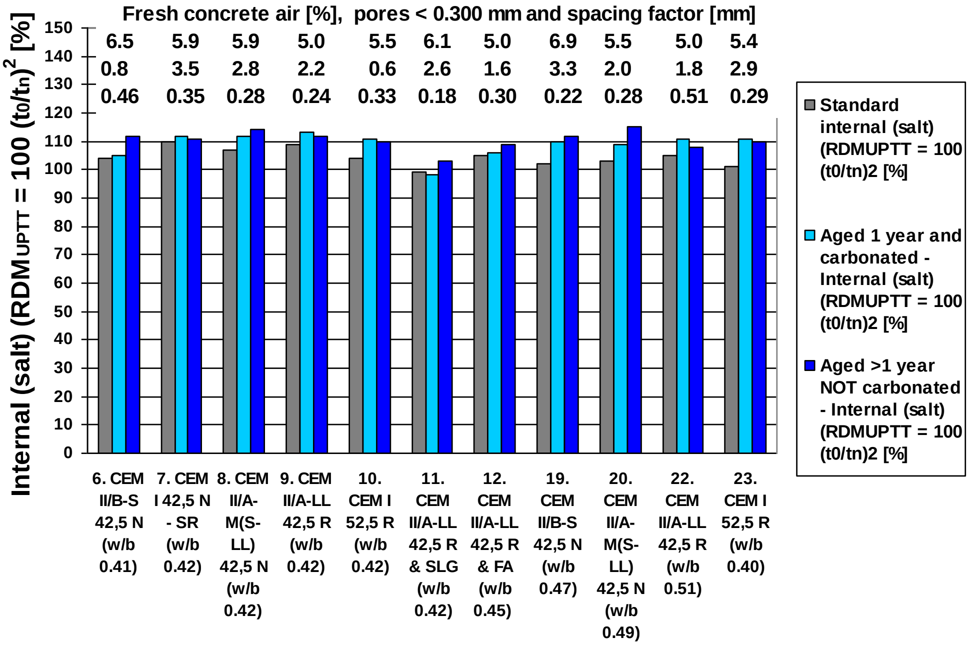


Figure 72. Relative dynamic modulus of elasticity (RDM) after frost salt testing (56 cycles) with three different testing methods (standard at 28 d and with 2 ageing methods before testing, see Chapter 8.2).

The scaling after frost salt testing (56 cycles) with three different testing methods (standard and with 2 ageing methods before testing, see Chapter 8.2) for the above air entrained concretes (nos 6 – 12, 19, 20, 22 and 23) is presented in Figure 73.

Binding material, w/b, air pore content and structure, and also surface ageing (i.e. carbonation and drying, which both can change cement paste pore structure and its properties, e.g. permeability, in the surface layer) can be expected to define the degree of scaling (see also Figures 75 – 77, where scaling is presented as a function of the number of frost cycles and Figures 83 – 85 and 87 – 89, where scaling is presented as a function of different air pore quality parameters).

For the testing case 2 (i.e. with carbonated surface, see Chapter 8.2) both the measured carbonation depth and estimated scaling depths are presented in Figure 74. It can be seen, that essentially the carbonation depth was always higher than the scaling depth. This means that the scaled material was always carbonated material.

There was always more scaling after ca 1 year hydration at RH 65 % with surface carbonation and drying (testing method 2) than after standard testing at 28 d according to (testing method 1) [CEN/TS 12390-9]. On an average this increase in scaling was from 0.21 kg/m^2 to 0.81 kg/m^2. For concrete no. 10 this increase was high, from 0.075 kg/m^2 to 1.549 kg/m^2, but for e.g. concrete no. 23 only from 0.390 kg/m^2 to 0.492 kg/m^2. (see Figure 73 below).

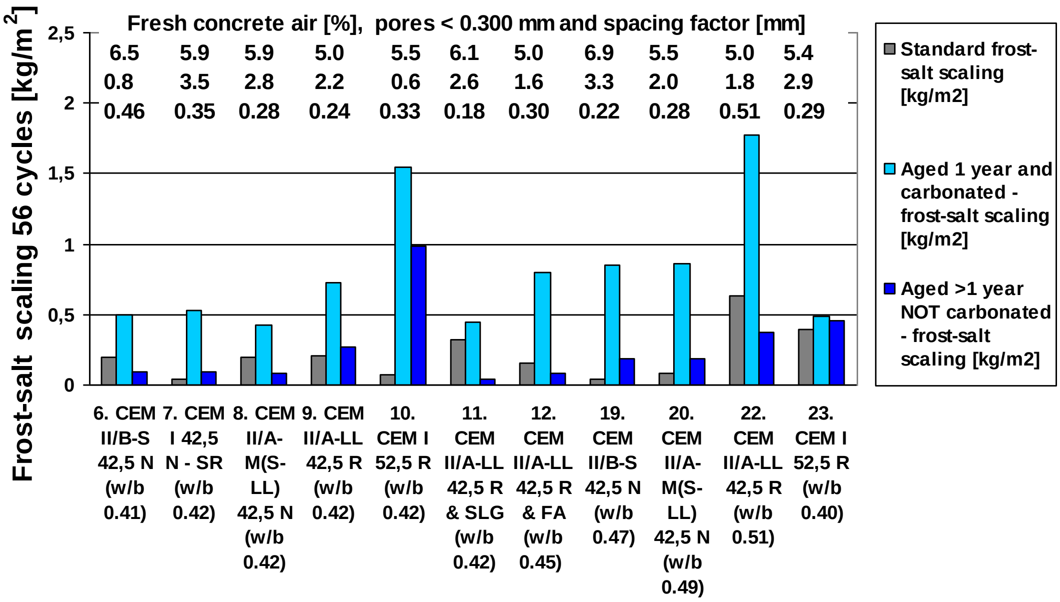


Figure 73. Frost salt scaling after frost testing (56 cycles) with three different testing methods (standard at 28 d and with 2 ageing methods before testing, see Chapter 8.2).

But instead, if after >1 year hydration at RH 65 %, there was no surface carbonation, and besides drying degree was less (because the outermost 10 mm surface of the specimen was sawn off before frost salt testing (testing method 3), there was normally either a small decrease or small increase in scaling compared with the scaling with standard testing at 28 d according to [CEN/TS 12390-9] (see Figures 73 below). On an average there was a small increase in scaling from 0.21 kg/m^2 to 0.26 kg/m^2, but this average increase was mainly because of one concrete (no. 10). If this concrete is not counted, there was on average a small decrease in scaling from 0.20 kg/m^2 to 0.19 kg/m^2.

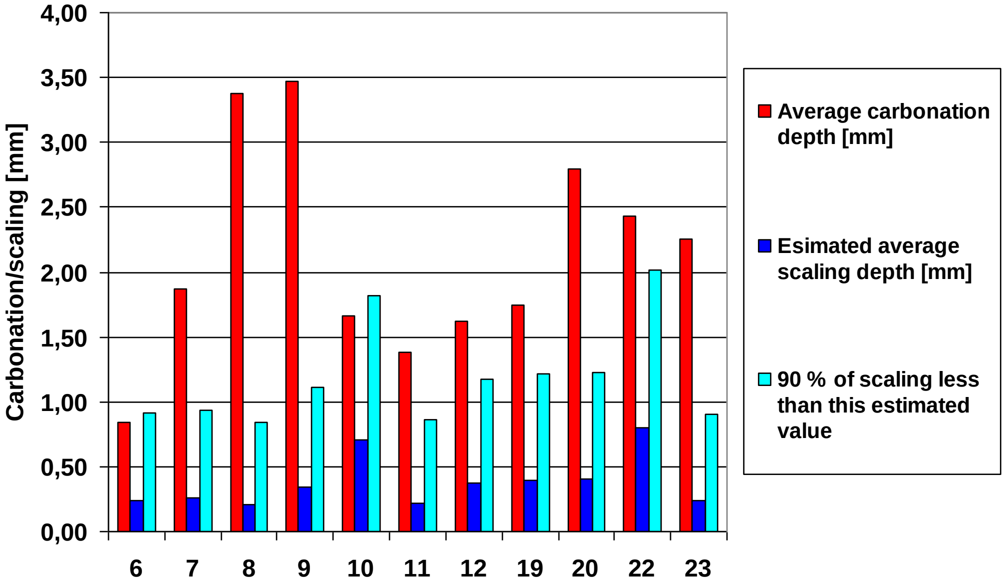


Figure 74. Average estimated carbonation and scaling depths and estimated scaling depth representing 90 % of all scaled material for frost-salt specimen in the testing case 2, i.e. with carbonation (see Chapter 8.2).

In Figures 75 – 77 the surface scaling is presented as a function of the number of cycles in all three testing cases (see Chapter 8.2) in above Figure 73.

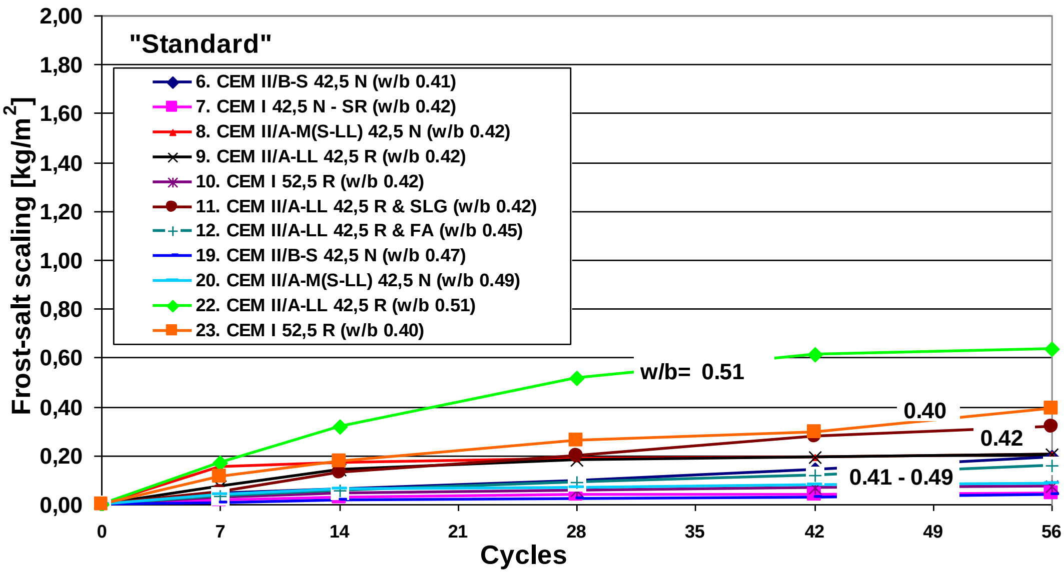


Figure 75. Frost salt testing by the standard method and procedure [CEN/TR 15177]. Scaling as a function of the number of cycles.

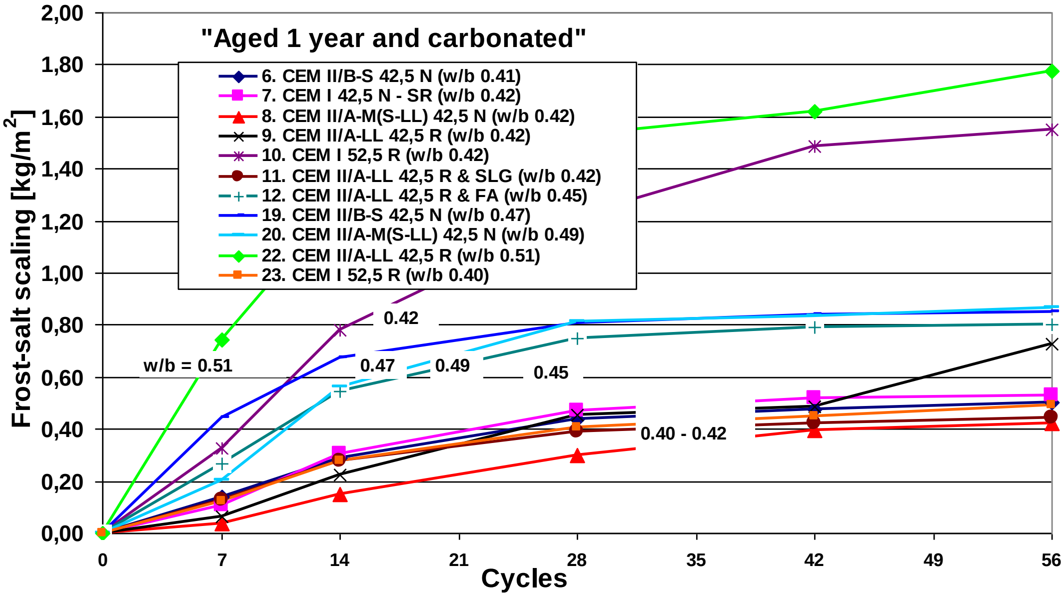


Figure 76. Frost salt testing as "aged and carbonated" after about 1 year at RH 65%, i.e. including also the surface drying at RH 65 % (see Chapter 8.2). Scaling as a function of the number of cycles.

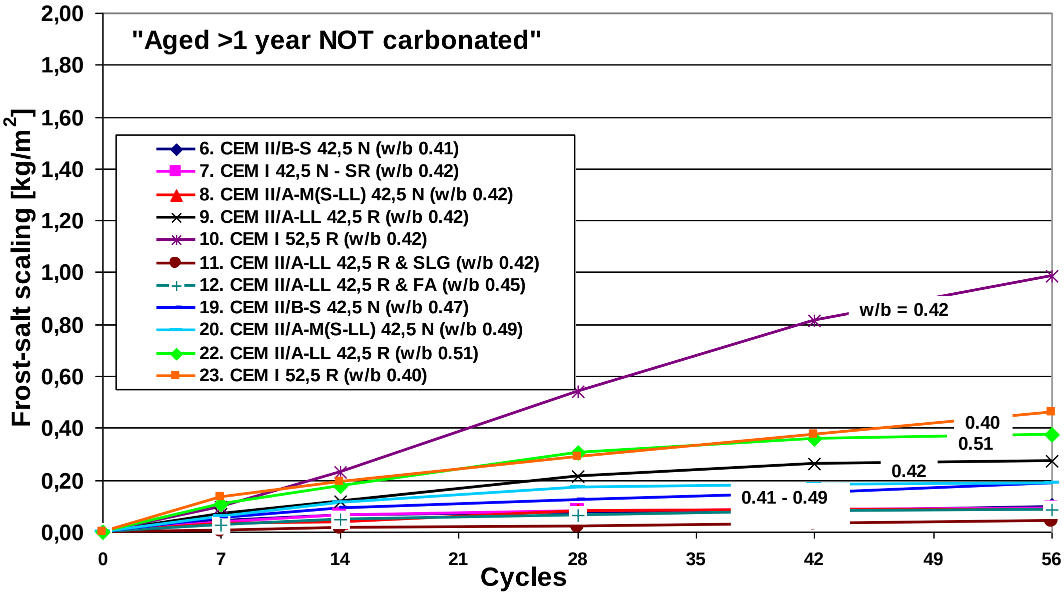


Figure 77. Frost salt testing as "aged but not carbonated". In this case the 10 mm surface including at RH 65 % carbonated surface layer was sawn off before testing (see Chapter 8.2). Scaling as a function of the number of cycles.

Based on the results in Figures 75 - 77 above, it can be concluded that hydration and all kind of ageing, and especially surface ageing by carbonation and drying, may significantly interact with frost-salt scaling. This is in agreement with past experience and literature.

The effect of drying only was clearly less significant than the effect of drying and carbonation (at RH 65 %). It must however be noted that drying of the carbonated specimen surfaces was more intensive than drying of the specimen with non-carbonated surface. This was because for the non-carbonated specimen a 10 mm surface layer (with carbonation and drying) was sawn off, and drying degree at 10 mm depth was not as high as drying degree of the initial carbonated surface.

Carbonation and drying is known to change concrete permeability. In unfavourable cases, e.g. with high enough slag content in concrete, coarsening and increase of continuity of pores happens. An increase of freezable water content and at the same time a decrease in the efficiency of protective air pores is possible. In the case of concrete no. 10, these changes may have caused the inferior frost-salt scaling resistance after ageing. More knowledge is still needed to properly consider all the effects and especially surface layer ageing on overall concrete quality and e.g. on frost salt scaling resistance. It should also be studied how much natural field ageing will affect frost salt scaling in different cases and environments. Binding material and also other material properties of concrete such as air pore content and structure should be considered, as well as chemical ageing and surface carbonation and drying at field. In addition, changes to the concrete pore structure with different binding materials after exposure to chloride solution plays a role. [Thomas & Jennings 2006, Espinosa & Franke 2006, Parrot 1992, Panesar & Chidiac 2009]

CEM II/A-M(S-LL) 42.5 N, w/b 0.41 – 0.42, different air contents (no air entrainment – 7.0 %)

With one cement CEM II/A-M(S-LL) 42.5 N and basically one w/b (0.41 – 0.42) the effect of air entrainment on frost salt scaling was studied more closely.

The values for relative dynamic modulus (RDM) after frost salt testing (56 cycles) are presented in Figure 78. The results here are also mostly (6/10) with three different testing methods (standard and with 2 ageing methods before testing, see above). The effect of air entrainment on RDM can be seen. For properly enough air entrained concretes, RDM increased here during the testing (see Figure 72 above). This happened more clearly after ageing, i.e. with higher hydration time (about 1 year). For many concretes the RDM was lowered and could not be measured properly because of heavy scaling. This happened especially in the standard testing cases (at 28 d age).

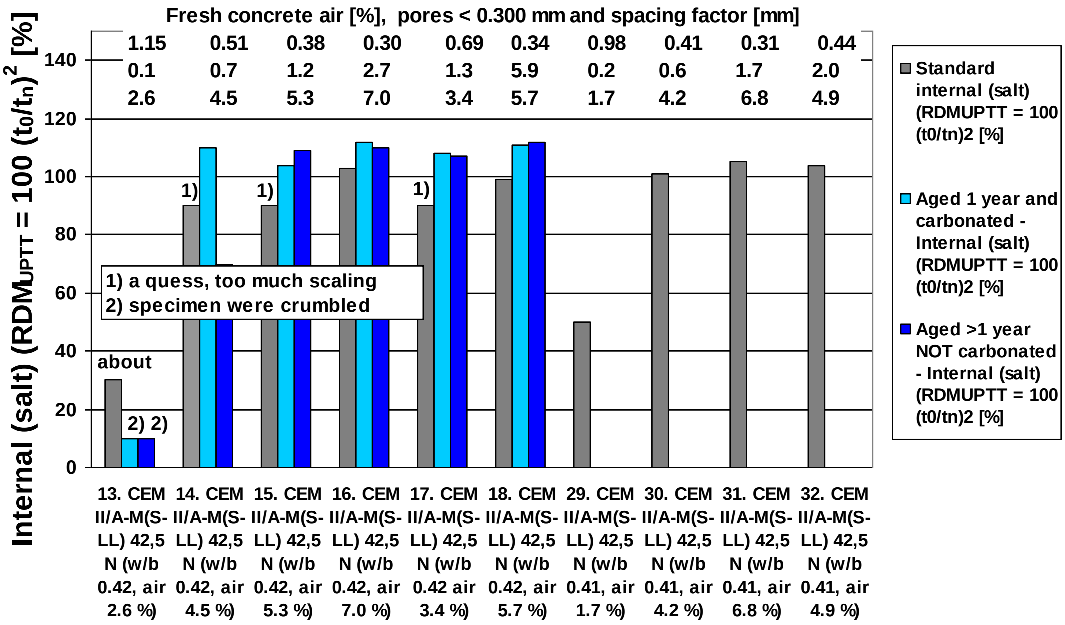


Figure 78. Relative dynamic modulus of elasticity (RDM) after frost salt testing (56 cycles). For 6 concretes with three different testing methods (standard and with 2 ageing methods before testing, see Chapter 8.2) and for 4 concretes with only standard method (at 28 d, method 1).

Scaling after frost salt testing (56 cycles) for the concretes with different air contents and qualities is presented in Figure 79. The results are mostly (6/10) with three different testing methods (standard and with 2 ageing methods before testing, see above and Chapter 8.2).

In Figures 80 - 82 the surface scaling is presented as a function of the number of cycles in the frost salt testing in all the three testing cases (see Chapter 8.2) in Figure 79.

The effect of air entrainment is even clearer than in the case of internal deterioration (see Figure 7). Here the relatively high air content (e.g. 5.3 %) did not guarantee low scaling. This was because there were many relatively big pores or compaction pores, and the amount of pores <0.300 mm was not high enough (see the added information on air pore structure in Figure 79). It can be concluded, that proper air entrainment is essential for low frost salt scaling (laboratory testing, slab test) both with and without ageing and surface carbonation and/or drying (here with CEM II/A-M(S-LL) 42.5 N and w/b 0.41 – 0.42).

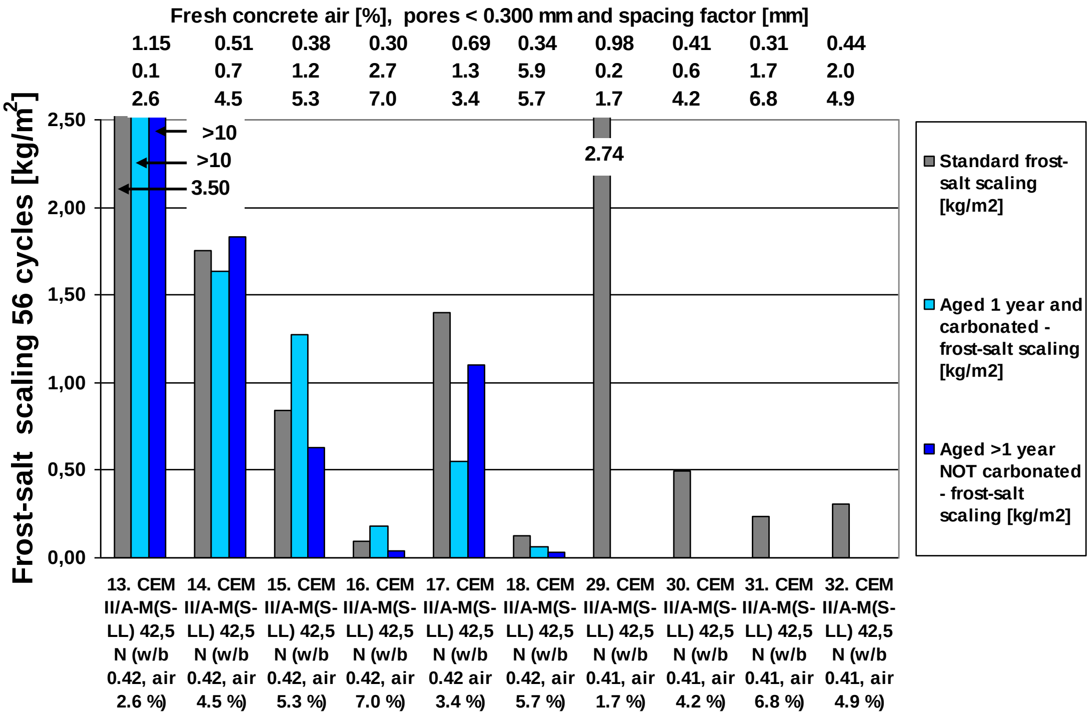


Figure 79. Scaling after frost salt testing (56 cycles). For 6 concretes with three different testing methods (standard and with 2 ageing methods before testing, see Chapter 8.2). For 4 concretes with only standard method (at 28 d, method 1).

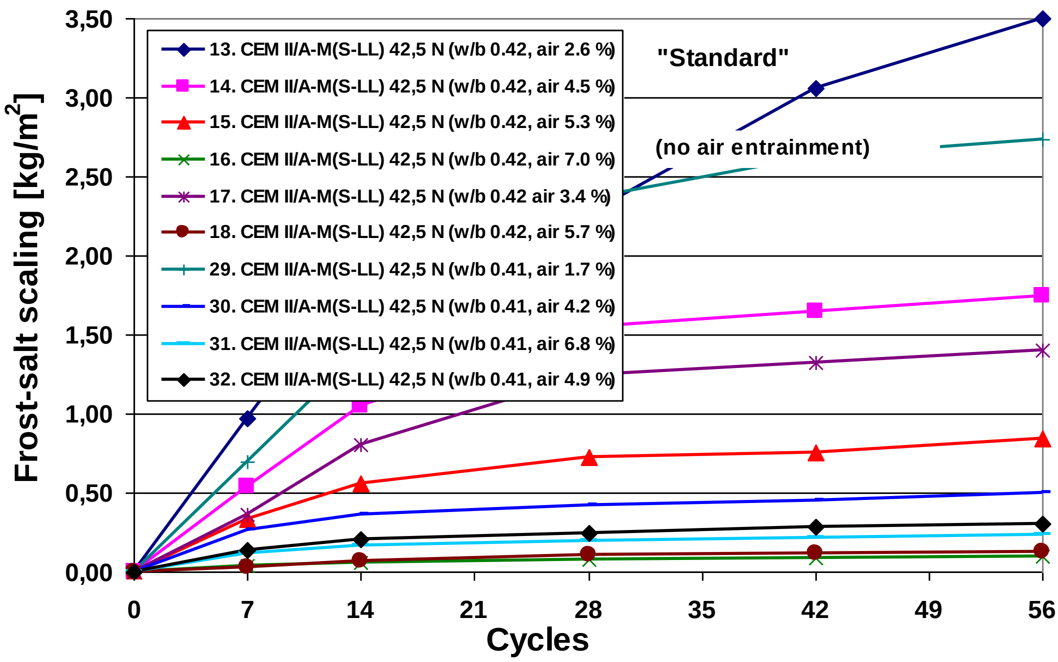


Figure 80. Frost salt testing by the standard method and procedure [CEN/TR 15177]. Scaling as a function of the number of cycles.

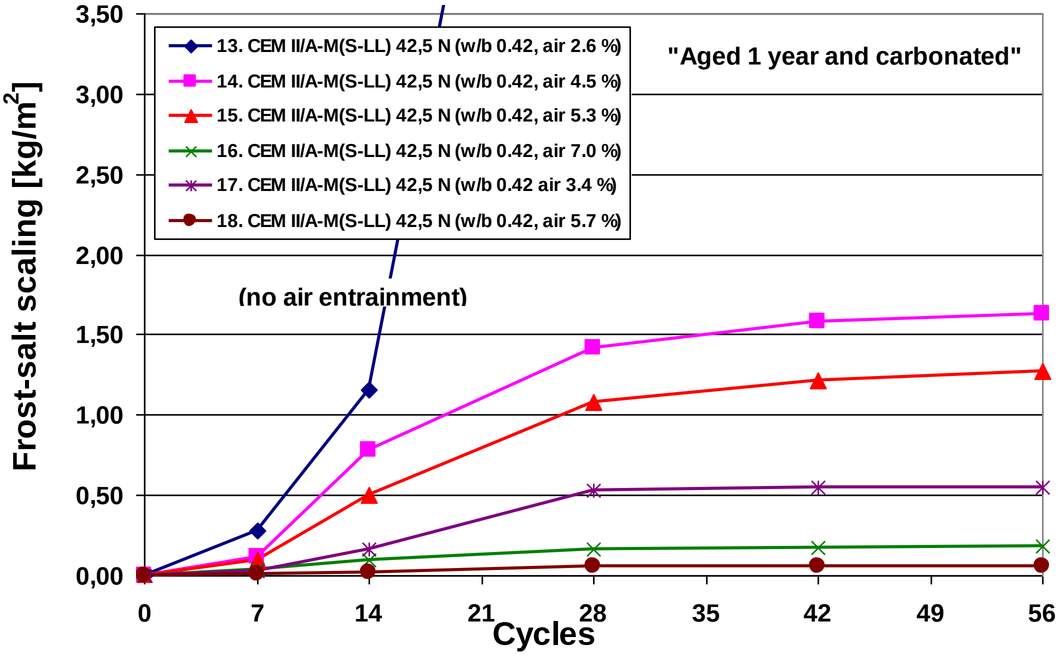


Figure 81. Frost salt testing as "aged and carbonated" after about 1 year at RH 65%, i.e. including also the surface drying at RH 65 % (see Chapter 8.2). Scaling as a function of the number of cycles.

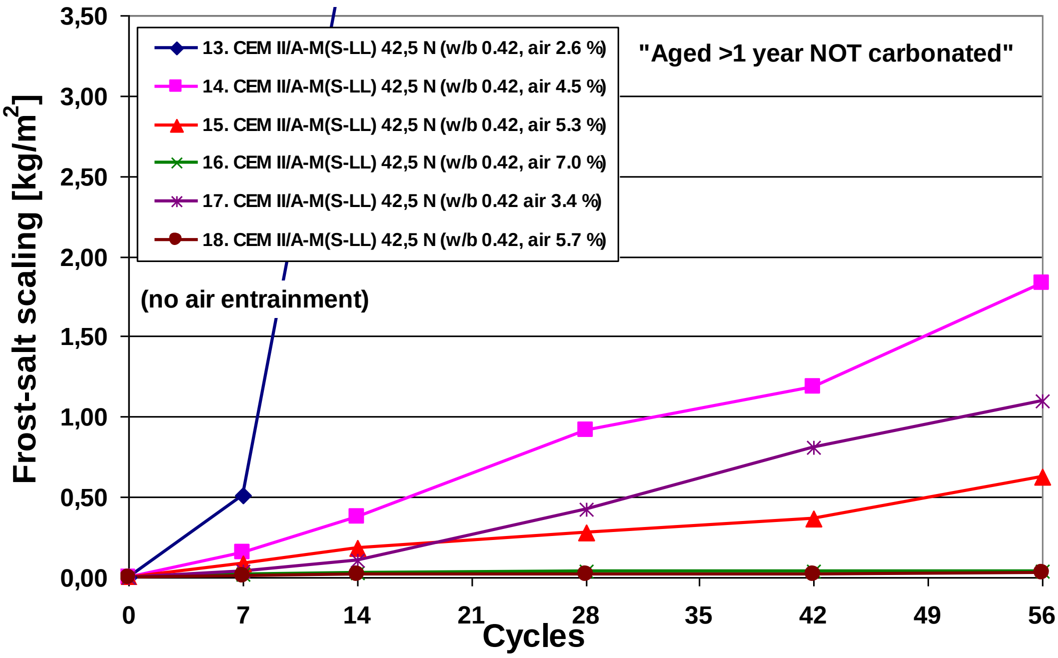


Figure 82. Frost salt testing as "aged but not carbonated". In this case the 10 mm surface including at RH 65 % carbonated surface layer was sawn off before testing (see Chapter 8.2). Scaling as a function of the number of cycles.

<u>General correlations</u>

In Figure 83 the internal deterioration is presented as a function of the spacing factor as measured by thin sections. In Figure 84 the surface scaling is presented as a function of the fresh concrete air content.

In Figure 85 both the spacing factor and the content of pores <0.300 mm in hardened concrete are presented as a function of the fresh concrete air content for all the concretes in the above frost salt testing. In Figure 86 only the concretes with CEM II/A-M(S-LL) 42.5 N and basically one w/b (0.41 – 0.42) but with different air contents are included. The spacing factor is relatively high, especially in Figure 86, compared with the fresh concrete total air content (see also Chapter 4 – Fresh and hardened concrete properties).

In Figure 87 the frost-salt scaling is presented as a function of a) fresh concrete air content, b) pores <0.300 mm in hardened concrete and c) hardened concrete spacing factor. All the binding materials and air contents in the frost salt testing are included.

Instead, in Figures 88 - 90 only concretes with CEM II/A-M(S-LL) 42.5 N, w/b 0.41 – 0.42 but with different air contents are included. In Figure 80 the frost-salt scaling is presented as a function of fresh concrete air content, in Figure 81 as a function of content of pores <0.300 mm in hardened concrete and in Figure 90 as a function of hardened concrete spacing factor.

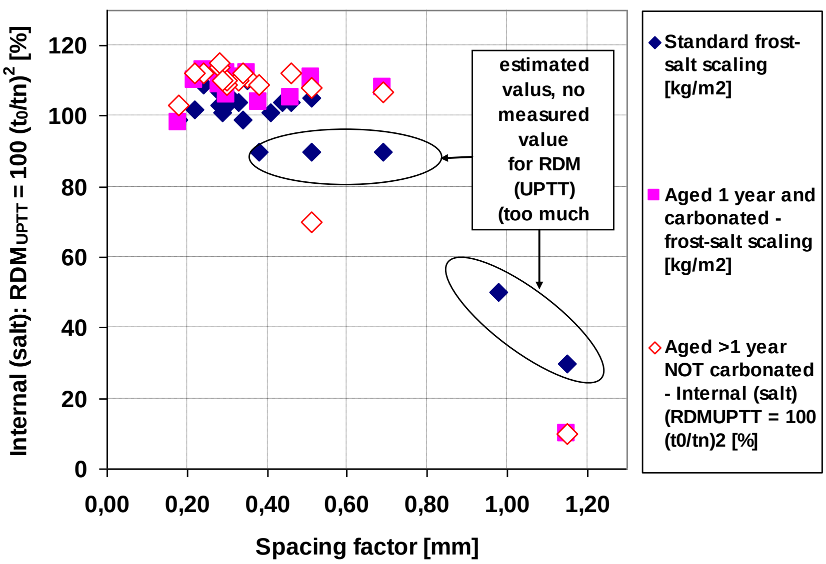


Figure 83. Internal deterioration (RDM) after frost salt testing (56 cycles) as a function of air pore spacing factor. In the case of only estimated values for RDM, specimen were so scaled that it was not possible to measure RDM properly by ultrasound sensors.

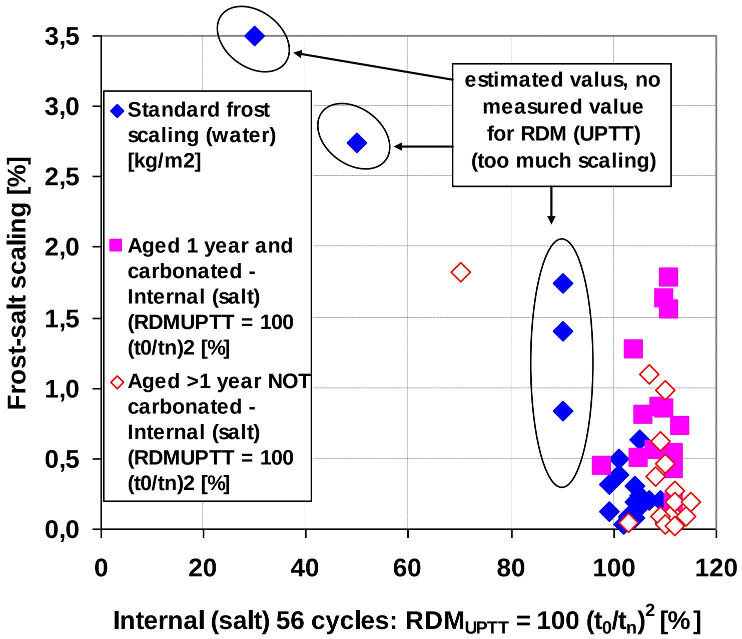


Figure 84. Frost salt scaling (56 cycles) as a function of internal deterioration (RDM). In the case of only estimated values for RDM, specimen were so scaled that it was not possible to measure RDM properly by ultrasound sensors.

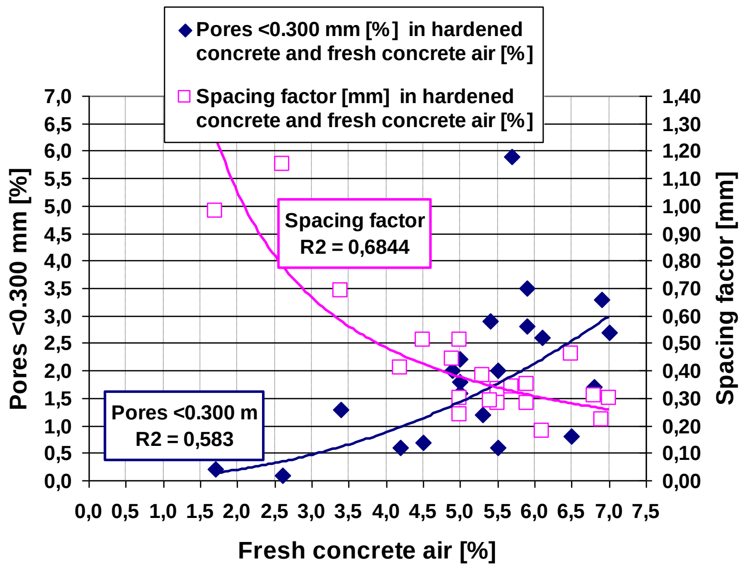


Figure 85. All the concretes for frost salt testing. Spacing factor and content of pores <0.300 mm in hardened concrete as a function of fresh concrete air content.

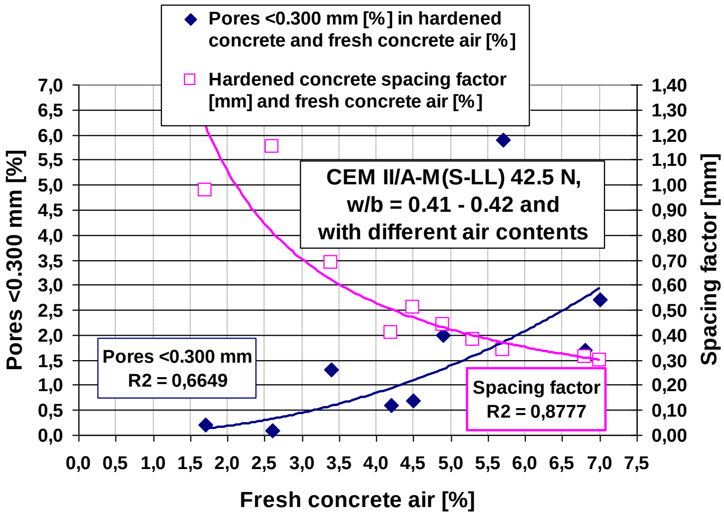


Figure 86. Concretes with CEM II/A-M(S-LL) 42.5 N and basically one w/b (0.41 – 0.42) but with different air contents. Spacing factor and content of pores <0.300 mm in hardened concrete as a function of fresh concrete air content.

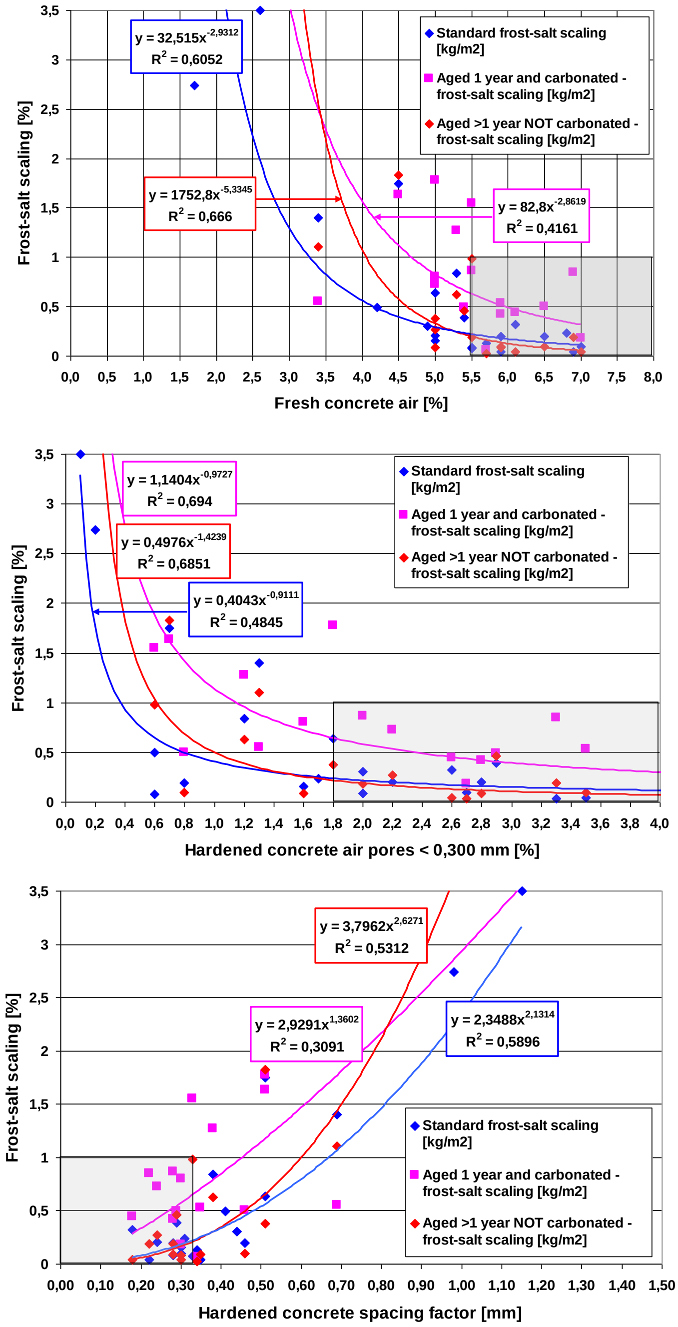


Figure 87. Frost-salt scaling as a function of a) fresh concrete air content, b) content of pores <0.3 mm in hardened concrete and c) hardened concrete spacing factor. All the binding materials and air contents are included.

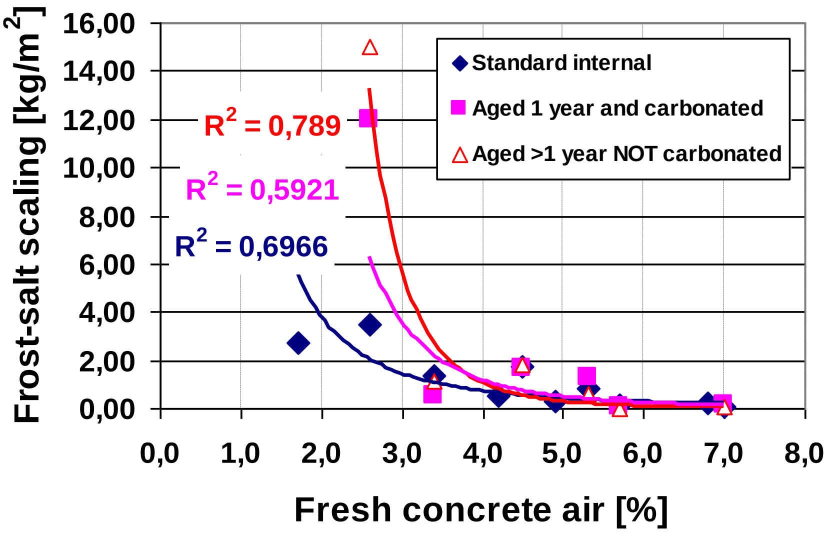


Figure 88. Frost-salt scaling as a function of fresh concrete air content. All concretes are with CEM II/A-M(S-LL) 42.5 N, w/b 0.41 – 0.42 but with different air contents.

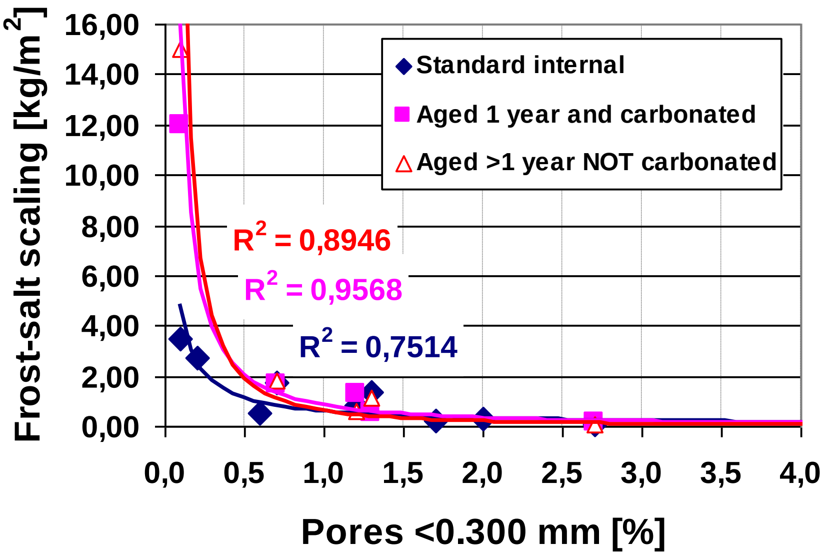


Figure 89. Frost-salt scaling as a function of content of pores <0.3 mm in hardened concrete. All concretes are with CEM II/A-M(S-LL) 42.5 N, w/b 0.41 – 0.42 but with different air contents.

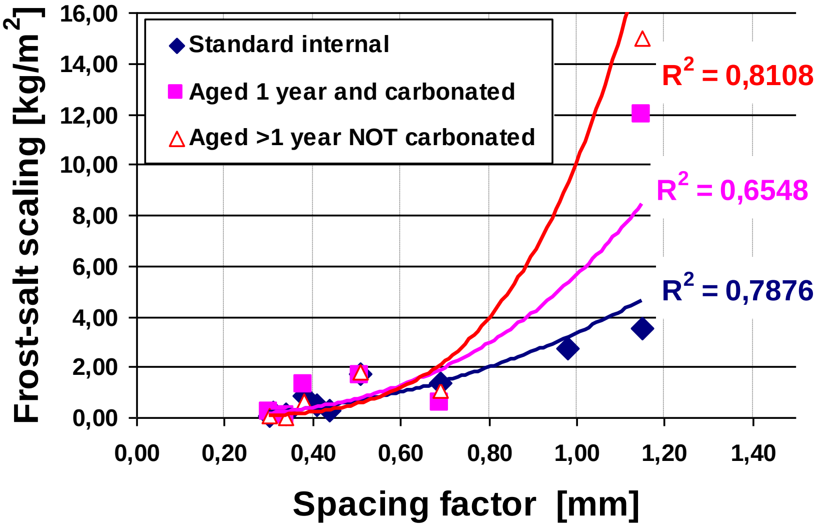


Figure 90. Frost-salt scaling as a function of hardened concrete spacing factor. All concretes are with CEM II/A-M(S-LL) 42.5 N, w/b 0.41 – 0.42 but with different air contents.

All the correlation coefficients in Figures 87 - 90 are presented in Figure 91. For both the concretes with CEM II/A-M(S-LL) 42.5 (w/b 0.41 – 0.42) and for all the concretes with different binding materials, there was the best correlation between the content of pores <0.300 mm in hardened concrete and the frost salt scaling in testing case 2., i.e. with surface carbonation and drying (ca. 1 year at RH 65 %). Especially with only one cement and w/b this correlation was good (R^2 = 0.96).

Also, with only one cement and w/b, all the correlations were better than in the case of all the concretes, i.e. with all the binding materials and w/b-values (in all the ratio of R^2-values was 1.15 – 2.12, and on average 1.44). This is only logical and means that the effects of air pore structure on frost salt scaling should be studied separately without the effects of binding material and w/b, as it also was done here (with CEM II/A-M(S-LL) 42.5 N and w/b 0.42).

When more long term field testing results with notable scaling will be available in the future it will be possible to get similar information also on the effect of air pores on frost salt scaling in the field, as in the case of laboratory testing here. This will help in the development of frost salt scaling deterioration and service life models.

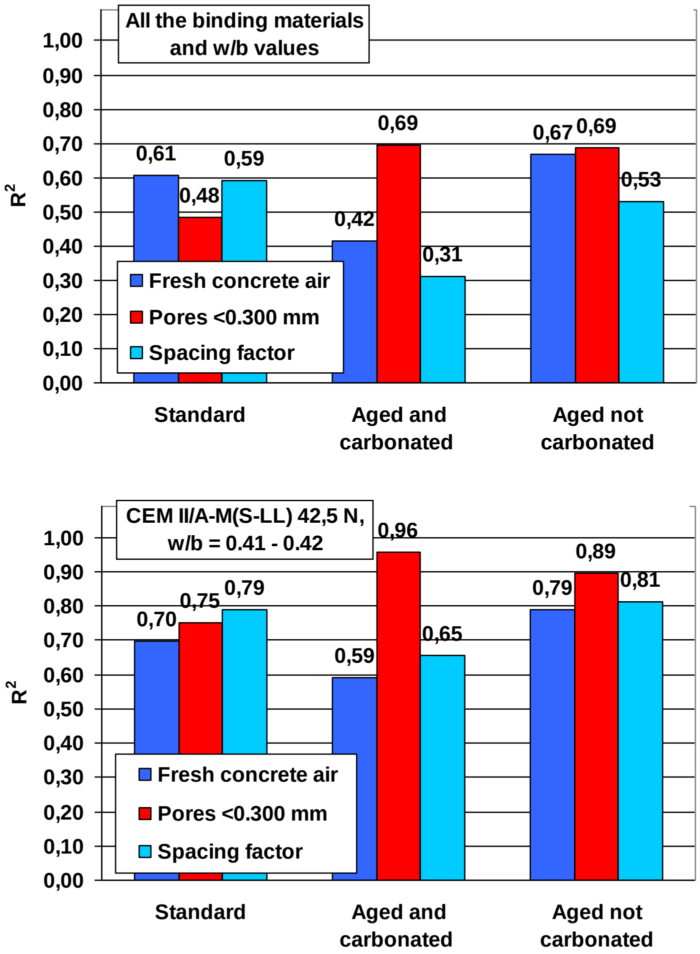


Figure 91. Correlation coefficients (R^2) in Figures 87 – 90 above.

In Table 11 and in Figure 92 there are limiting values, corresponding scaling less than 0.200 kg/m^2 in frost salt testing, for fresh concrete air content, content of pores <0.300 mm in hardened concrete and air pore spacing factor in hardened concrete. The meaning is only to demonstrate that these limits are different for different testing procedures (with or without surface ageing, see Chapter 8.2 - Testing methods), and also when counting one cement only or all the binding materials. Thus, these limits are not meant to be any demands for frost-salt resistant concrete. There is also in general poor correlation between e.g. spacing factor and frost-salt scaling. Here also the limits for total air pore content in fresh concrete is only for this project’s concretes and air pore structures. Many concretes here had a relatively coarse air pore structure, or had a high compaction pore content. At the same time, many concretes also had a good or normal air pore structure. It is difficult to know if these concretes represent average levels in daily concrete production.

It can be seen, that

- if all the binding materials are counted, the demands for air pore content and quality are much higher in the frost-salt testing case 2, i.e. with surface carbonation and drying, but not in the testing case 3., i.e. with no carbonation and a lower degree of surface drying before frost salt testing.

- if only CEM II/A-M(S-LL) 42.5 N concretes with w/b 0.41 - 0.42 are counted, the demands for air entrainment are not higher.

It can be concluded that when modelling of frost salt scaling, the effects of climatic exposure, ageing, w/b, binding material and air pore content and quality should be included.

Table 11. Limits based on correlation curves in Figures 87 – 90, for fresh concrete air content, content of pores <0.300 mm in hardened concrete and air pore spacing factor (pores <0.800 mm) in hardened concrete. These limits correspond to scaling less than 0.200 kg/m^2 in frost-salt testing with three different ways (see Chapter 8.2 Testing methods).

	Standard	Aged and carbonated	Aged NOT carbonated
	Scaling in frost-salt testing < 0.200 kg/m^2		
	For all binding materials and concretes		
Fresh concrete air [%]	5.7	8.2	5.5
Pores <0.300 mm [%]	2.2	6.0	1.9
Spacing factor [mm]	0.3	0.1	0.3
	for CEM II/A-M(S-LL) 42.5 N and w/b 0.41 - 0.42		
Fresh concrete air [%]	6.9	6.3	5.3
Pores <0.300 mm [%]	3.4	3.0	2.0
Spacing factor [mm]	0.3	0.3	0.4

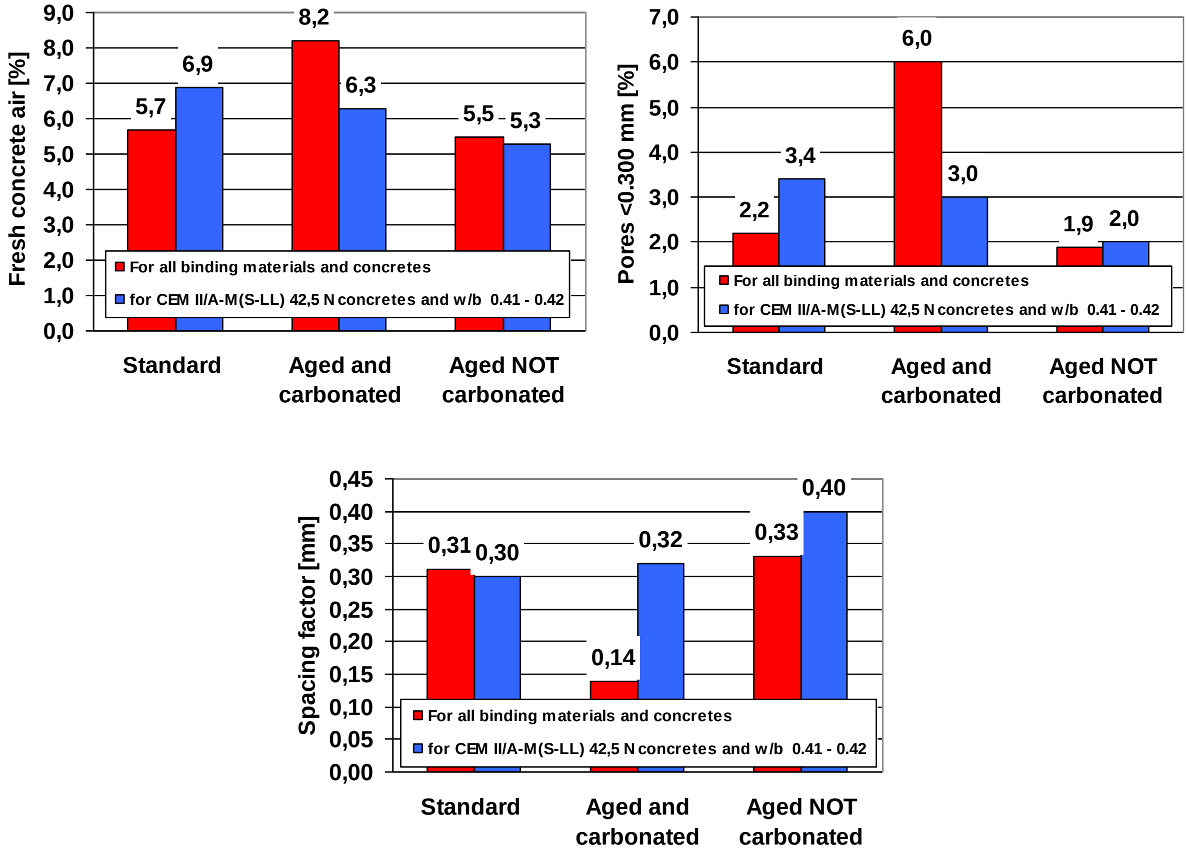


Figure 92. Limits from Table 11, which are based on correlation curves in Figures 87 – 90, for fresh concrete air content, content of pores <0.300 mm in hardened concrete and air pore spacing factor (pores <0.800 mm) in hardened concrete. These limits correspond scaling less than 0.200 kg/m^2 in frost-salt testing with three different ways (see Chapter 8.2 Testing methods).

8.4.2 Field testing results (frost salt, HW 7 field)

Field testing results are presented in Appendix 22 and in Figures 93 - 96. Simple correlations are presented in Figures 97 - 99.

The average relative dynamic modulus (RDM) of the concretes nos. 6 – 12 and 19, 20, 22 and 23 with different binding materials and w/b-values after the 1st, 2nd and 3rd winter is presented in Figure 93.

The average RDM of the concretes nos 13 – 18 (to the field Autumn 2007) and nos. 29 – 32 (to the field Spring 2008) all with CEM II/A-M(S-LL) 42.5 N and w/b 0.41 – 0.42, but with different air contents are presented in Figure 94.

The increase of RDM is presumably because of strength gain (see Figure 70 in Chapter 7.4) and it may be also because of higher moisture content or some other changes. For some concretes there was also a minor decrease of RDM, but the changes are small and it is impossible to know if this means also minor deterioration.

The volume changes of the concrete stored at the field are presented in Figures 95 and 96.

Because both the RDM-values and volume changes are quite similar for most of the concretes (small increase or decrease after winter/summer), it can be expected that they are caused by other reasons than scaling and cracking at this early phase of field testing. Presumably they are caused by strength gain, moisture and salt content variation, swelling and shrinkage. At least it can be seen that it is possible to reliably measure small changes in field specimens. There are no signs of mistakes in the field exposure or deterioration measurements or sample handling. All the concretes are in equal exposure and it will be possible to detect future deterioration reliably.

In Figure 97 RDM of concrete by FF is presented as a function of RDM by UPTT (three separate measurement times, 2008 – 10). The correlation is not good, but this is mainly because the change of RDM is small. There is no real detectable deterioration yet (RDM mainly > 100 %).

In Figure 98 the volume change of concretes after 3rd winter is presented as a function of weight change separately for frost-salt (HW 7 field) and frost specimen (Otaniemi field).

In Figure 99 the volume change of concretes is presented as a function of RDM after 1 - 3 winters.

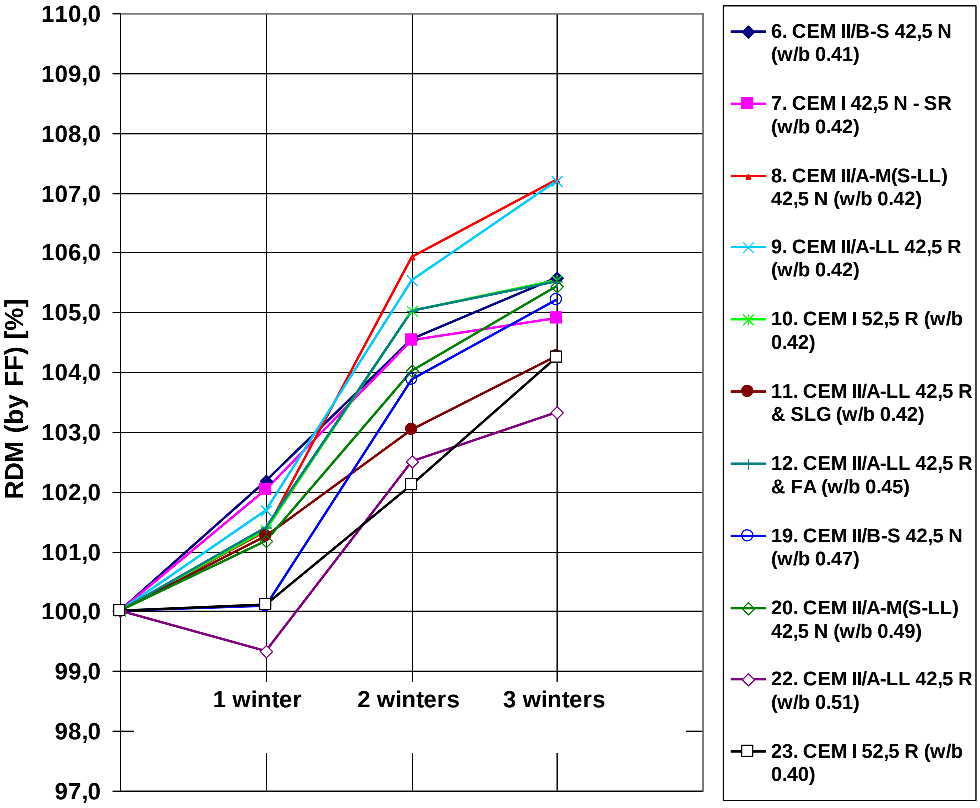


Figure 93. Relative dynamic modulus (RDM) by FF of concretes nos. 6 – 12 and 19, 20, 22 and 23 with different binding materials and w/b-values after the 1st, 2nd and 3rd winters.

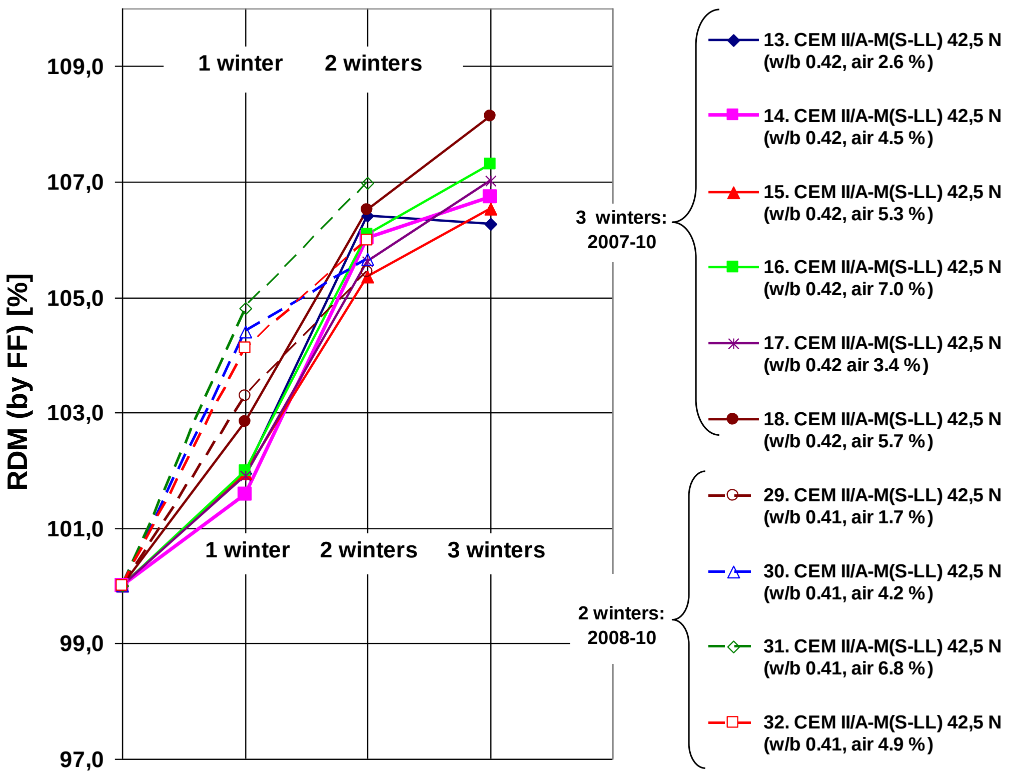


Figure 94. Relative dynamic modulus (RDM) by FF of concretes nos. 13 – 18 (to the field Autumn 2007) and nos. 29 – 32 (to the field Spring 2008) all with CEM II/A-M(S-LL) 42.5 N and w/b 0.41 – 0.42, but with different air contents.

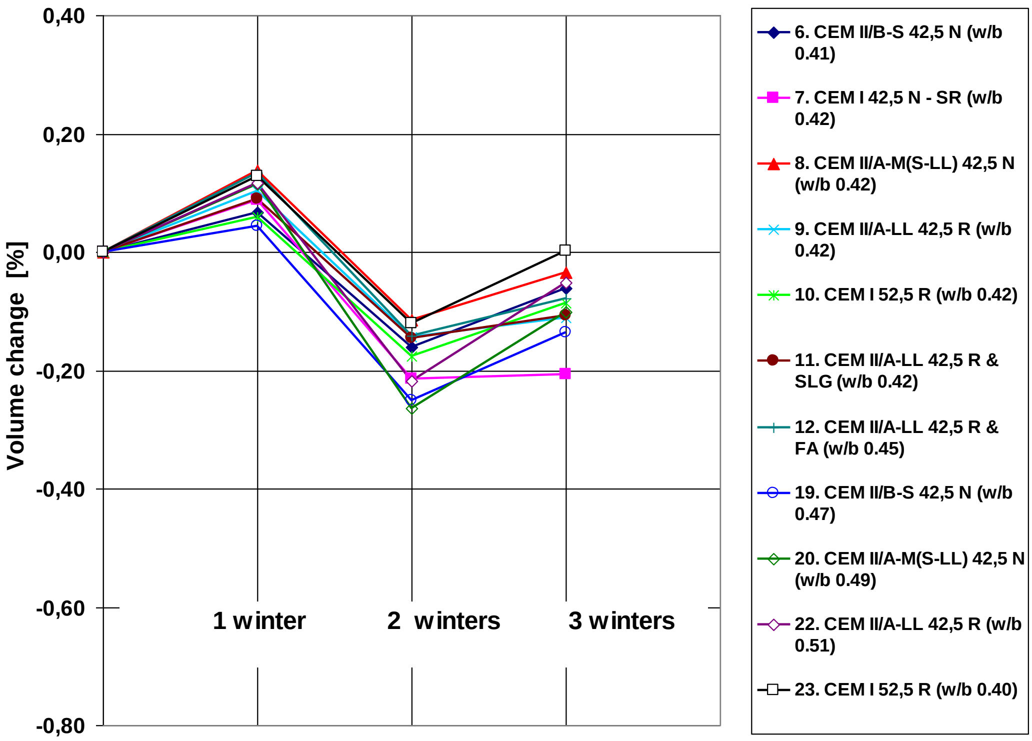


Figure 95. Average volume changes (3 specimen) for concretes nos. 6 – 12 and 19, 20, 22 and 23 with different binding materials and w/b-values after the 1st, 2nd and 3rd winters. Positive (+) volume change means increase of volume.

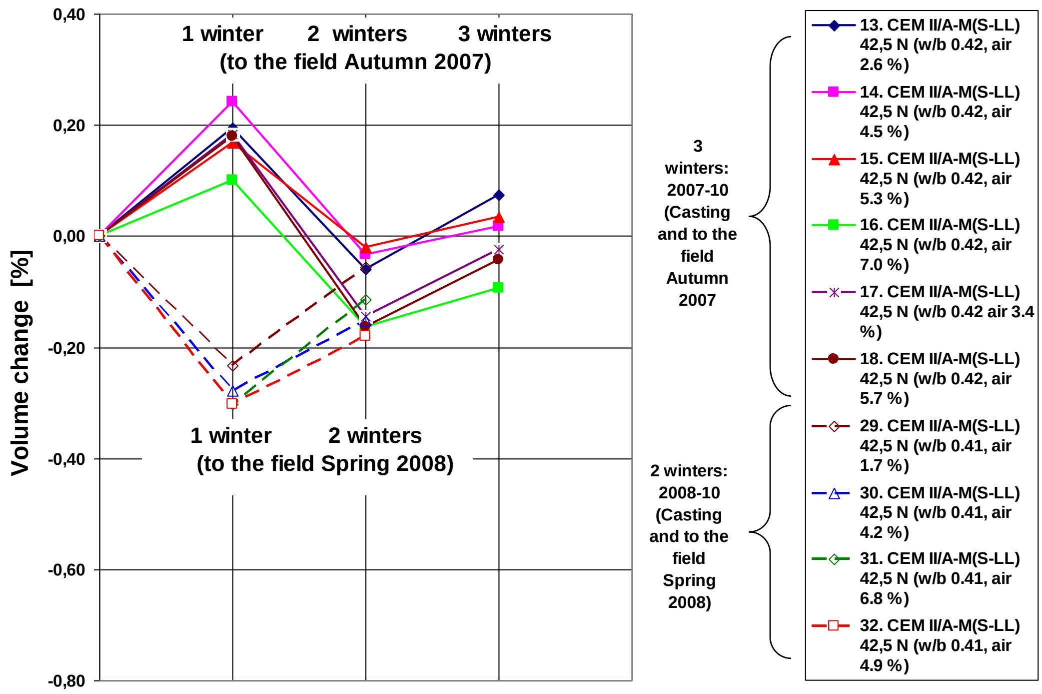


Figure 96. Average volume changes for concretes nos. 13 – 18 (to the field Autumn 2007) and nos. 29 – 32 (to the field Spring 2008) all with CEM II/A-M(S-LL) 42.5 N and w/b 0.41 – 0.41, but with different air contents.

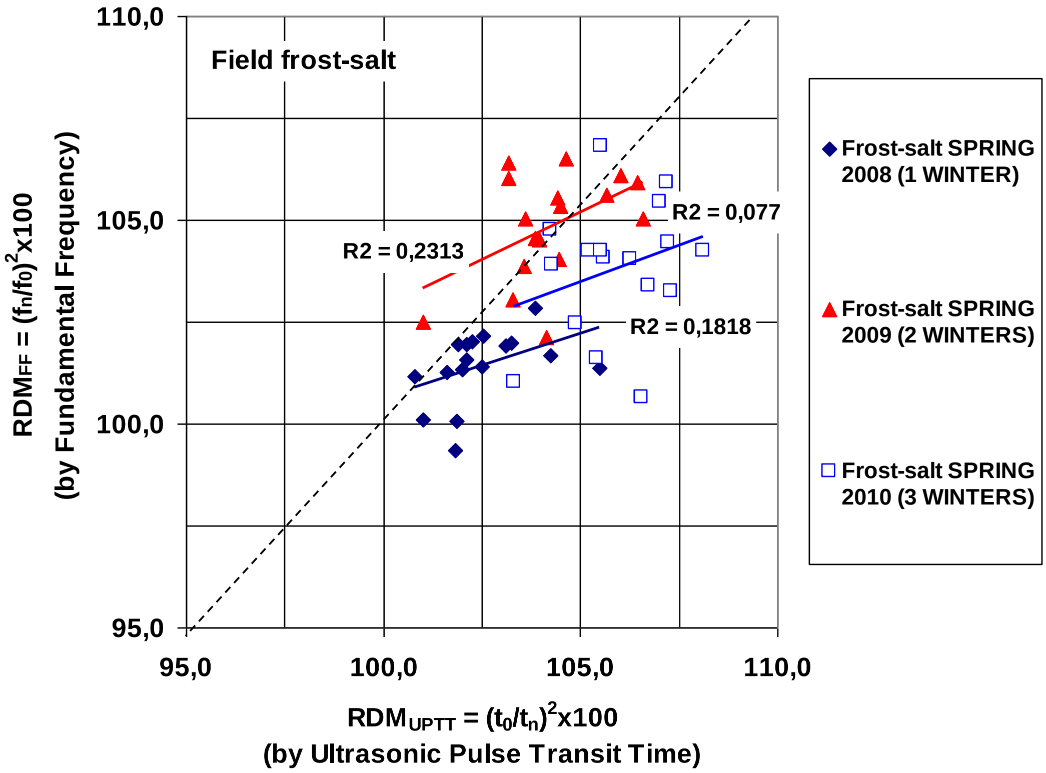


Figure 97. RDM measured by FF as a function of RDM measure by UPTT. Results after three separate measurement times (2008 – 10).

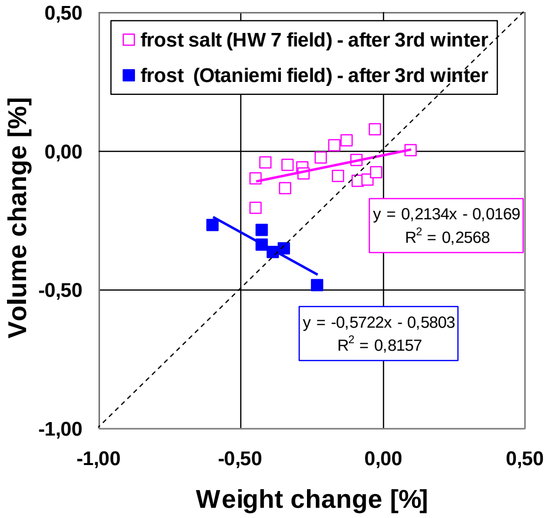


Figure 98. Volume change after 3 winters as a function of weight change for frost salt (HW 7 field) and frost specimen (Otaniemi field). Positive (+) volume change means increase of volume.

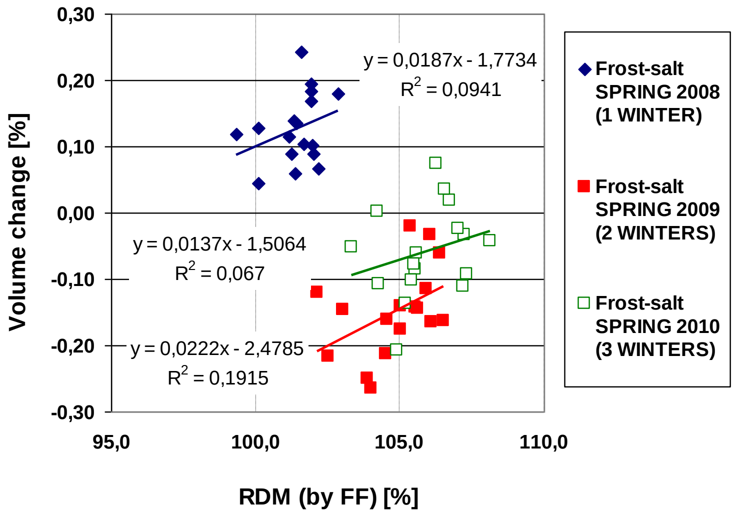


Figure 99. HW 7 field testing results. Volume change as a function of RDM when measured by FF after one, two and three winters (Spring 2008 – 10). Positive (+) volume change means increase of volume.

9 DATA BANK

A documentation Data bank is an essential separate appendage to this report.

The DuraInt data bank is located in VTT Document Management System, DOHA. Customer or extranet user registration, and how to start, is presented in Appendix 23. It is also possible to contact VTT to possibly get the DuraInt data bank data/documents by some other way such as by CDrom.

The data bank includes all of the numerical data in Excel-files to be in hand for any further use. It includes also PDF-files and photographs. Reporting (as this VTT Research report) and some additional information are mainly in PDF-files.

Former field testing project results updated during DuraInt with new field measurement results are also included in the Data bank. These projects are:

- Swedish BTB-project (Beständighet Tösaltade Betongkonstruktioner ´Durability of de-iced concrete structures´, 1996 - 1998),
- CONLIFE (EU 5th Framework project: Life-time Prediction of High-Performance Concrete with Respect to Durability, 2001 - 04) and
- YMPBET (Ympäristöystävälliset ja hyvin säilyvät betonit, ´Environmental and durable concretes´, 2002 - 04).

For example, reporting available in PDF-files and Excel-files including laboratory and field testing data are included.

The documentation database will be kept up for decades to serve as a basis for future deterioration and service life modelling and normative or directive work.

References

AVA 2000/3000. A brochure. http://www.germann.org/TestSystems/AVA%20-%20Air%20Void%20Analyzer/AVA%20-%20Air%20Void%20Analyzer.pdf

ASTM C 457. 2010. Standard Test Method for Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete. 15 p.

ASTM C 856. 2011. ASTM C856. Standard Practice for Petrographic Examination of Hardened Concrete. 17 p.

By 43. 2001. Betonin kiviainekset 2001. Concrete Aggregates 2001. Suomen Betoniyhdistys r.y. 64 p. (In Finnish).

CEN/TR 15177. 2005. Testing the freeze-thaw resistance of concrete. Internal structural damage. 16.5.2006. 34 p.

CEN/TS 12390-9. 2006. Testing hardened concrete Part 9: Freeze-thaw resistance. Scaling. 21.8.2006. 13 p.

Distlehorst J. A., Kurgan, G. J. 2007. Development of Precision Statement for Determining Air Void Characteristics of Fresh Concrete with Use of Air Void Analyzer. Transportation Research Record: Journal of the Transportation Research Board, Vol. 2020 / 2007, p. 45–49.

Espinosa, R. M. & Franke, L. 2006. Influence of the age and drying process on pore structure and sorption isotherms of hardened cement paste. Cement and Concrete Research 36 (2006), p. 1969–1984.

EN 12350-2. 2000. Testing fresh concrete. Part 2: Slump test. 8 p.

EN 12350-6. 2009. EN 12350-6 Testing fresh concrete Part 6: Density. 9 p.

EN 12350-8. 2010. Testing fresh concrete. Part 8: Self-compacting concrete. Slump-flow test. 9 p.

EN 12390-1. 2000. Testing hardened concrete. Shape, dimensions and other requirements for specimens and moulds. 11 p.

EN 13295. 2004. Products and systems for the protection and repair of concrete structures.Test methods. Determination of resistance to carbonation. 16 p.

EN 14629. 2007. Products and systems for the protection and repair of concrete structures. Test methods. Determination of chloride content in hardened concrete. 11 p.

EN 934-2. 2009. Admixtures for concrete, mortar and grout. Part 2: Concrete admixtures. Definitions, requirements, conformity, marking and labelling. 21 p.

Englund, M. 2011. Kuituoptiset vesipitoisuuden mittaukset betonin säilyvyyden pitkäaikaisseurannassa. DuraInt–betonikappaleiden kuituoptiset lämpötilan ja vesipitoisuuden mittaukset. Water content measurement by optical fibres in long term concrete durability follow up. Temperature and water content measurement of DuraInt-specimens by optical fibres. 15 p. Fortum Report. (In Finnish).

Finnish Meteorological Institute. 2011. Climatological statistics for the normal period 1971-2000. http://en.ilmatieteenlaitos.fi/normal-period-1971-2000

Gulikers, J. 2011. Analysis and Evaluation of the European Round Robin Test on Rapid Chloride Migration.

LAM. 2008. Liikenteen automaattinen mittausjärjestelmä (LAM). Automatic traffic counting system. Finnish Road Administration. (In Finnish).
http://www.tiehallinto.fi/servlet/page?_pageid=71&_dad=julia&_schema=PORTAL30&menu=5195&_pageid=71&linkki=990&julkaisu=502&kieli=fi

NT Build 361. 1999. Concrete, hardened: water-cement ratio. 5 p.

NT Build 492. 1999. Concrete, mortar and cement-based repair materials: chloride migration coefficient from non-steady-state migration experiments. 8 p.

NT Build 381. 1991. Concrete, hardened: air void structure and air content. 5 p.

Panesar, D. K. & Chidiac, S. E. 2009. Capillary suction model for characterizing salt scaling resistance of concrete containing GGBFS. Cement and Concrete Research 31 (2009), p. 570–576.

Parrott, L. J. 1992. Variations of water absorption rate and porosity with depth from an exposed concrete surface: Effects of exposure conditions and cement type. Cement and Concrete Research 22 (1992), p. 1077-1088.

Patel, R. G., Parrott L. J., Martin J. A. and Killoh, D. C. 1985. Gradients of microstructure and diffusion properties in cement paste caused by drying. Cement and Concrete Research 15 (1985), p. 343–356.

Petersen, C. G. 2009. Air Void Analyzer (AVA) for fresh concrete, latest advances. Ninth ACI International Conference on Superplasticizers and Other Chemical Admixtures in Concrete. Sevilla, Spain, October 13-18, 2009. 12 p.

RILEM TC 178-TMC. 2002. Analysis of water soluble chloride content in concrete. Recommendation. Materials and Structures/Matériaux et Constructions, Vol. 3S, November 2002, pp. 586-588.

Thomas, J. J & Jennings, H. M. 2006. A colloidal interpretation of chemical aging of the C-S-H gel and its effects on the properties of cement paste. Cement and Concrete Research, 36(1), p. 30 – 38.

Utgenannt P. 2004. The influence of ageing on the salt –frost resistance of concrete. Lund Institute of Technology. Division of Building Materials. Report TVBM-1021. Doctoral Thesis. 346 p. + App. 110 p.

Venäläinen, A. 2000. Tiesuolan käytön arviointi talvikuukausien lämpötilan avulla. Estimation of road salting based on wintertime temperature measurements. Helsinki 2000. Tielaitos, Tie- ja liikennetekniikka, Tielaitoksen selvityksiä 9/2000. 24 p. (In Finnish).

Vesikari, E. 2004. BTB-projekti. Yhteenvetoraportti. BTB-project. Summary report. VTT Rakennus- ja yhdyskuntatekniikka, sisäinen raportti (Internal report), RTE-IR-16/2004, 25.11.2004. 55 p. + App. 19 p. (In Finnish).

Vesikari, E. 2009. Carbonation and Chloride Penetration in Concrete - with Special Objective of Service Life Modelling by the Factor Approach. VTT Research Report VTT-R-04881-09. 38 p.

VTT TEST R003-00. 2000. TESTING INSTRUCTION: Air void analysis. Method of measurement. Definition of the air void parameters of concrete from thin sections. Translation from Finnish to English. 6 p.

VTT-R-03466-11. 2011. TESTING INSTRUCTION: VTT Hardened concrete air content. Method of measurement. Determination of the air content of hardened concrete at early stages of hardening. Translation from Finnish to English. 4 p.

VTT Tutkimusraportti VTT-R-07974-10. 2010. Kuparibetonin, kuparilaastipin-noitteen ja vertailubetonin kenttäkokeet (DuraInt). - VTT Research Report. Field testing of copper concrete, copper mortar coating and reference concrete. 17 p. Confidential. (In Finnish).

Wang, K., Mohamed-Metwally, M., Bektas, F. & Grove, J. 2008. Improving Variability and Precision of Air-Void Analyzer (AVA) Test Results and Developing Rational Specification Limits. Center for Transportation Research and Education. Phase I Report, June 2008. 82 p.
http://www.intrans.iastate.edu/reports/ava.pdf

Highway testing field. Monthly average, minimum and maximum temperatures and relative humidities 8.2007 – 10.2010.

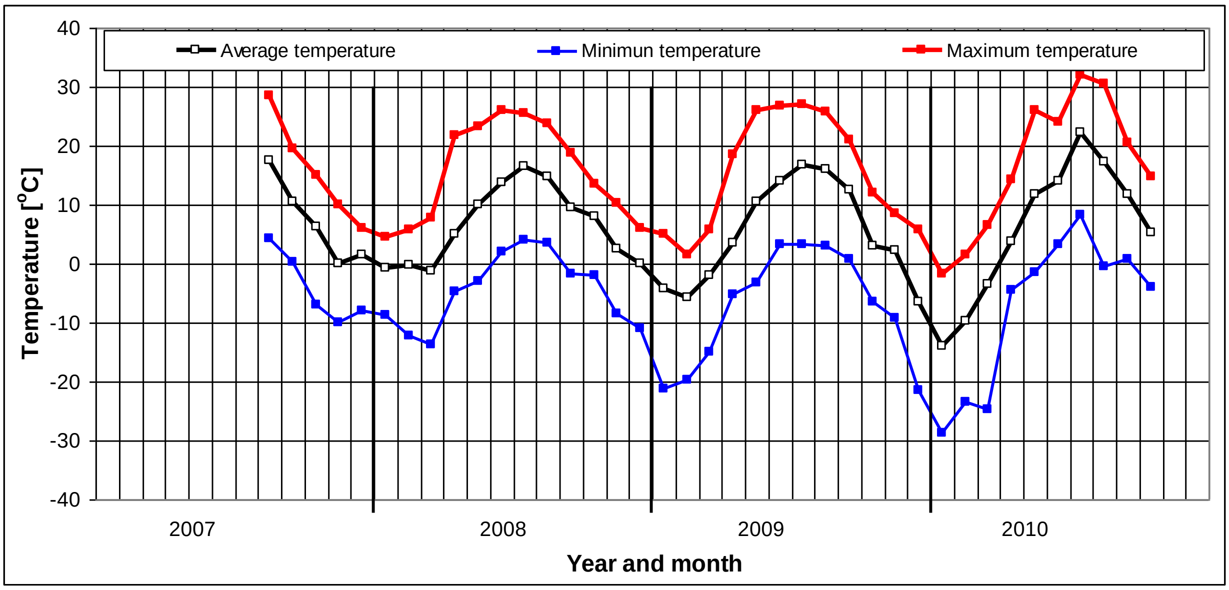
Year	2007											
Month	1	2	3	4	5	6	7	8	9	10	11	12
Average temperature [^oC]								17,4	10,5	6,3	-0,1	1,4
Minimum temperature [^oC]								4,2	0,3	-7	-10,1	-8,1
Maximum temperature [oC]								28,5	19,5	14,9	10	6
Average relative humidity [%]								81,4	89,5	91,6	93,1	96,2
Minimum relative humidity [%]								37	34	44	54	74
Maximum relative humidity [%]								100	100	100	100	100

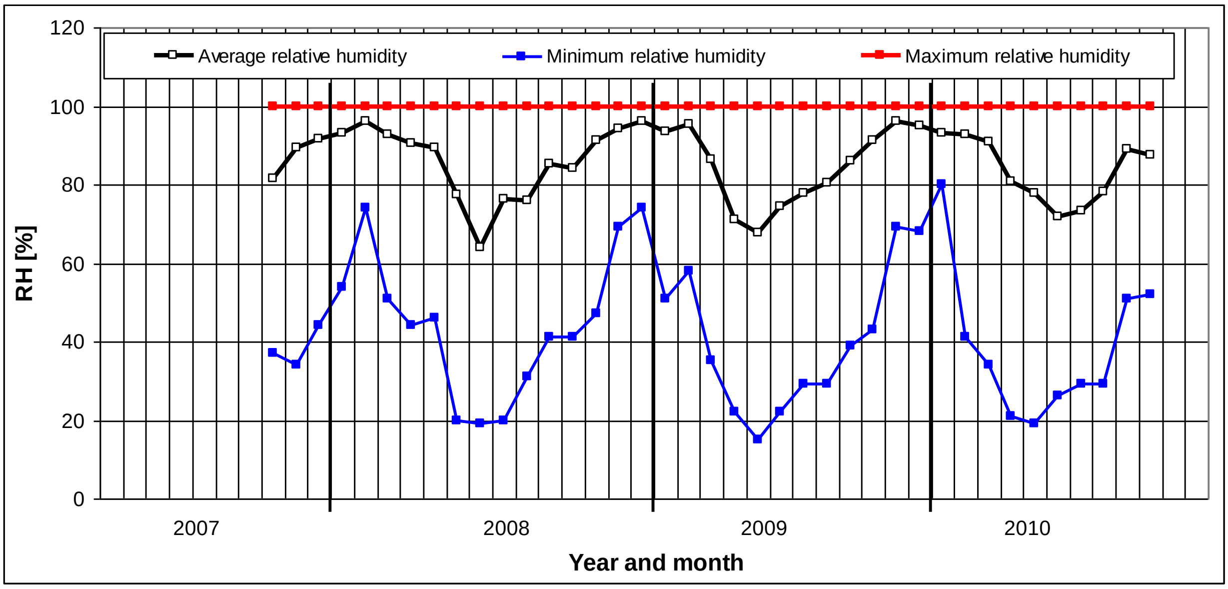
Year	2008											
Month	1	2	3	4	5	6	7	8	9	10	11	12
Average temperature [^oC]	-0,8	-0,2	-1,3	5	9,9	13,8	16,6	14,7	9,5	8	2,5	-0,1
Minimum temperature [^oC]	-8,7	-12,3	-13,7	-4,7	-3	1,9	4	3,5	-1,8	-1,9	-8,5	-10,9
Maximum temperature [oC]	4,5	5,8	7,7	21,8	23,3	26	25,5	23,7	18,7	13,6	10,3	6
Average relative humidity [%]	92,7	90,4	89,3	77,5	64,1	76,1	76	85,3	84	91,3	94,2	95,9
Minimum relative humidity [%]	51	44	46	20	19	20	31	41	41	47	69	74
Maximum relative humidity [%]	100	100	100	100	100	100	100	100	100	100	100	100

Year	2009											
Month	1	2	3	4	5	6	7	8	9	10	11	12
Average temperature [^oC]	-4,3	-5,7	-2	3,5	10,6	14	16,8	15,9	12,4	2,9	2,3	-6,6
Minimum temperature [^oC]	-21,3	-19,8	-15,1	-5,3	-3,3	3,3	3,3	2,9	0,7	-6,4	-9,2	-21,6
Maximum temperature [oC]	4,9	1,6	5,7	18,5	26,1	26,8	27	25,7	21,1	12	8,6	5,8
Average relative humidity [%]	93,5	95,2	86,2	71	67,6	74,4	77,6	80,2	85,9	91,4	96,2	95
Minimum relative humidity [%]	51	58	35	22	15	22	29	29	39	43	69	68
Maximum relative humidity [%]	100	100	100	100	100	100	100	100	100	100	100	100

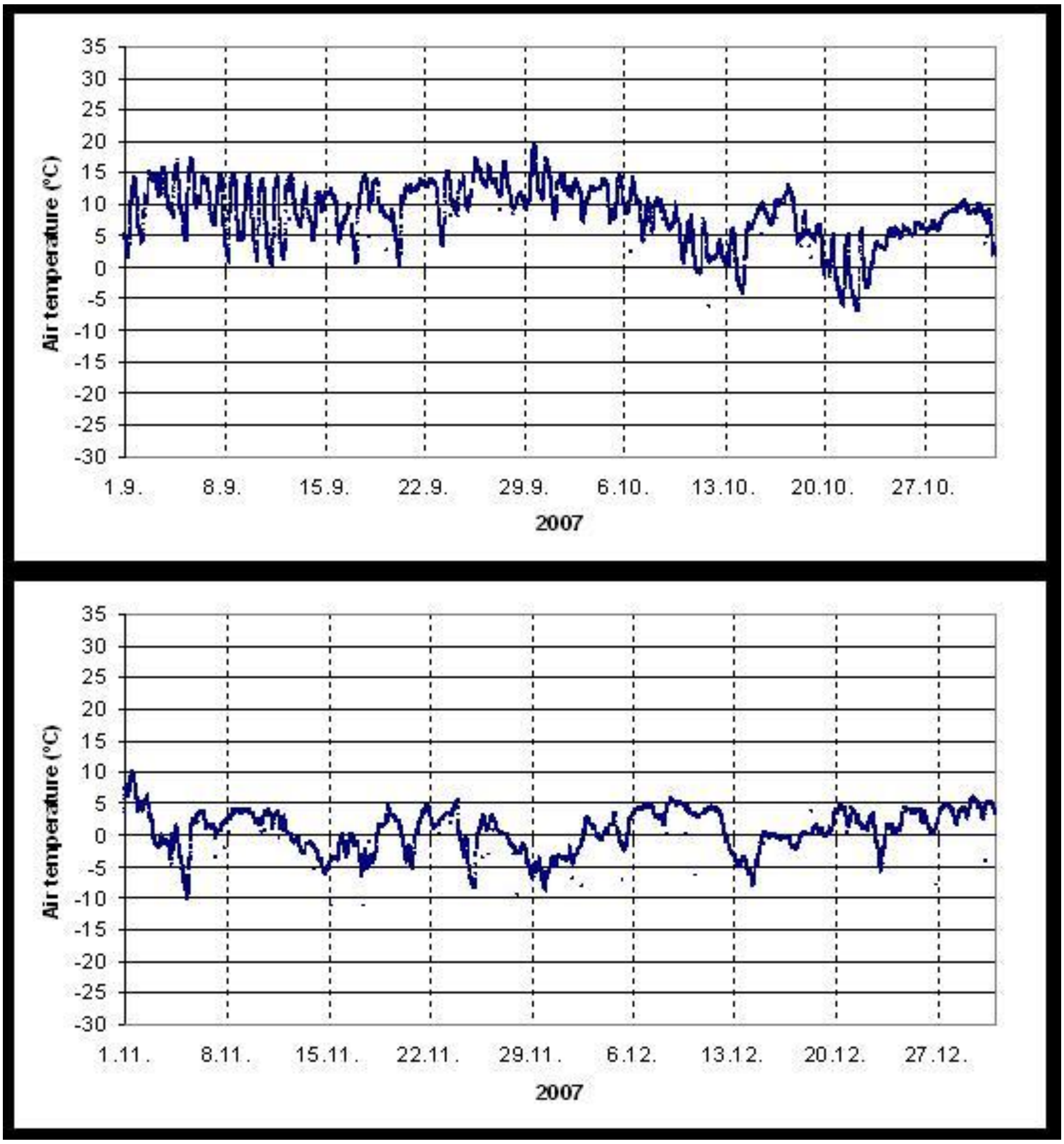
Year	2010											
Month	1	2	3	4	5	6	7	8	9	10	11	12
Average temperature [^oC]	-13,9	-9,7	-3,5	3,8	11,8	14,1	22,2	17,3	11,7	5,2		
Minimum temperature [^oC]	-28,7	-23,6	-24,7	-4,5	-1,4	3,3	8,2	-0,6	0,8	-3,9		
Maximum temperature [oC]	-1,7	1,4	6,6	14,3	25,9	24	32,1	30,4	20,6	14,7		
Average relative humidity [%]	93,2	92,8	90,9	80,9	77,6	71,7	73,2	78,1	88,8	87,6		
Minimum relative humidity [%]	80	41	34	21	19	26	29	29	51	52		
Maximum relative humidity [%]	100	100	100	100	100	100	100	100	100	100		

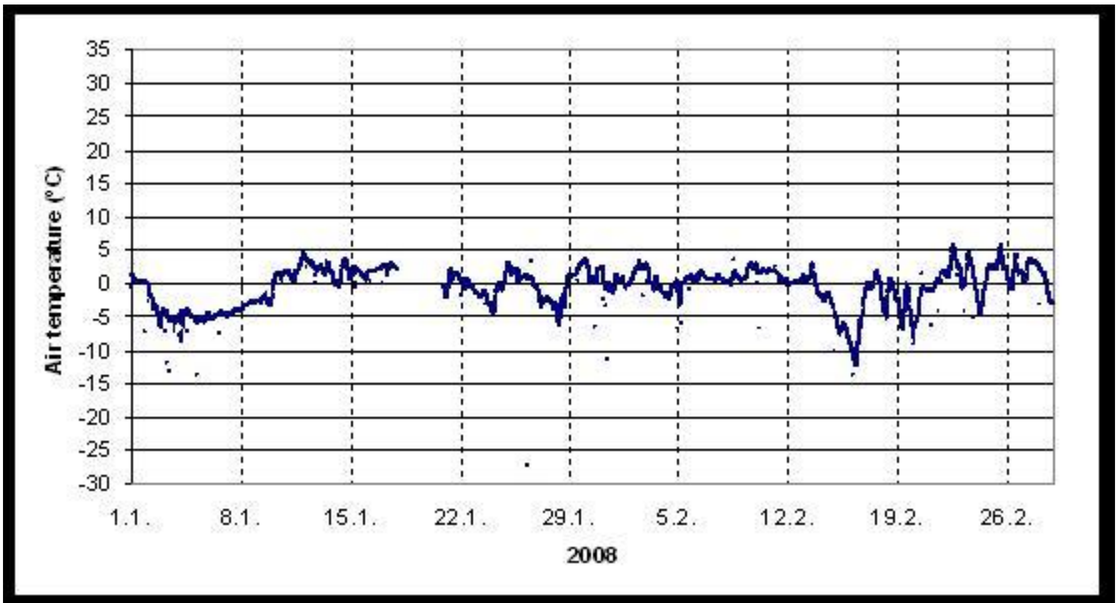
Highway testing field. Average, minimum and maximum temperature and relative humidity for each month 8.2007 – 10.2010.





Highway testing field. Air temperature 1.9.2007 – 31.10.2010.

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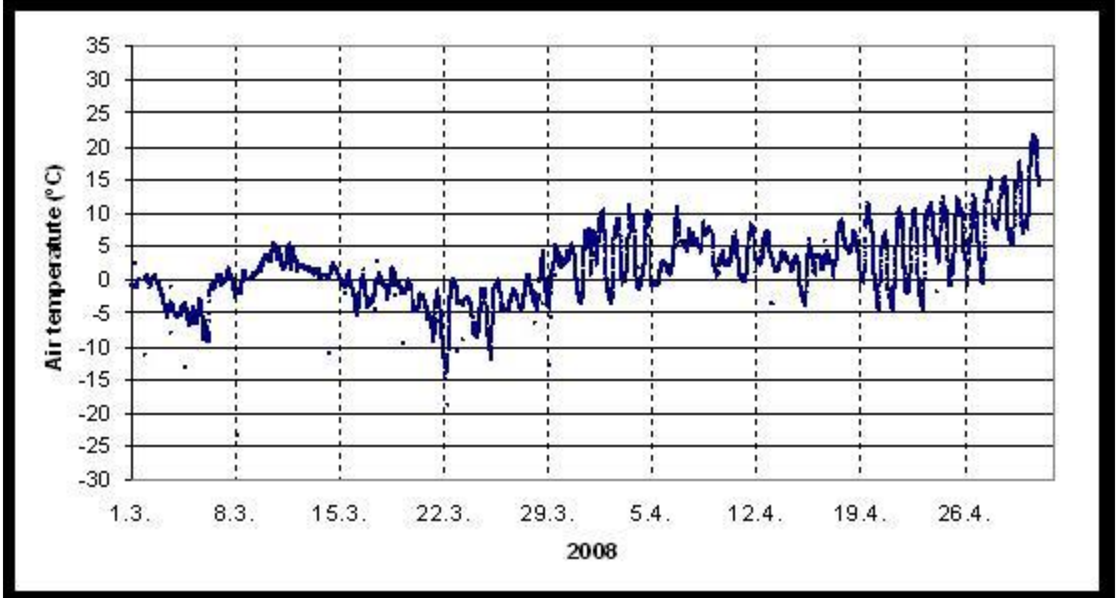
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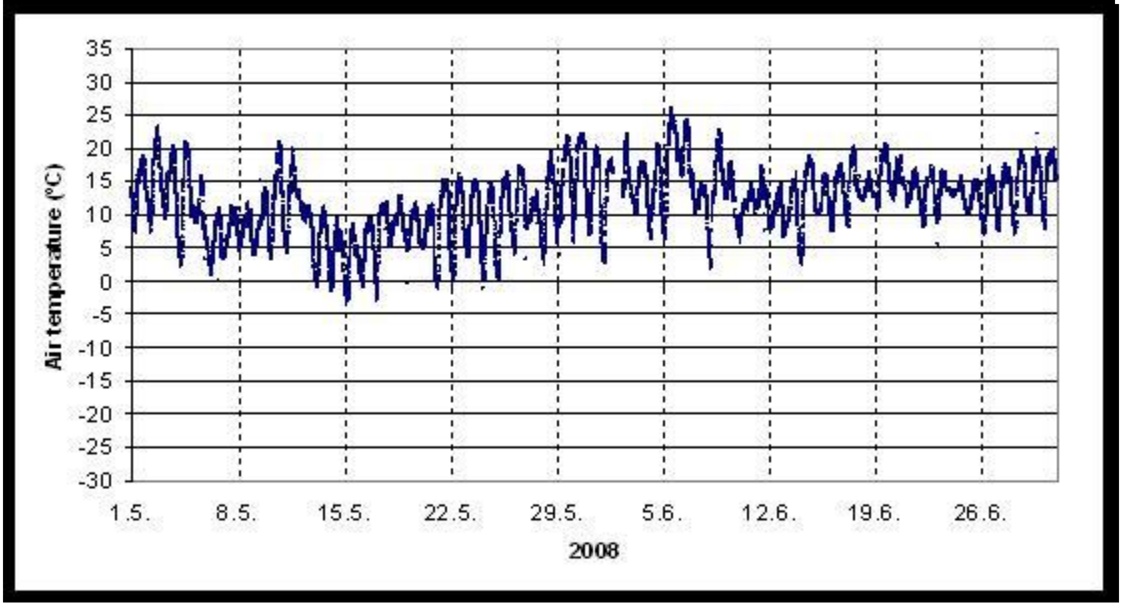
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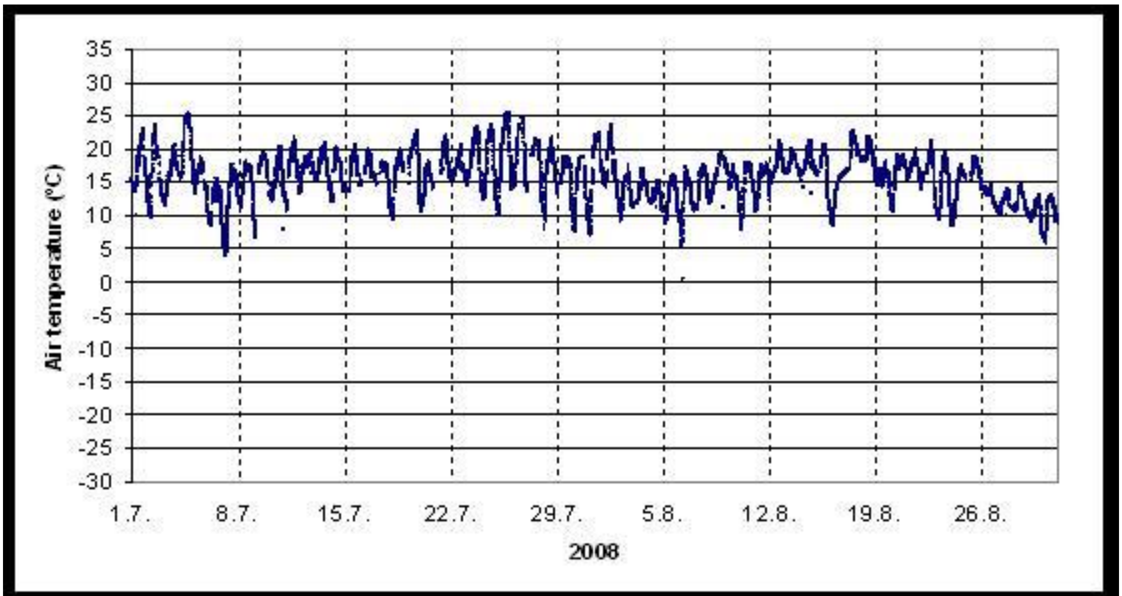
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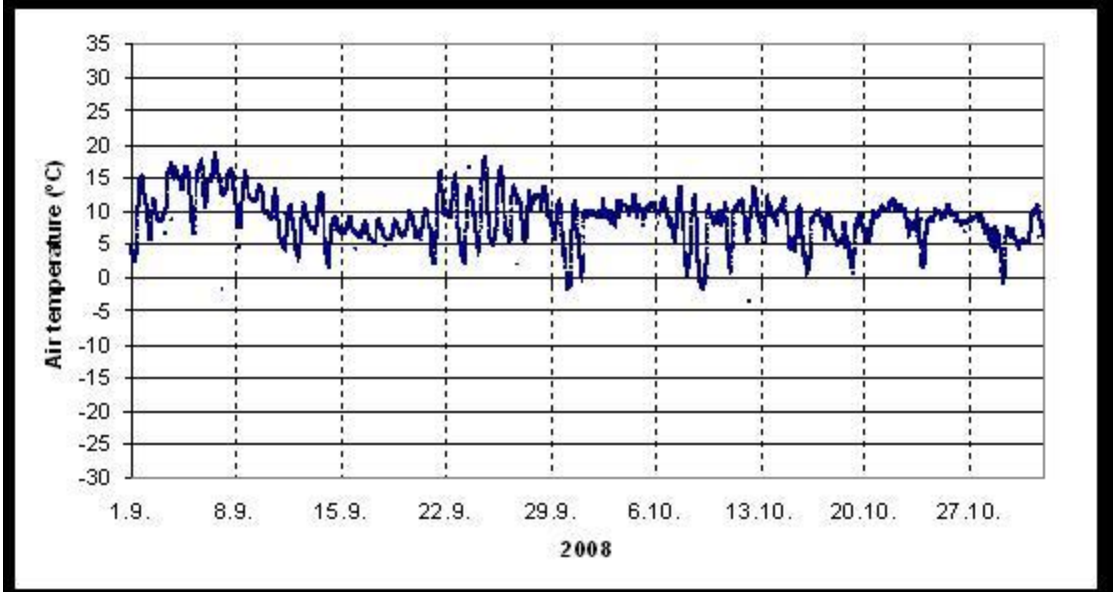
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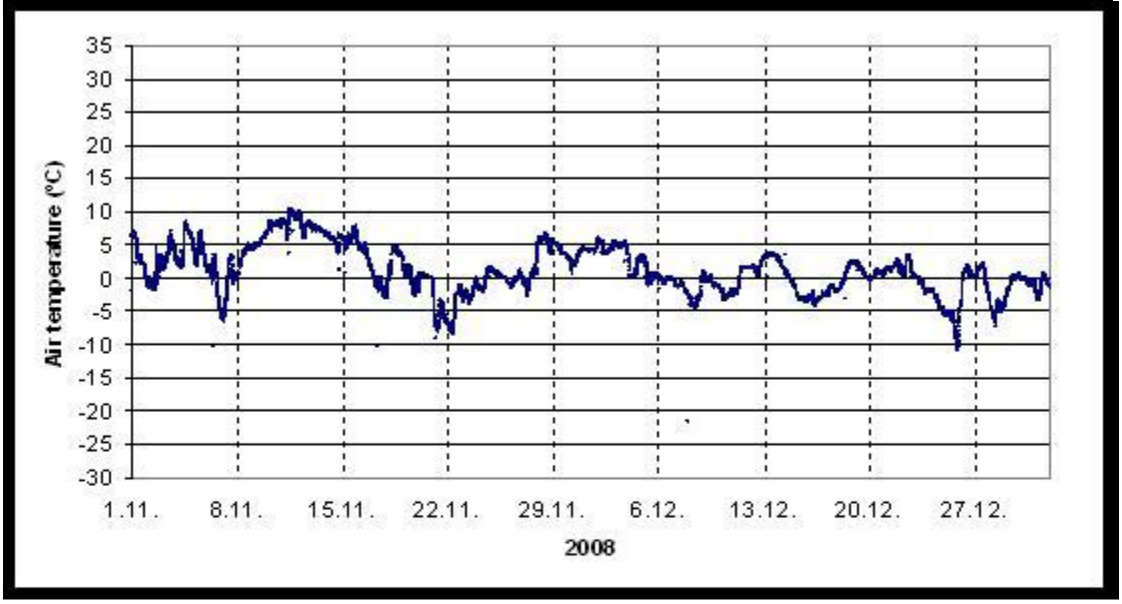
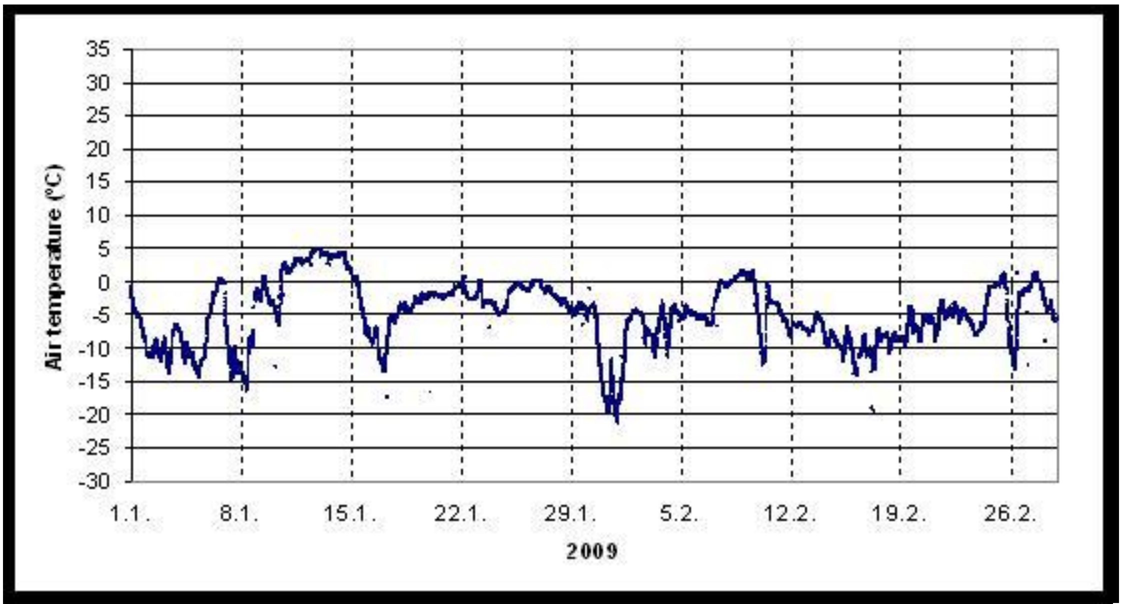
6.10.
13.10.
20.10.
27.10.
2008


Air temperature (°C)
35
30
25
20
15
10
5
0
-5
-10
-15
-20
-25
-30
1.11.
8.11.
15.11.
22.11.
29.11.
6.12.
13.12.
20.12.
27.12.
2008


Air temperature (°C)
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30
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20
15
10
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0
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-20
-25
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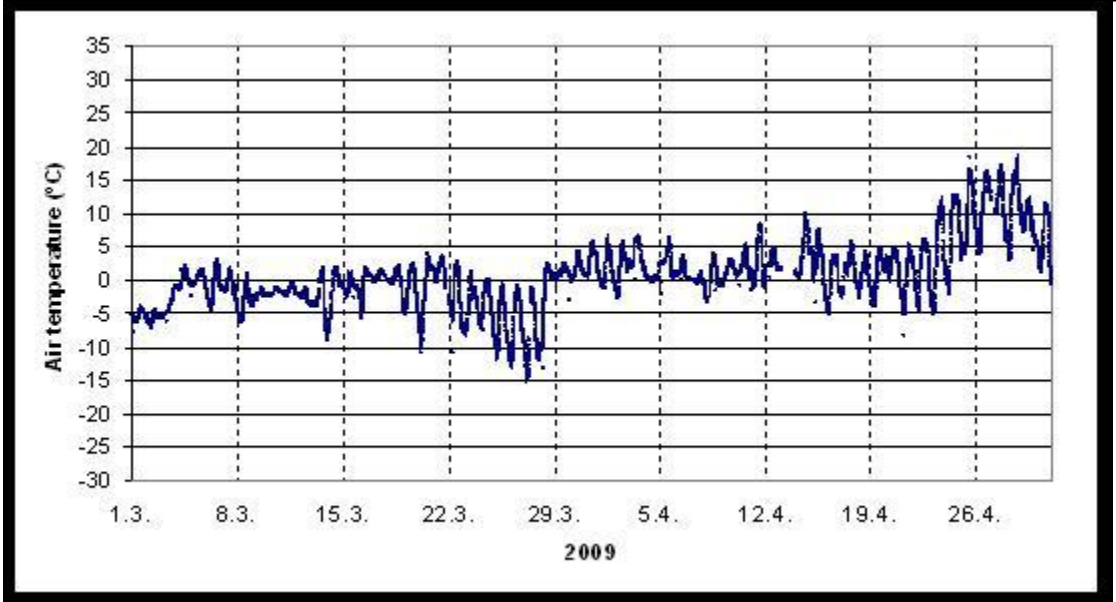
22.1.
29.1.
5.2.
12.2.
19.2.
26.2.
2009


Air temperature (°C)
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25
20
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0
-5
-10
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-25
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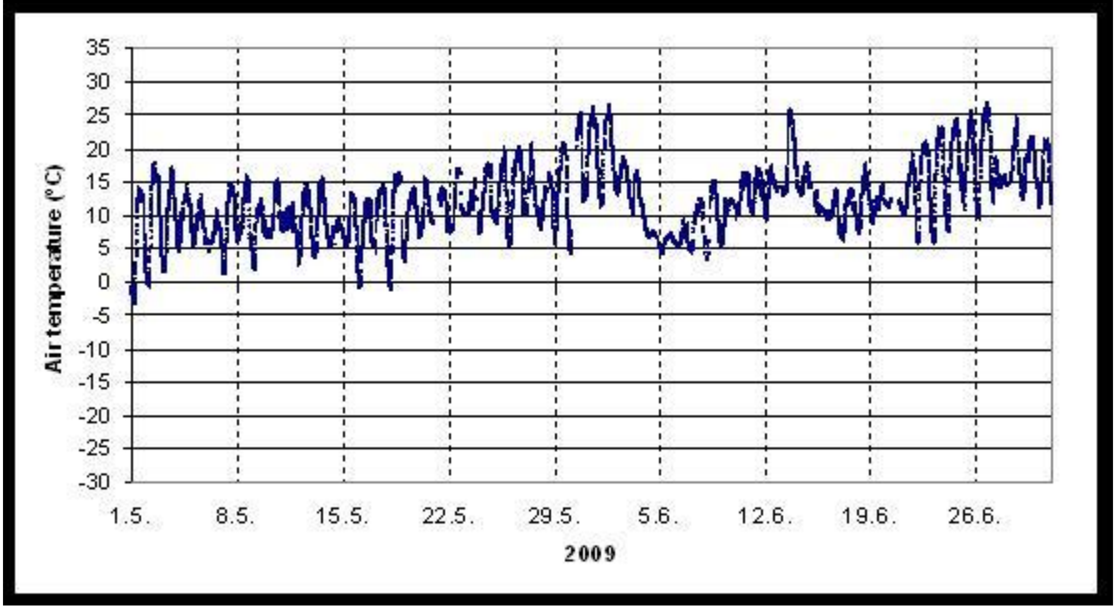
15.3.
22.3.
29.3.
5.4.
12.4.
19.4.
26.4.
2009


Air temperature (°C)
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30
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-10
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22.5.
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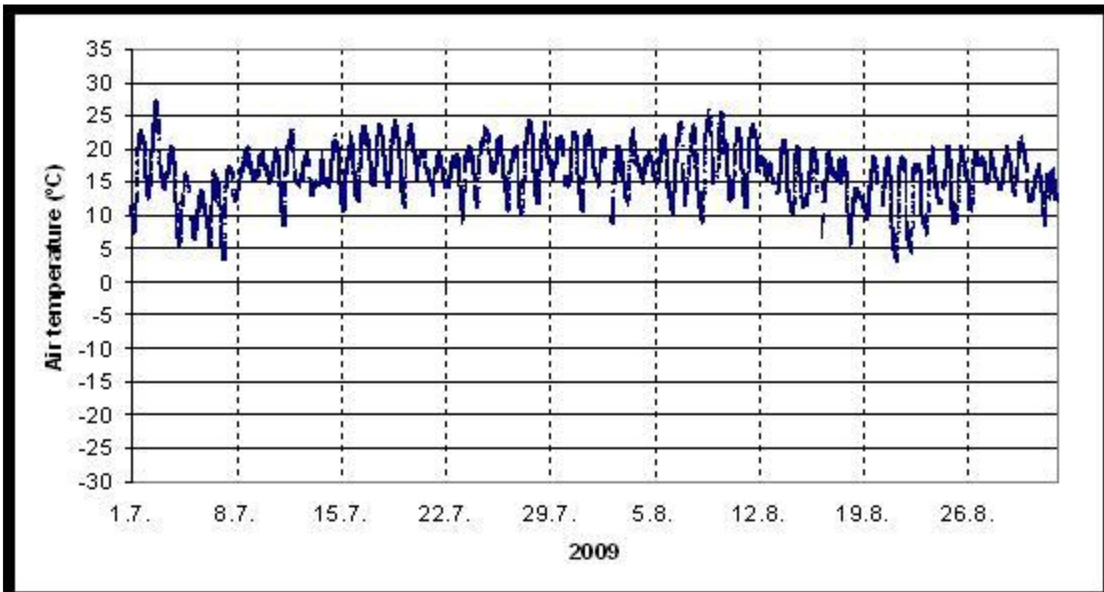
12.6.
19.6.
26.6.
2009


Air temperature (°C)
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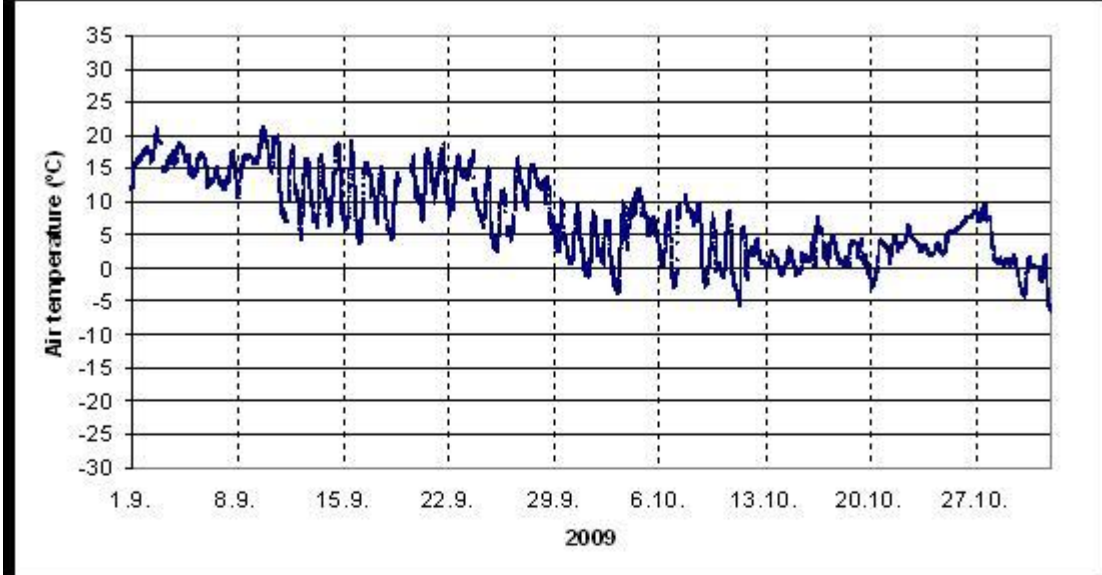
12.8.
19.8.
26.8.
2009


Air temperature (°C)
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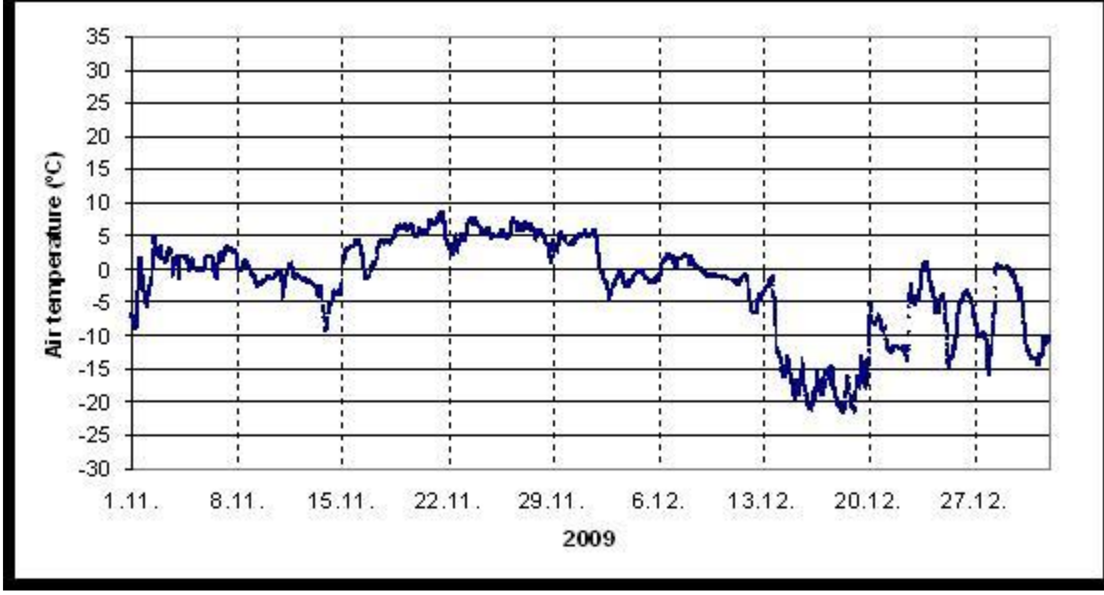
13.10.
20.10.
27.10.
2009


Air temperature (°C)
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0
-5
-10
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-20
-25
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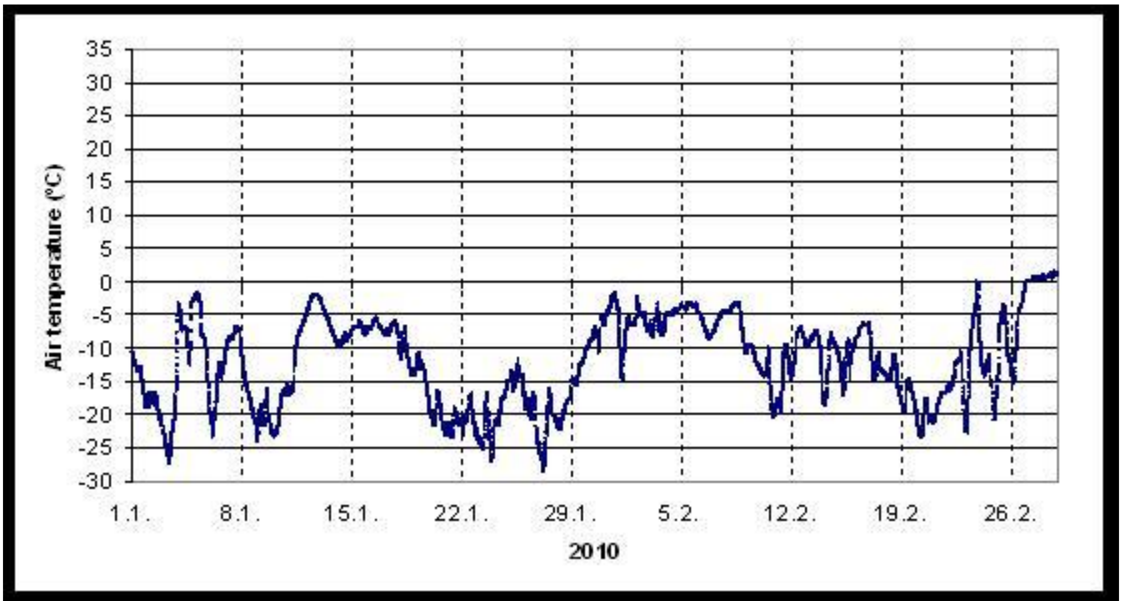
15.11.
22.11.
29.11.
6.12.
13.12.
20.12.
27.12.
2009


Air temperature (°C)
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0
-5
-10
-15
-20
-25
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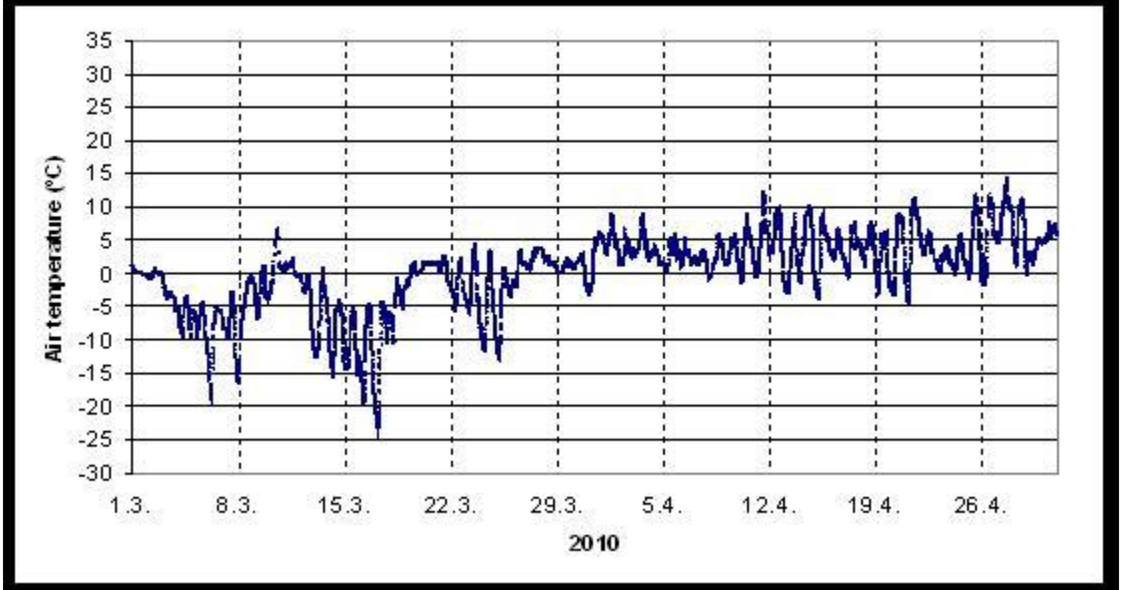
15.1.
22.1.
29.1.
5.2.
12.2.
19.2.
26.2.
2010


Air temperature (°C)
35
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-5
-10
-15
-20
-25
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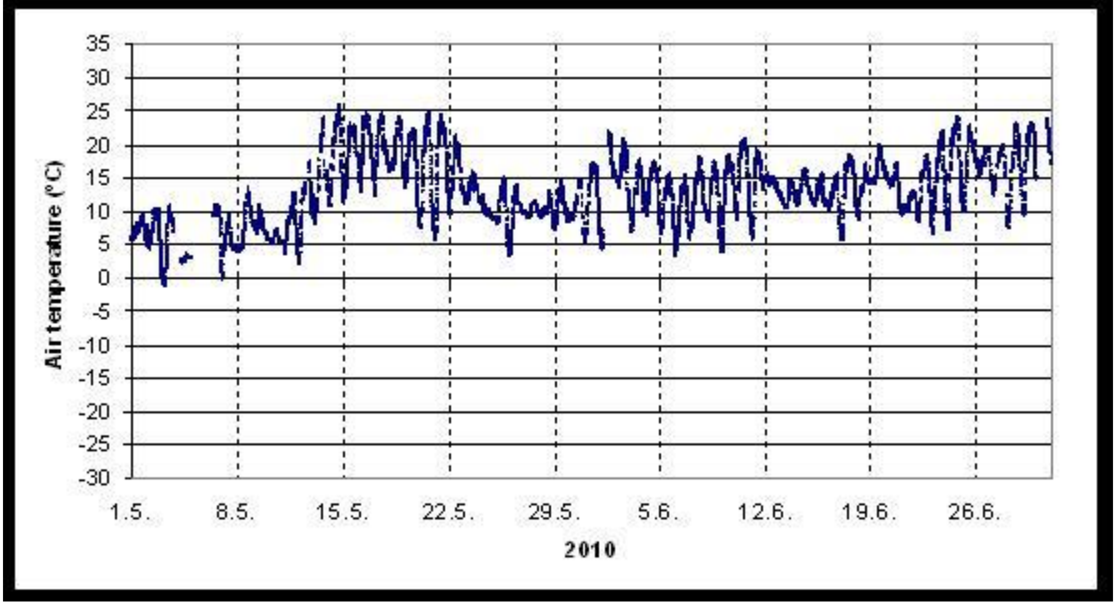
1.3.
8.3.
15.3.
22.3.
29.3.
5.4.
12.4.
19.4.
26.4.
2010


Air temperature (°C)
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30
25
20
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10
5
0
-5
-10
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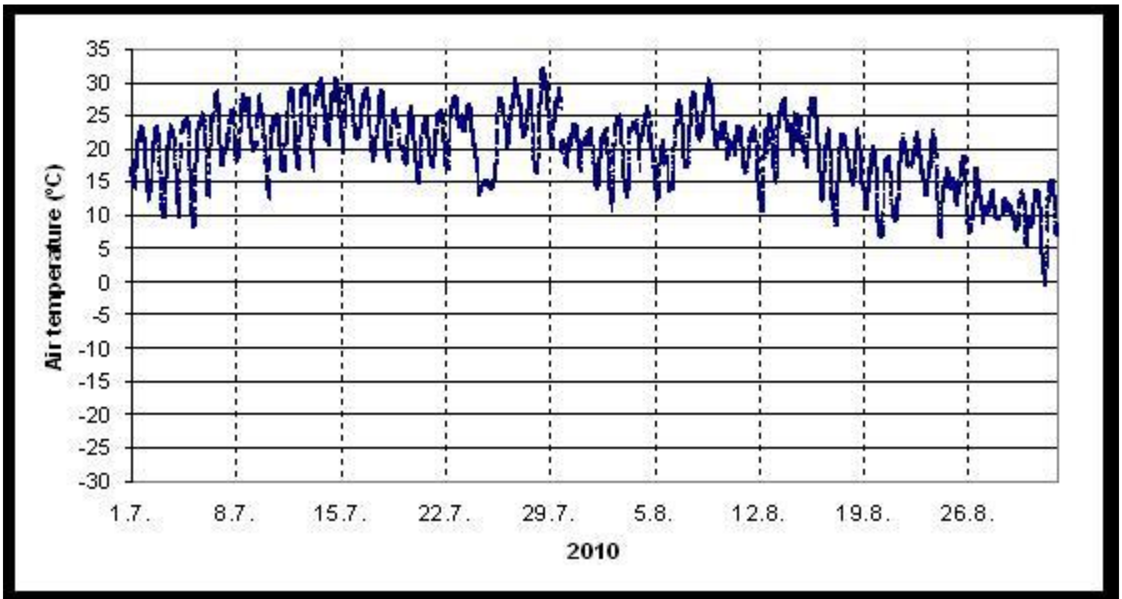
19.6.
26.6.
2010


Air temperature (°C)
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30
25
20
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5
0
-5
-10
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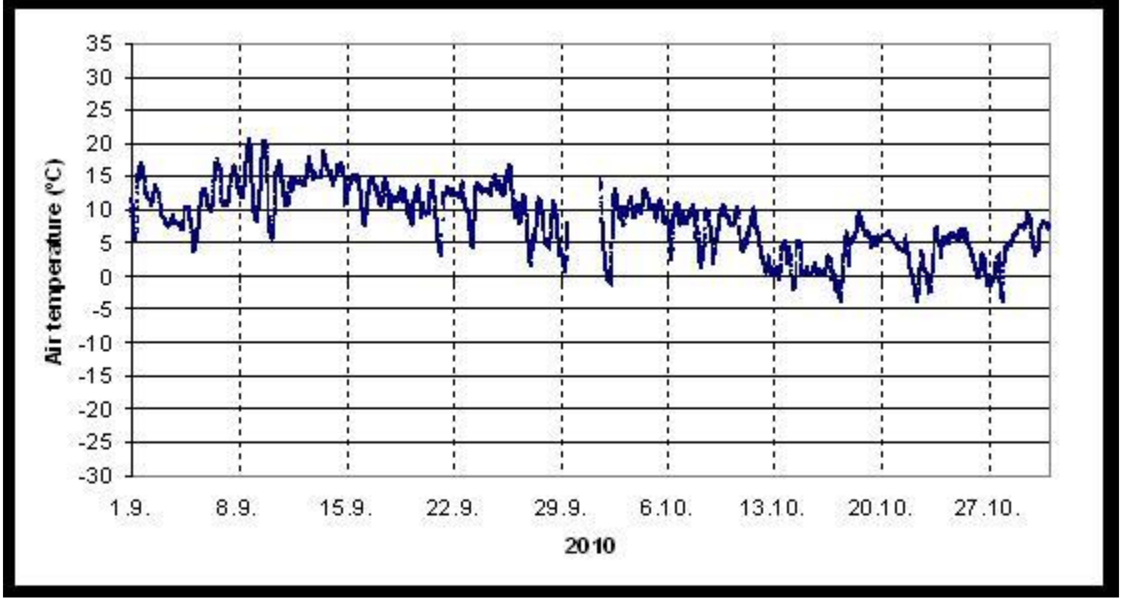
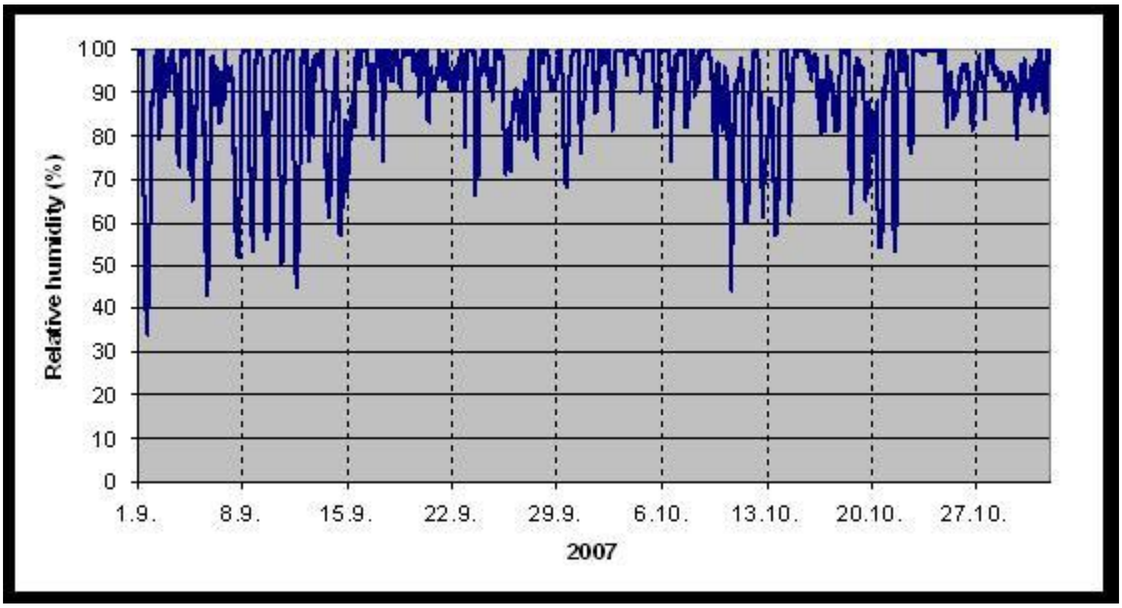
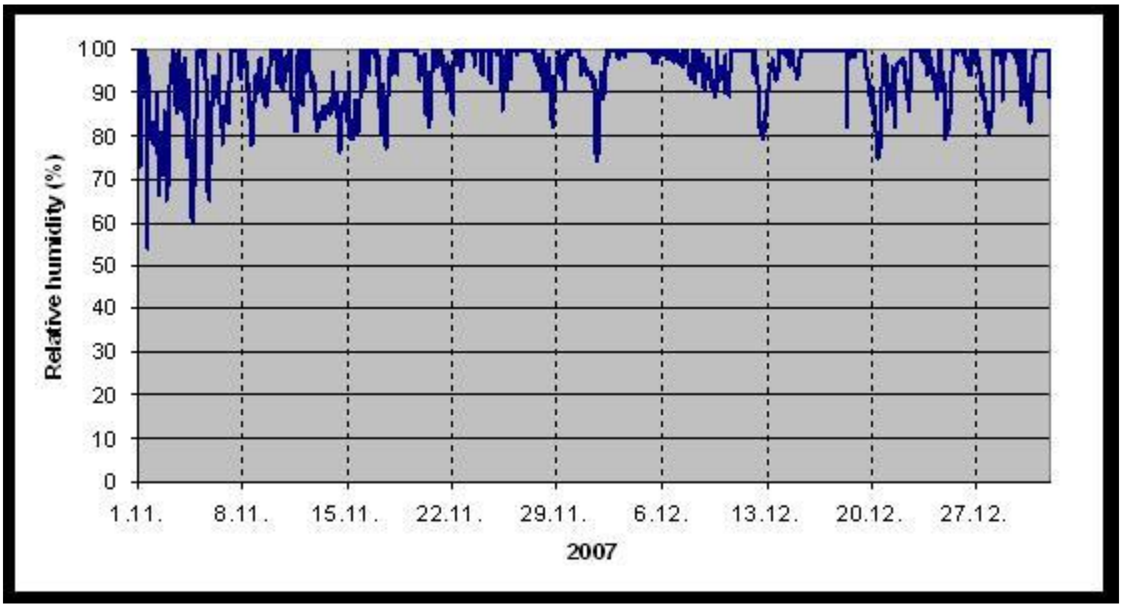
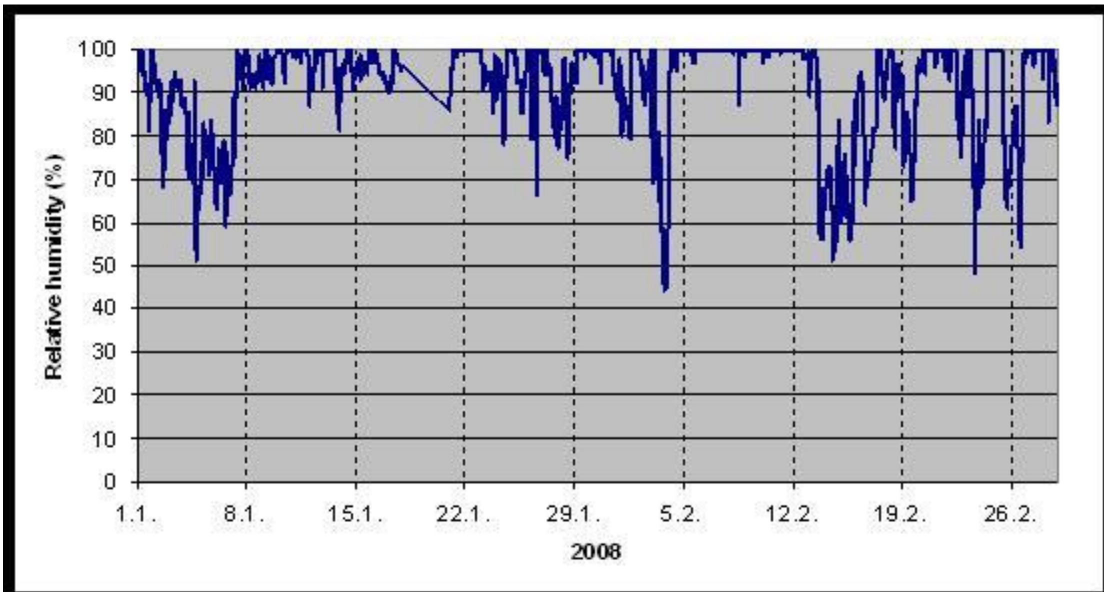
-20
-25
-30
1.7.
8.7.
15.7.
22.7.
29.7.
5.8.
12.8.
19.8.
26.8.
2010


Air temperature (°C)
35
30
25
20
15
10
5
0
-5
-10
-15
-20
-25
-30
1.9.
8.9.
15.9.
22.9.
29.9.
6.10.
13.10.
20.10.
27.10.
2010

Highway testing field. Relative humidity 1.9.2007 - 31.10.2010.






Relative humidity (%)
100
90
80
70
60
50
40
30
20
10
0
1.1.
8.1.
15.1.
22.1.
29.1.
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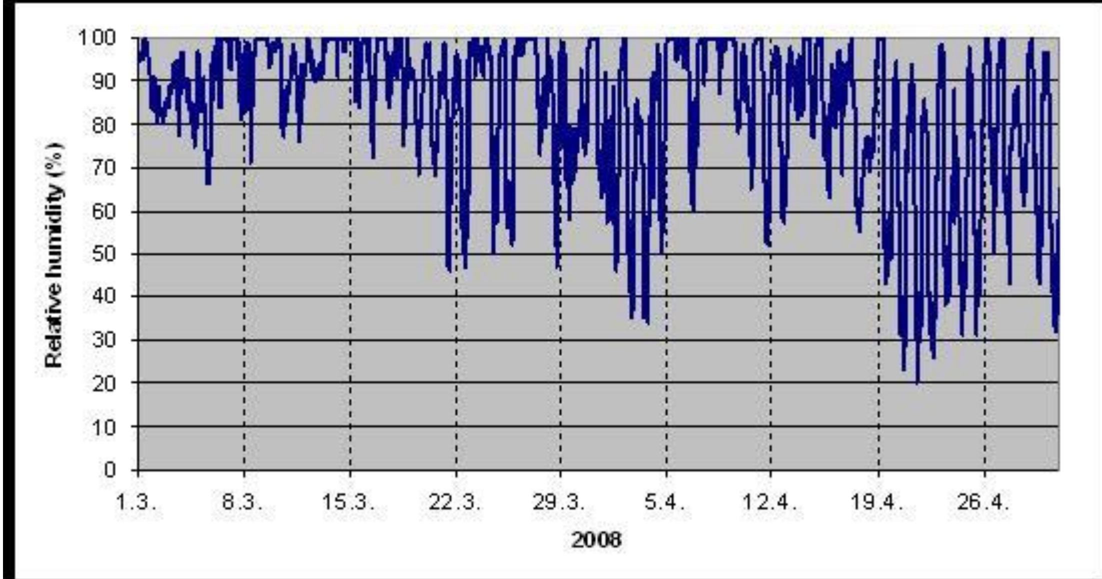
12.2.
19.2.
26.2.
2008


Relative humidity (%)
100
90
80
70
60
50
40
30
20
10
0
1.3.
8.3.
15.3.
22.3.
29.3.
5.4.
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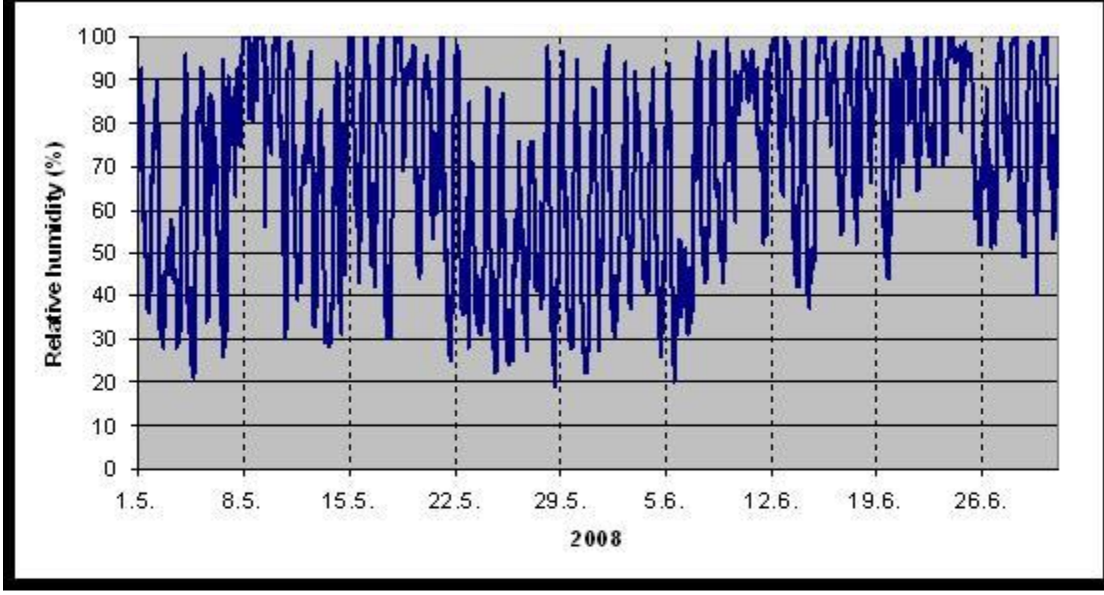
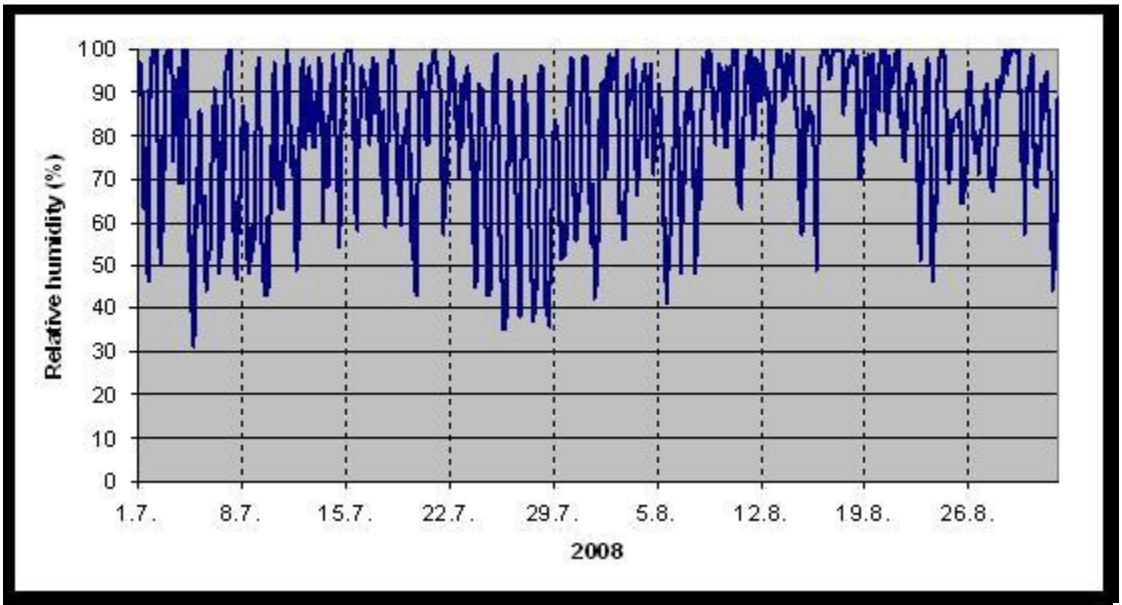
19.4.
26.4.
2008


Relative humidity (%)
100
90
80
70
60
50
40
30
20
10
0
1.5.
8.5.
15.5.
22.5.
29.5.
5.6.
12.6.
19.6.
26.6.
2008


100
90
80
70
60
50
40
30
20
10
0
Relative humidity (%)
1.7.
8.7.
15.7.
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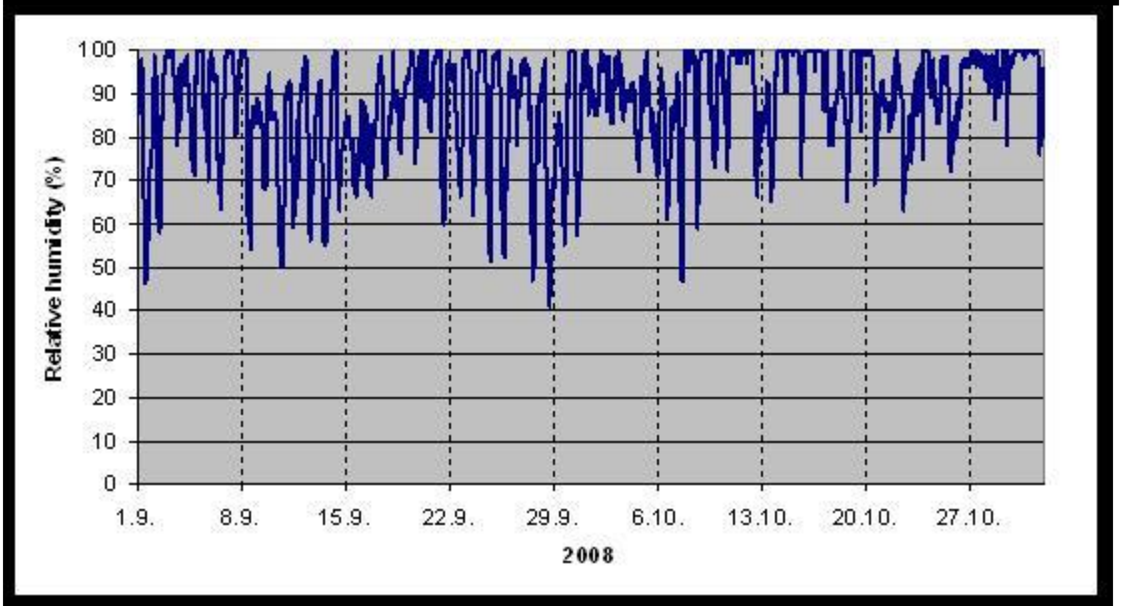
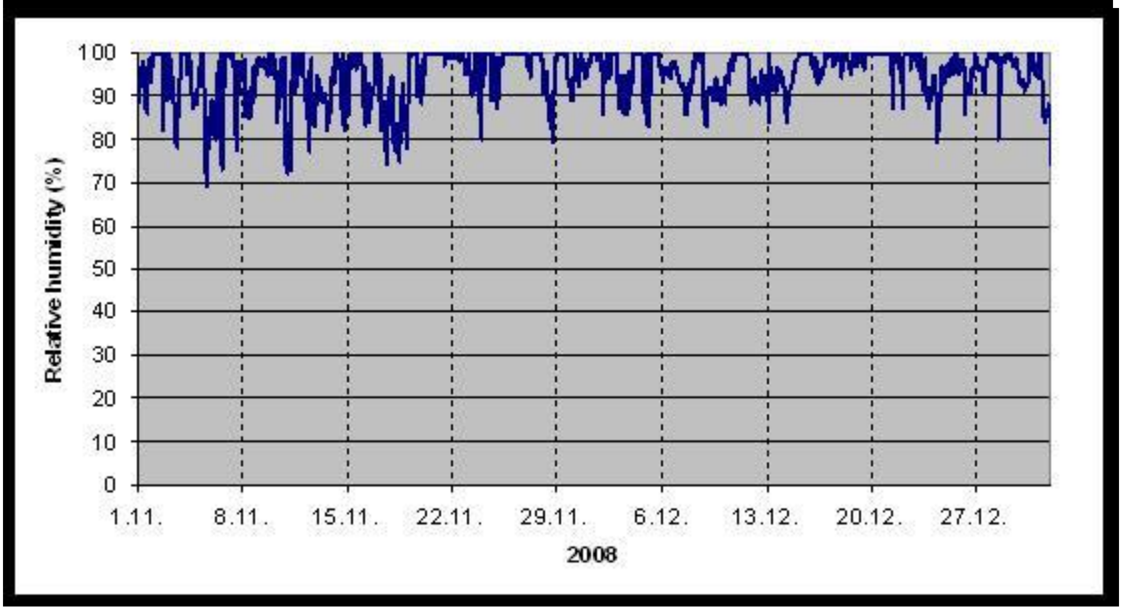
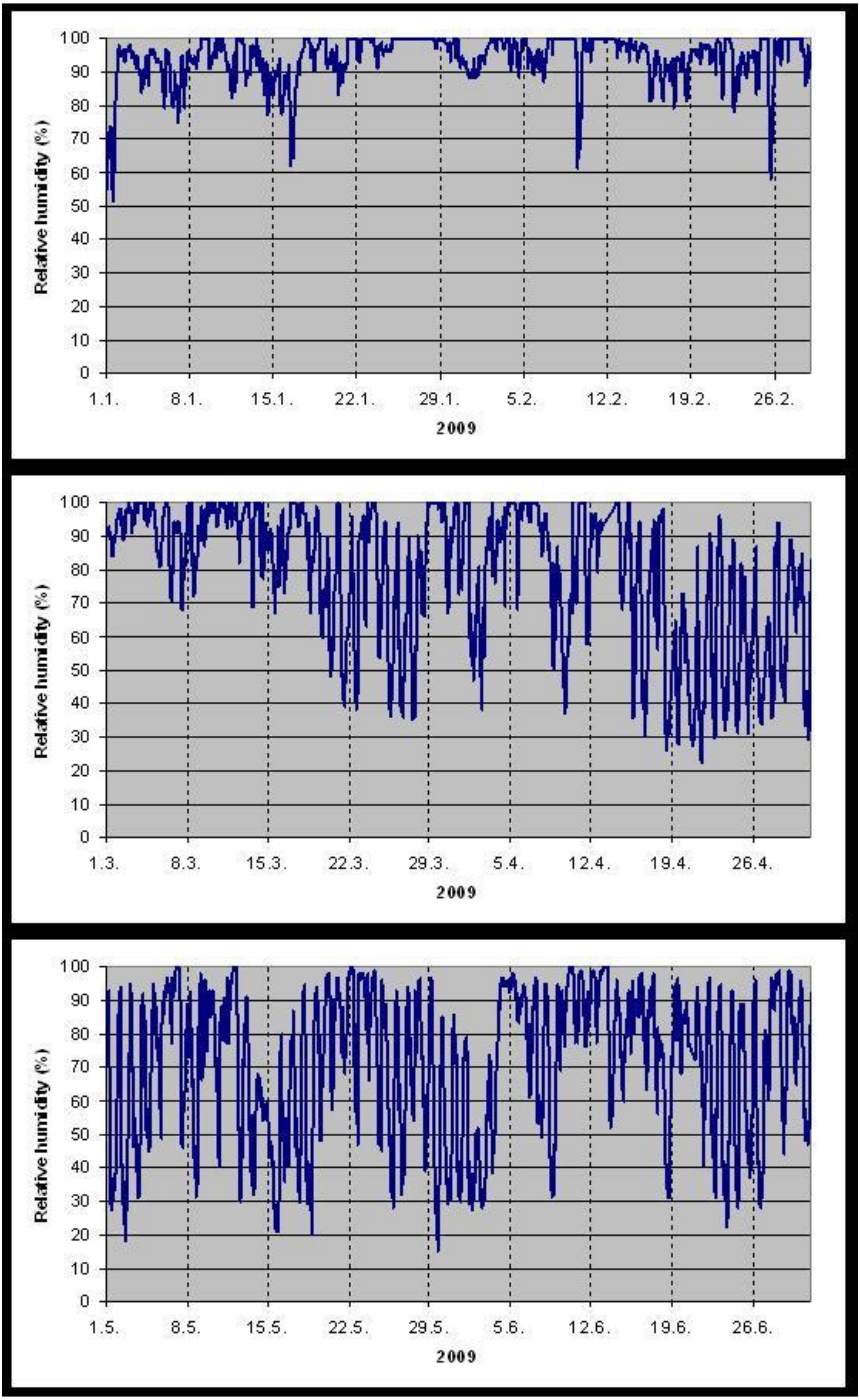
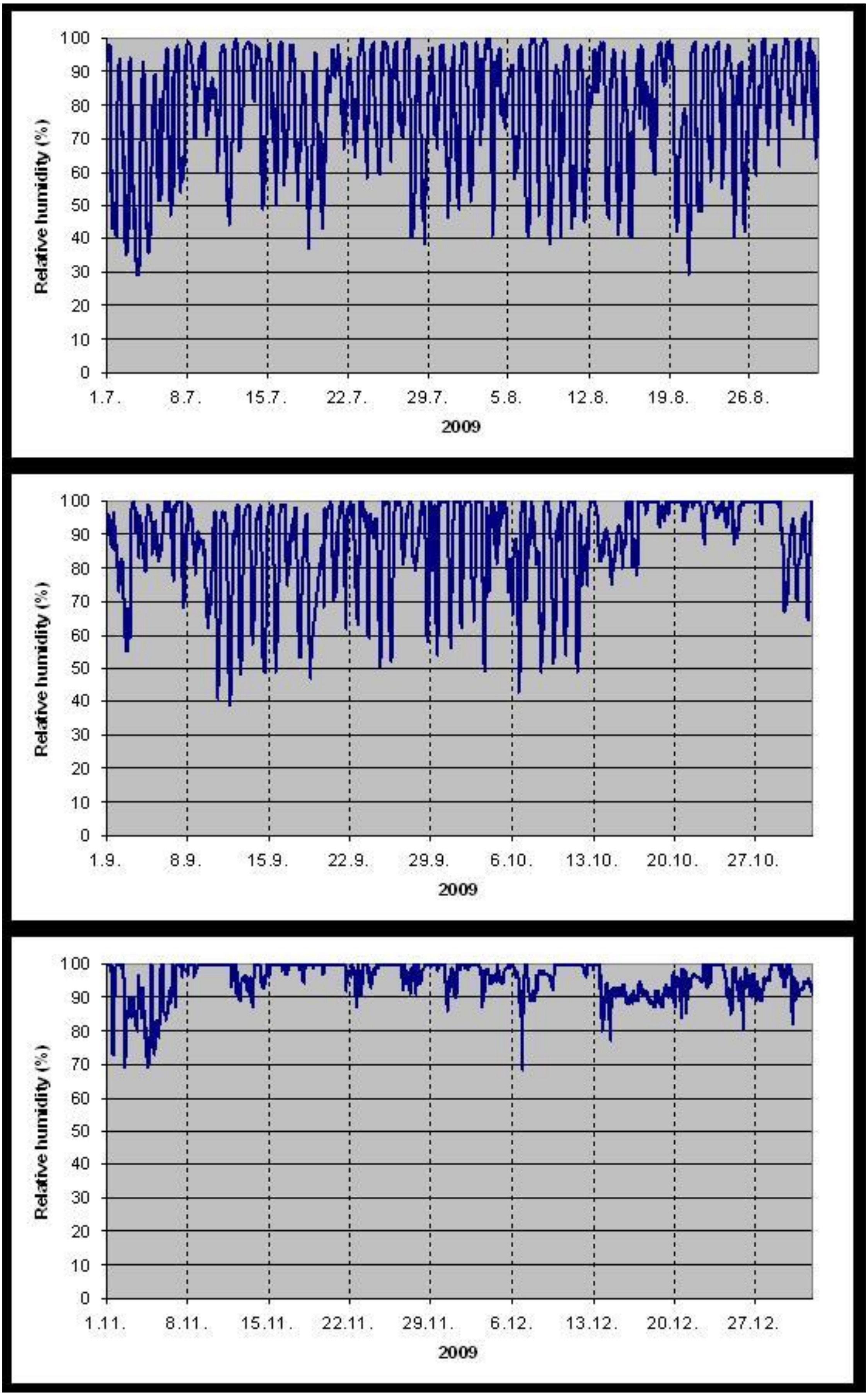
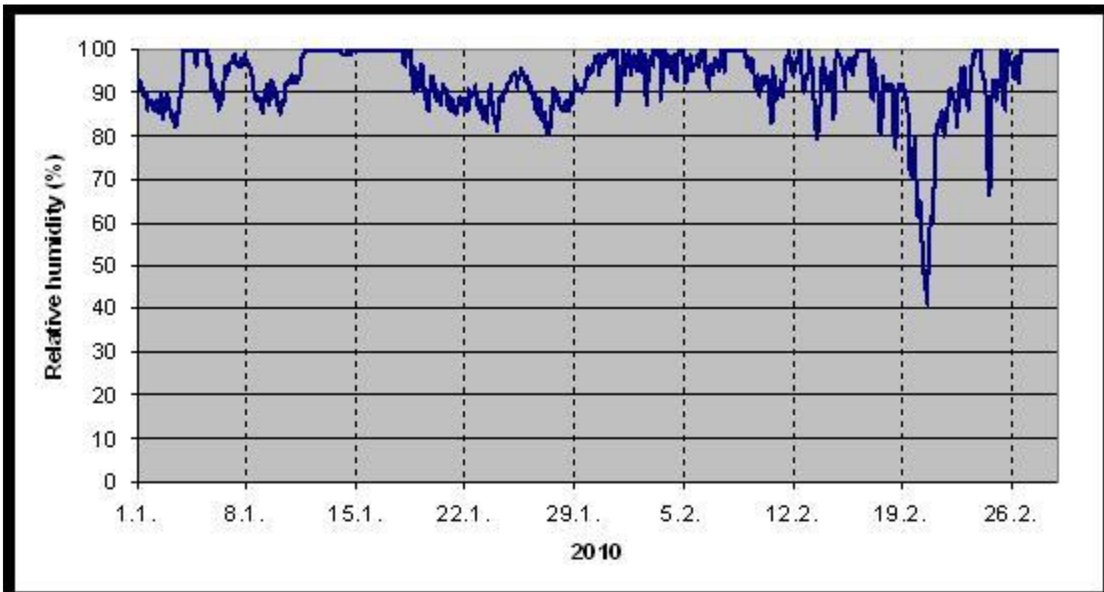
29.7.
5.8.
12.8.
19.8.
26.8.
2008


100
90
80
70
60
50
40
30
20
10
0
Relative humidity (%)
1.9.
8.9.
15.9.
22.9.
29.9.
6.10.
13.10.
20.10.
27.10.
2008


100
90
80
70
60
50
40
30
20
10
0
Relative humidity (%)
1.11.
8.11.
15.11.
22.11.
29.11.
6.12.
13.12.
20.12.
27.12.
2008


Relative humidity (%)
100
90
80
70
60
50
40
30
20
10
0
1.1.
8.1.
15.1.
22.1.
29.1.
5.2.
12.2.
19.2.
26.2.
2009
Relative humidity (%)
1.3.
8.3.
15.3.
22.3.
29.3.
5.4.
12.4.
19.4.
26.4.
2009
Relative humidity (%)
1.5.
8.5.
15.5.
22.5.
29.5.
5.6.
12.6.
19.6.
26.6.
2009


Relative humidity (%)
100
90
80
70
60
50
40
30
20
10
0
1.7.
8.7.
15.7.
22.7.
29.7.
5.8.
12.8.
19.8.
26.8.
2009
Relative humidity (%)
1.9.
8.9.
15.9.
22.9.
29.9.
6.10.
13.10.
20.10.
27.10.
2009
Relative humidity (%)
1.11.
8.11.
15.11.
22.11.
29.11.
6.12.
13.12.
20.12.
27.12.
2009


Relative humidity (%)
100
90
80
70
60
50
40
30
20
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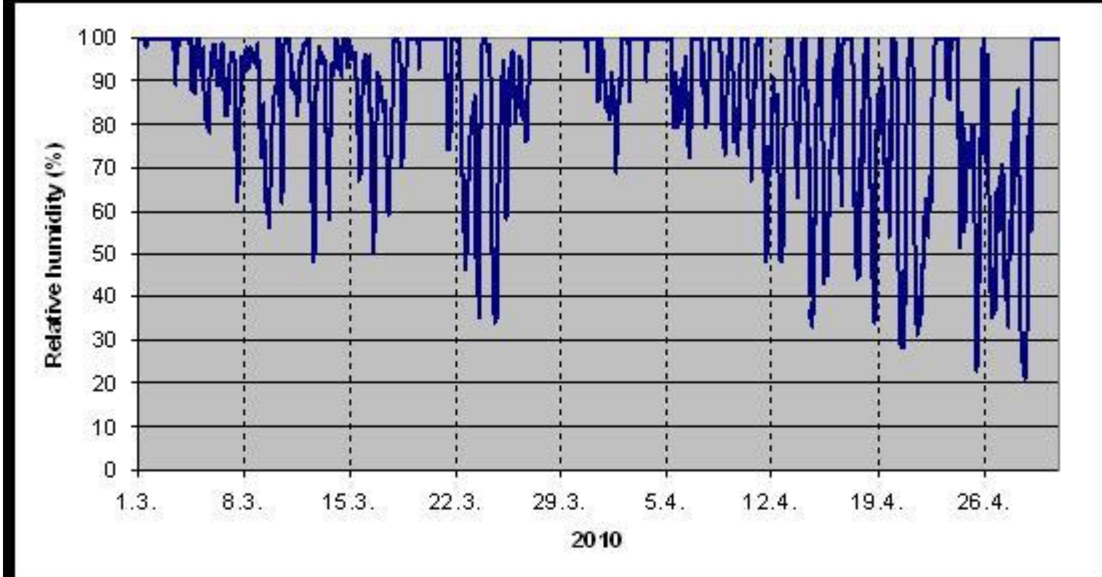
1.1.
8.1.
15.1.
22.1.
29.1.
5.2.
12.2.
19.2.
26.2.
2010


Relative humidity (%)
100
90
80
70
60
50
40
30
20
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1.3.
8.3.
15.3.
22.3.
29.3.
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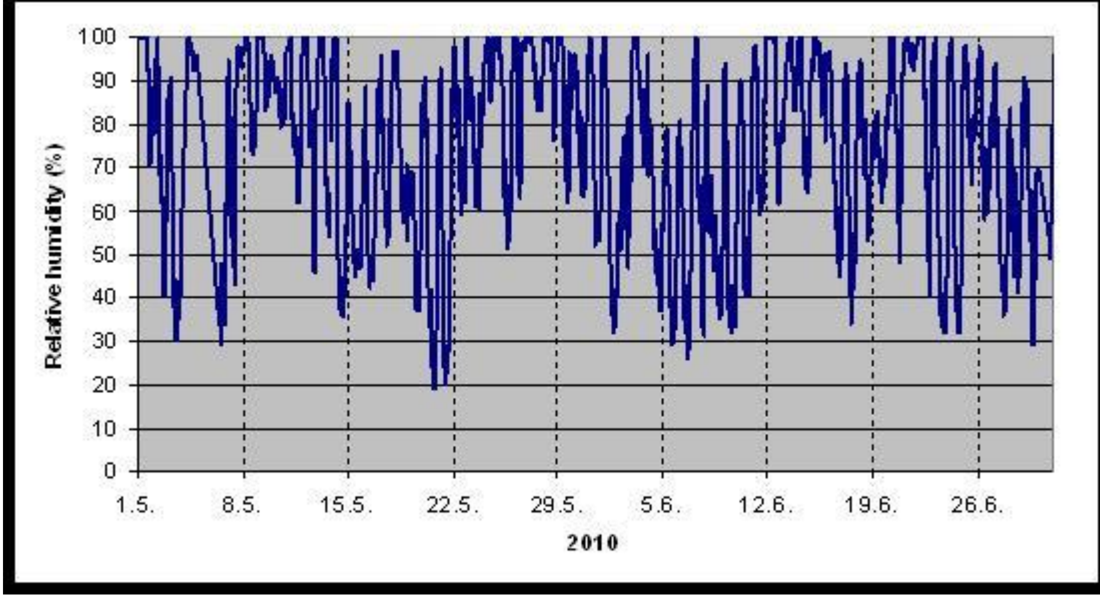
19.4.
26.4.
2010


Relative humidity (%)
100
90
80
70
60
50
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15.5.
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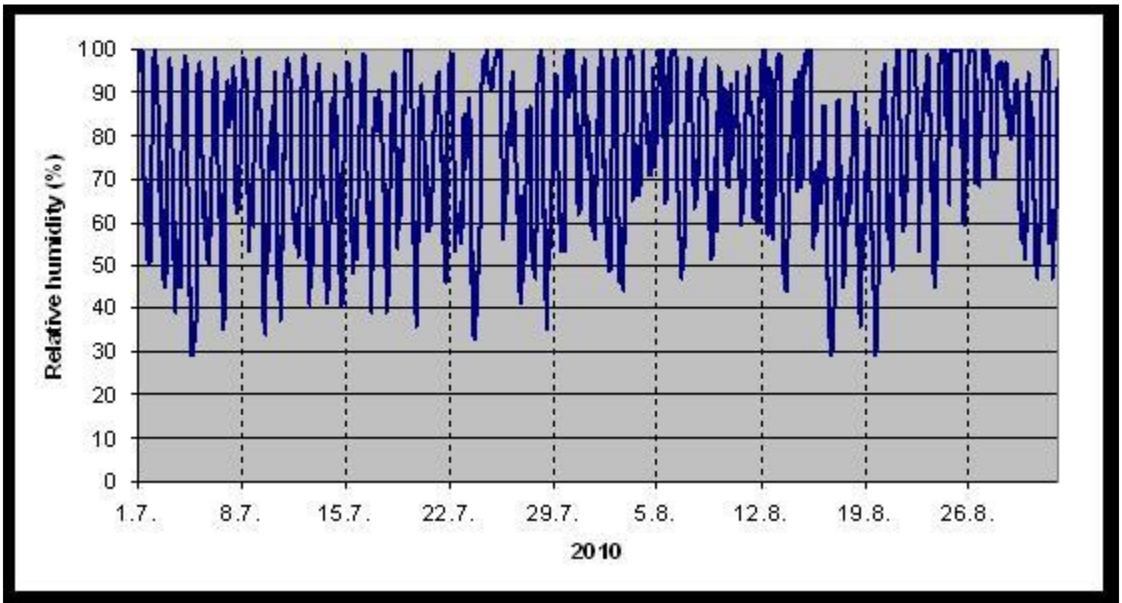
2010


Relative humidity (%)
100
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80
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60
50
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30
20
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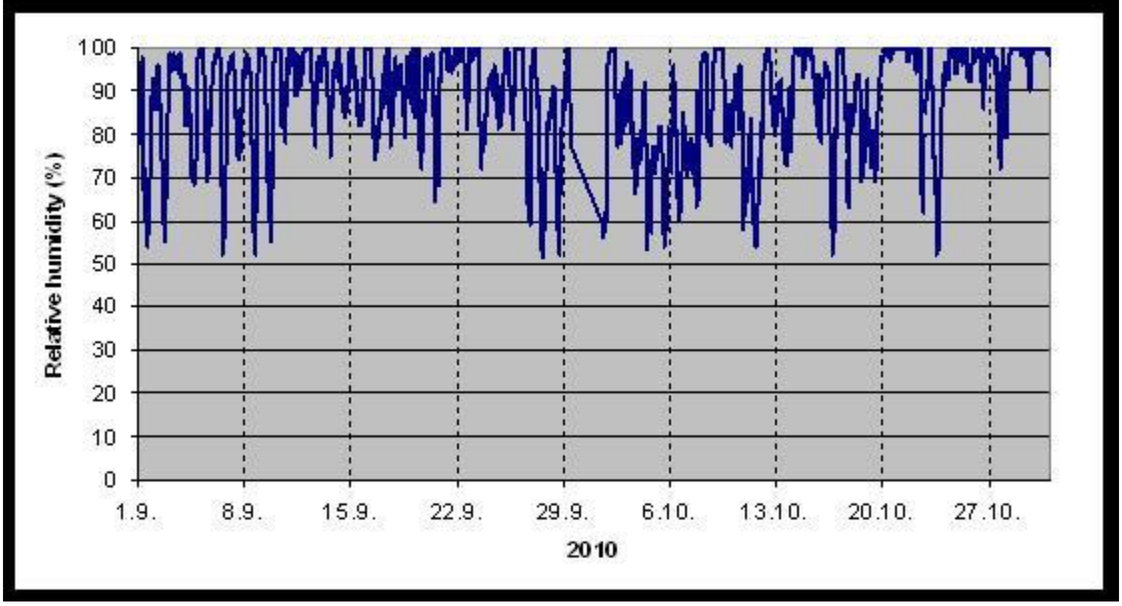
26.8.
2010


Relative humidity (%)
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90
80
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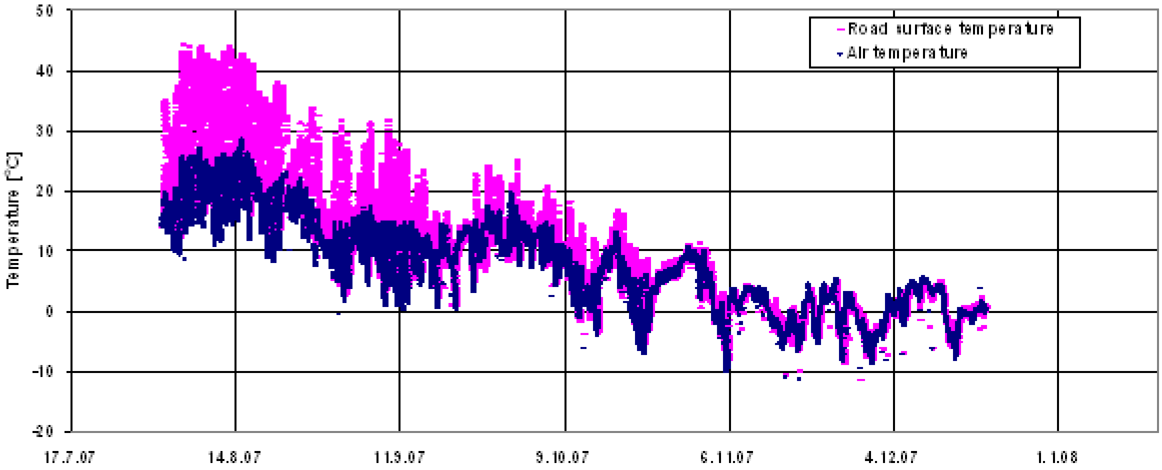
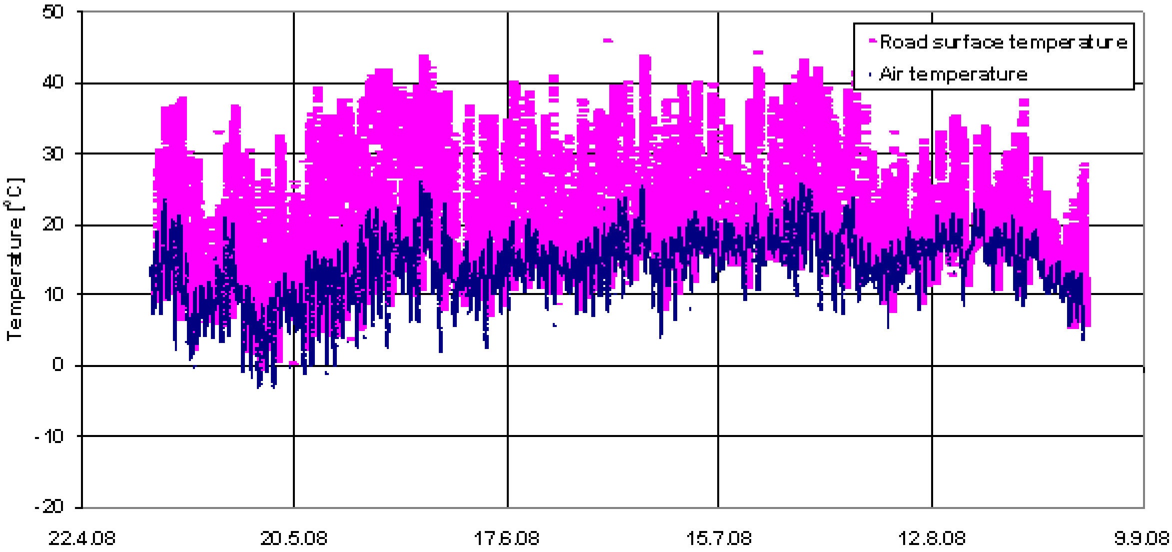
60
50
40
30
20
10
0
1.9.
8.9.
15.9.
22.9.
29.9.
6.10.
13.10.
20.10.
27.10.
2010

Highway testing field.
Road surface temperature and air temperature: 2.8.2008 – 31.8.2008.





Concrete temperature and humidity (RH-%) follow-up. Examples.

There are two concrete compositions (w/c-ratio 0.50 and 0.42) and two specimen sizes (300 x 300 x 500 mm^3 and 75 x 150 x150 mm^3) for these measurements.

Concretes (B and C)				Concretes (B and C)			
Small specimen (1 & 2) Specimen size: 150x150xh75mm^3				Big specimen (3 & 4) Specimen size: 300x400xh300mm^3			
Concrete and specimen				Concrete and specimen			
B1	B2	C1	C2	B3	B4	C3	C4

Basic mix design information		
	B	**C**
Cement	CEM II/A-M(S-LL) 42,5 N	
w/c	0,42	0,50
Air ca. [%]	5	5
Slump [mm]	100	100
Maximum aggregate size [mm]	16	16
Cement content [kg/m^3]	428	333
Weff = effective total water content [kg/m^3]	180	167
Admixtures	Plasticizer and Air entraining agent	

Temperature and humidity measurement in big field specimen (400 x 300 x 300 mm^3). Measurements were also made by optical fibres. Sensors and optical fibres were casted inside the specimen in different levels and points. (Englund, M. & Lehtiniemi, P. /Fortum R&D)

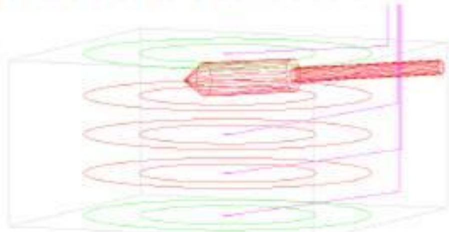
Lämpötila ja kosteusanturit isommissa betoneissa B3, B4, C3 ja C4 (400 x 300 x 300)

	B3	B4	C3	C4
Jatkuvana lämpötila kappaleiden keskellä (T)	yläpinta (mahd. lähellä yläpintaa)		yläpinta (mahd. lähellä yläpintaa)	
	37,5 mm		37,5 mm	
	150 mm (keskellä)		150 mm (keskellä)	
	262,5 mm (=37,5 mm alapinnasta)		262,5 mm (= 37,5 mm alapinnasta)	
	alapinta (mahd. lähellä alapintaa)		alapinta (mahd. lähellä alapintaa)	
	sivupinta (mahd. lähellä sivupintaa)		sivupinta (mahd. lähellä sivupintaa)	
Jatkuvana kosteus (RH) & lämpötila kappaleiden keskellä	50 mm yläpinnasta ja 50 mm alapinnasta [1]		50 mm yläpinnasta ja 50 mm alapinnasta [1]	
Kulturenkaat 3 kpl sisäkkäin	yläpinta (mahd. lähellä yläpintaa)	yläpinta (mahd. lähellä yläpintaa)	yläpinta (mahd. lähellä yläpintaa)	yläpinta (mahd. lähellä yläpintaa)
	50	50	50	50
	100	100	100	100
	150 (keskellä)	150 (keskellä)	150 (keskellä)	150 (keskellä)
	200(= 100 mm alapinnasta)	200(= 100 mm alapinnasta)	200(= 100 mm alapinnasta)	200(= 100 mm alapinnasta)
	250 (= 50 mm alapinnasta)	250 (= 50 mm alapinnasta)	250 (= 50 mm alapinnasta)	250 (= 50 mm alapinnasta)
	alapinta (mahd. lähellä alapintaa)	alapinta (mahd. lähellä alapintaa)	alapinta (mahd. lähellä alapintaa)	alapinta (mahd. lähellä alapintaa)

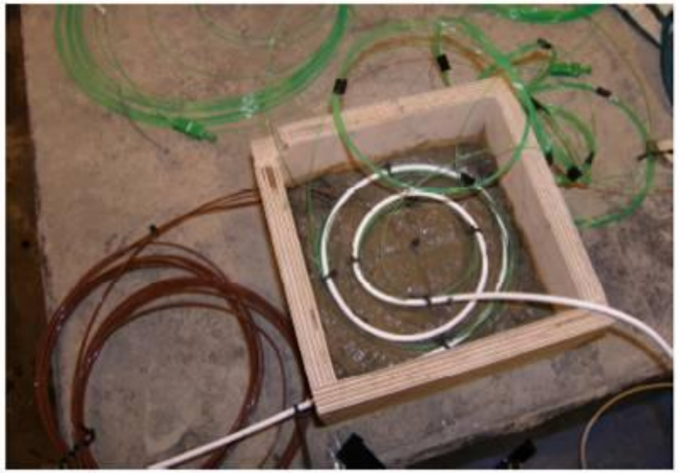
2 Power / M Englund P Lehtiniemi Fortum

Temperature and humidity measurement in small field specimen (400 x 300 x 300 mm^3). Measurements were also made by optical fibres. Sensors and optical fibres were casted inside the specimen in different levels and points. (Englund, M. & Lehtiniemi, P. /Fortum R&D)

Lämpötila ja kosteusanturit pienemmissä betoneissa B1, B2, C1 ja C2 (150 x 150 x 75)

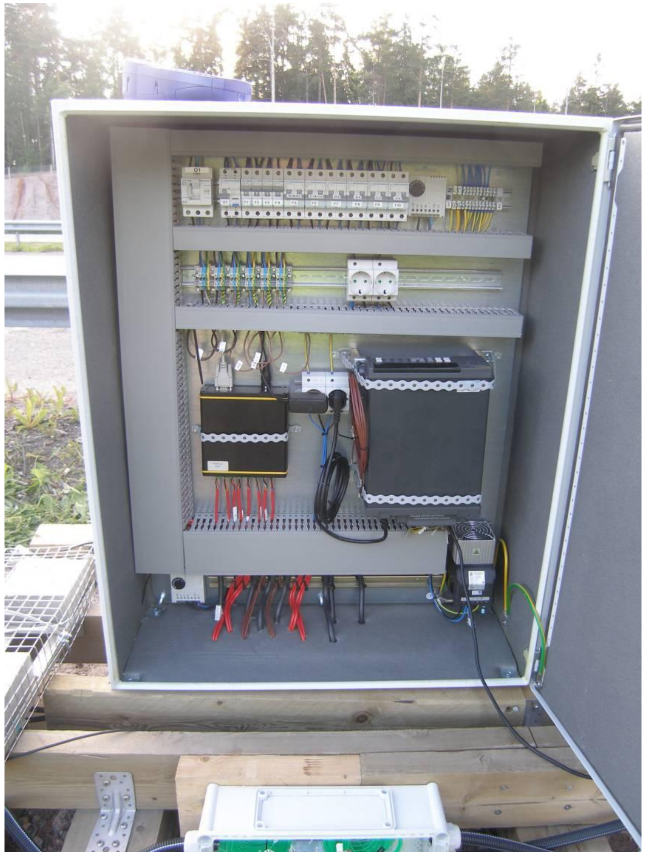


	B1	B2	C1	C2
Jatkuvana lämpötila kappaleiden keskellä (T)	yläpinta (mahd. lähellä yläpintaa)		yläpinta (mahd. lähellä yläpintaa)	
	20 mm		20 mm	
	37,5 mm (=keski)		37,5 mm (=keski)	
	55 mm (= 20 mm alapinnasta)		55 mm (= 20 mm alapinnasta)	
	alapinta (mahd. lähellä alapintaa)		alapinta (mahd. lähellä alapintaa)	
Jatkuvana kosteus (RH) & lämpötila kappaleiden keskellä	5 mm yläpinnasta	5 mm ylä-pinnasta	5 mm yläpinnasta	5 mm ylä-pinnasta
Kuiturenkaat 2 kpl sisäkkäin	yläpinta (mahd. lähellä yläpintaa)	yläpinta (mahd. lähellä yläpintaa)	yläpinta (mahd. lähellä yläpintaa)	yläpinta (mahd. lähellä yläpintaa)
	20 mm	20 mm	20 mm	20 mm
	37,5 mm (=keski)	37,5 mm (=keski)	37,5 mm (=keski)	37,5 mm (=keski)
	55 mm (= 20 mm alapinnasta)	55 mm (= 20 mm alapinnasta)	55 mm (= 20 mm alapinnasta)	55 mm (= 20 mm alapinnasta)
	alapinta (mahd. lähellä alapintaa)	alapinta (mahd. lähellä alapintaa)	alapinta (mahd. lähellä alapintaa)	alapinta (mahd. lähellä alapintaa)

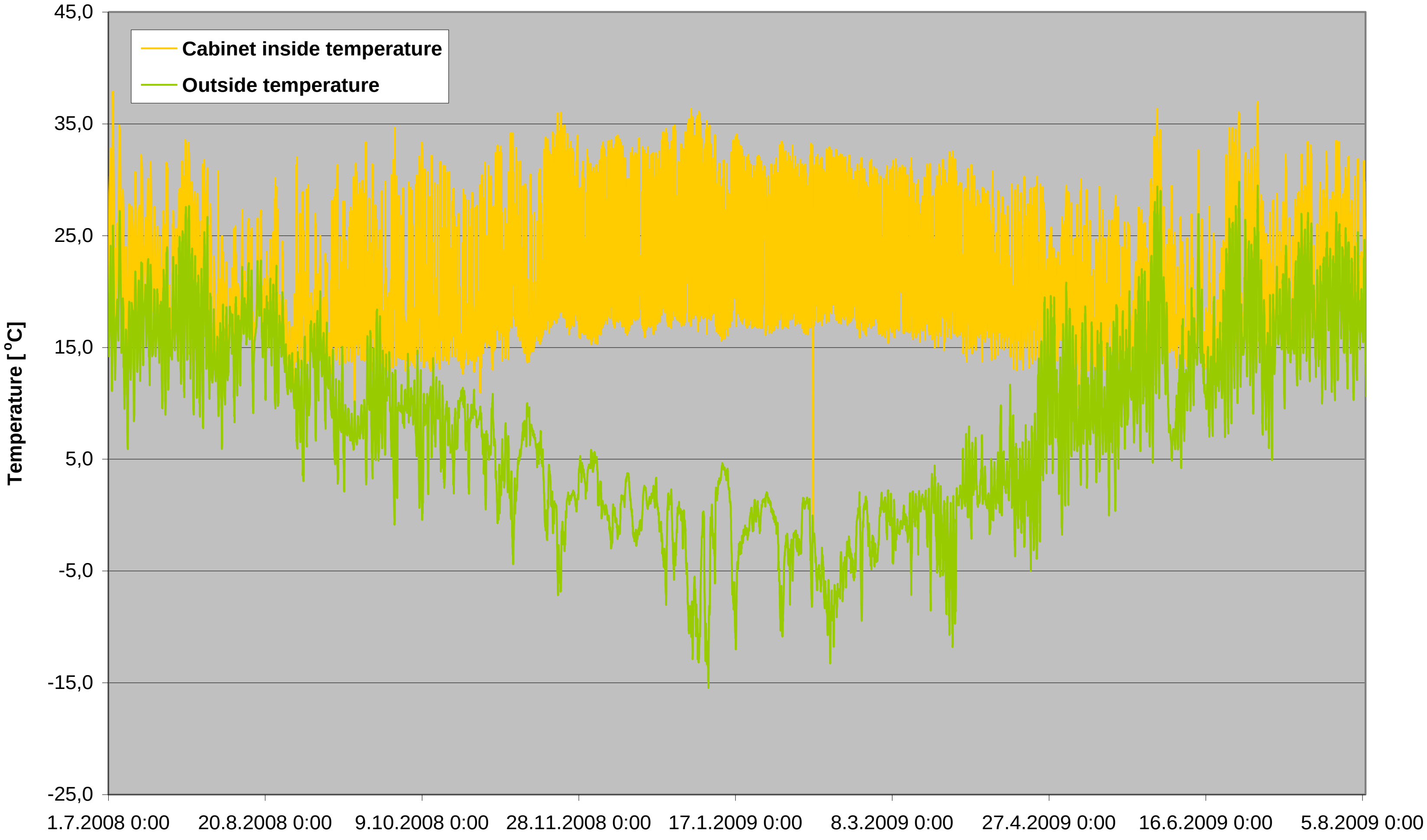


3 Power / M Englund P Lehtiniemi Fortum

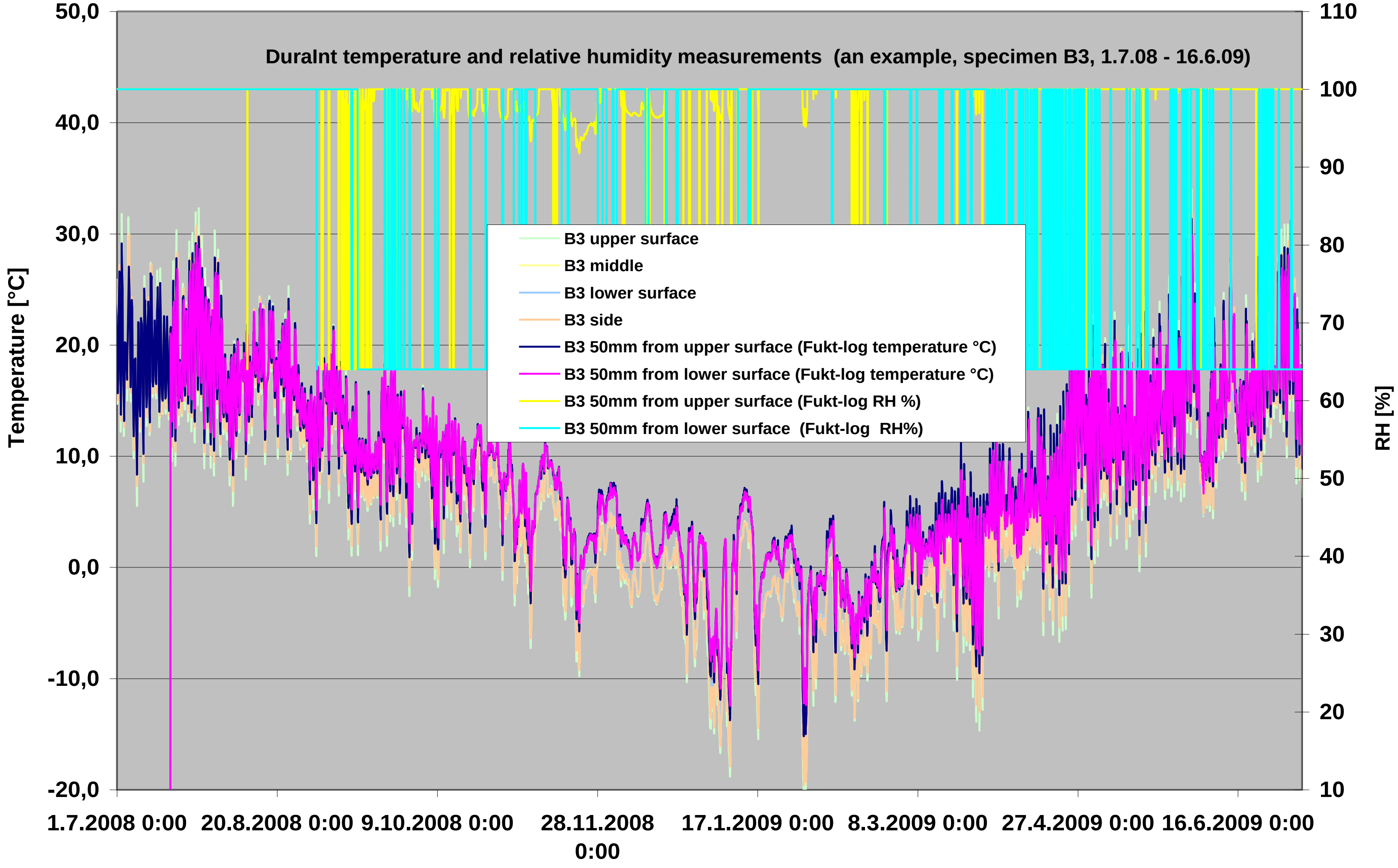
Temperature and humidity measurements at HW 7 testing field. (Englund, M. & Lehtiniemi, P. /Fortum R&D). Left: measuring cabinet; right concrete measurement specimen at field (at left small and at right big specimen



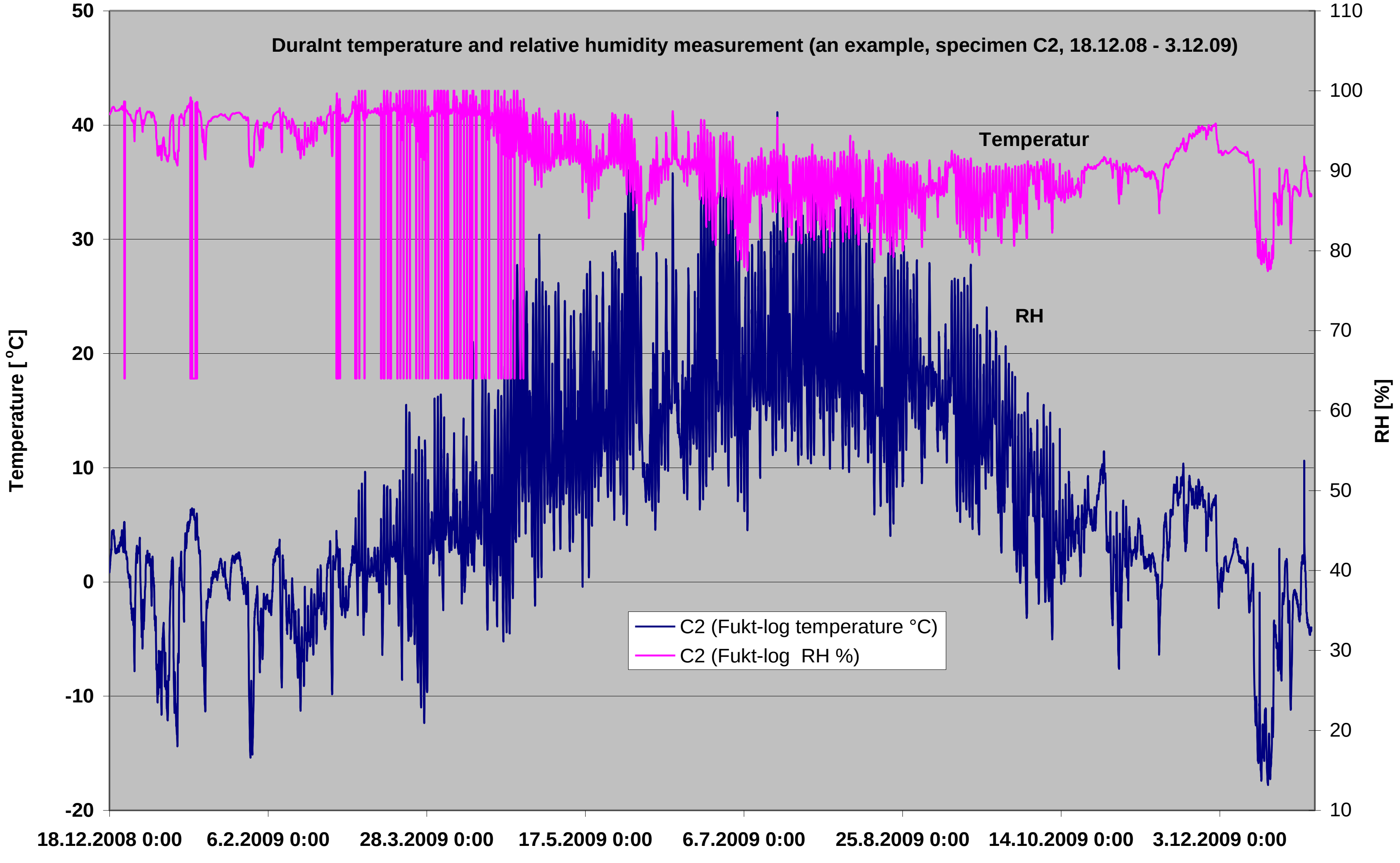
DuraInt temperature measurement, June 2008 – December 2009.
Measuring cabinet indoor (yellow) and outdoor (green) temperatures



DuraInt temperature and humidity (RH) measurement, June 2008 – December 2009.



DuraInt temperature and humidity (RH) measurement, June 2008 – December 2009.



DuraInt concretes. Composition.

Num-ber	Casting place	Casting date	Short code	Descriptive code	Cement/Binding material type	Weff/(Cement+ 2*SF+0,8*BFS +0,4*FA)	Weff/(Cement+ BFS+FA+SF)	Binder materials [kg/m3]				Total eff. water [kg/m3]	Aggregates				Plasticizer		Air-entraining agent	
								Ce-ment	BFS	FA	SF		Aggregate total [kg/m3]	Aggregate < 0,125 mm [%]	Aggregate < 0,250 mm [%]	Aggregate < 4 mm [%]	Product name	Amount [% of all binder materials]	Product name	Amount [% of all binder materials]
1	VTT	25.5.07	SR1	SR1; 0,42; air=4,5%	CEM I 42,5 N - SR	0,42	0,42	421	0	0	0	175	1756	3	7	40		0,5		0,060
2	VTT	25.5.07	SR2	SR2; 0,50; air=4,8%	CEM I 42,5 N - SR	0,50	0,50	360	0	0	0	180	1791	3	7	41		0,278		0,060
3	VTT	28.5.07	SR3	SR3: 0,60; air=6,5%	CEM I 42,5 N - SR	0,60	0,60	294	0	0	0	176	1807	4	10	47		0,22		0,050
4	VTT	28.5.07	SR4	SR4; 0,50; air=2,3%	CEM I 42,5 N - SR	0,50	0,50	357	0	0	0	178	1863	4	10	47		0,44		0,000
5	VTT	28.5.07	SR5	SR5; 0,50; air=2,4%; +SF	CEM I 42,5 N - SR & SF	0,50	0,52	328	0	0	13	176	1872	4	10	47		0,87		0,000
6	VTT	12.9.07	1A	Perus-cem.; w/b=0,42; i=4-5,5%	CEM II/B-S 42,5 N	0,41	0,41	405	0	0	0	165	1746	3	8	46	VB-Parmix	0,692	Ilma-Parmix	0,010
7	R	16.8.07	2A	SR-cem.; w/b=0,42; i=4-5,5%	CEM I 42,5 N - SR	0,42	0,42	387	0	0	0	161	1796	4	11	50	Glenium G 51	0,78	Ilma-Parmix	0,017
8	R	14.8.07	3A	Yleis-cem.; w/b=0,42; i=4-5,5%	CEM II/A-M(S-LL) 42,5 N	0,42	0,42	428	0	0	0	179	1709	3	9	49	Glenium G 51	0,8	Ilma-Parmix	0,014
9	R	14.8.07	5A	Rapid-cem.; w/b=0,42; i=4-5,5%	CEM II/A-LL 42,5 R	0,42	0,42	421	0	0	0	176	1748	3	9	49	Glenium G 51	0,82	Ilma-Parmix	0,017
10	VTT	20.8.07	6A	Pika-cem.; w/b=0,42; i=4-5,5%	CEM I 52,5 R	0,42	0,42	417	0	0	0	175	1737	3	7	40	VB-Parmix	0,873	Ilma-Parmix	0,060
11	VTT	11.9.07	7A	Rapid+BFS 50%; w/b=0,42; I=4-5,5%	CEM II/A-LL 42,5 R & Finnsementti SLG KJ400	0,42	0,37	217	217	0	0	163	1725	2	7	36	VB-Parmix	1,26	Ilma-Parmix	0,030
12	R	6.9.07	8A	Rapid-cem.+FA; w/b=0,42; i=4-5,5%	CEM II/A-LL 42,5 R & FA [EN 450-1. 2005] Fineness N, Class A	0,45	0,38	344	0	106	0	173	1706	3	8	48	Glenium G 51	1,01	Ilma-Parmix	0,018
13	VTT	30.8.07	3Ba	Yleis-cem.; w/b=0,42; i=1-2%	CEM II/A-M(S-LL) 42,5 N	0,42	0,42	410	0	0	0	172	1844	3	9	46	VB-Parmix	1,27		
14	VTT	3.9.07	3Bb	Yleis-cem.; w/b=0,42; i=3-4%	CEM II/A-M(S-LL) 42,5 N	0,42	0,42	406	0	0	0	170	1784	3	9	46	VB-Parmix	1,27	Ilma-Parmix	0,010
15	VTT	3.9.07	3Bc	Yleis-cem.; w/b=0,42; i=5-6%	CEM II/A-M(S-LL) 42,5 N	0,42	0,42	407	0	0	0	172	1756	3	9	46	VB-Parmix	1,5	Ilma-Parmix	0,028
16	VTT	10.9.07	3Bc2	Yleis-cem.; w/b=0,42; i=6-7%	CEM II/A-M(S-LL) 42,5 N	0,42	0,42	406	0	0	0	170	1715	3	9	46	VB-Parmix	1,25	Ilma-Parmix	0,030
17	VTT	4.9.07	3Bd-SCC1	Yleis-cem.; w/b=0,42; i=3-4%; SCC	CEM II/A-M(S-LL) 42,5 N	0,42	0,42	435	0	0	0	185	1746	7	16	53	VB-Parmix	3,045	Ilma-Parmix	0,010
18	VTT	4.9.07	3Be-SCC2	Yleis-cem.; w/b=0,42; i=5-6%; SCC	CEM II/A-M(S-LL) 42,5 N	0,42	0,42	426	0	0	0	178	1709	7	16	53	VB-Parmix	2,539	Ilma-Parmix	0,025
19	VTT	13.9.07	1C	Perus-cem.; w/b=0,50; i=4-5,5%	CEM II/B-S 42,5 N	0,47	0,47	339	0	0	0	160	1808	3	9	46	VB-Parmix	0,668	Ilma-Parmix	0,007
20	R	23.8.07	3C	Yleis-cem.; w/b=0,50; i=4-5,5%	CEM II/A-M(S-LL) 42,5 N	0,49	0,49	333	0	0	0	163	1847	4	10	51	Glenium G 51	0,6	Ilma-Parmix	0,012
21	P	20.9.07	4C	Valko-cem.; w/b=0,50; i=4-5,5%	CEM I 52,5 N	0,46	0,46	334	0	0	0	154	1816	4	8	41	Teho-Parmix	0,826	Mischöl	0,047
22	R	28.8.07	5C	Rapid-cem.; w/b=0,50; i=4-5,5%	CEM II/A-LL 42,5 R	0,51	0,51	337	0	0	0	172	1833	4	10	51	Glenium G 51	0,78	Ilma-Parmix	0,012
23	P	18.9.07	6C	Pika-cem.; w/b=0,40; i=4-5,5%	CEM I 52,5 R	0,40	0,40	451	0	0	0	180	1722	5	11	53	Teho-Parmix	2,54	Mischöl	0,045
24	R	24.8.07	3D	Yleis-cem.; w/b=0,50; i=3-4%	CEM II/A-M(S-LL) 42,5 N	0,50	0,50	333	0	0	0	166	1895	4	10	51	Glenium G 51	0,61	Ilma-Parmix	0,008
25	VTT	12.9.07	1E	Perus-cem.; w/b=0,60; i=4-5,5%	CEM II/B-S 42,5 N	0,60	0,60	273	0	0	0	163	1845	4	10	49	VB-Parmix	0,536	Ilma-Parmix	0,009
26	R	6.9.07	3E	Yleis-cem.; w/b=0,60; i=4-5,5%	CEM II/A-M(S-LL) 42,5 N	0,58	0,58	321	0	0	0	185	1828	5	12	49			Ilma-Parmix	0,020
27	P	20.9.07	4E	Valko-cem.; w/b=0,60; i=4-5,5%	CEM I 52,5 N	0,54	0,54	300	0	0	0	162	1840	5	9	44	Teho-Parmix	0,527	Mischöl	0,042
28	P	18.9.07	5E	Rapid-cem.; w/b=0,60; i=4-5,5%	CEM II/A-LL 42,5 R	0,54	0,54	322	0	0	0	174	1764	3	9	46	Teho-Parmix	1,58	Mischöl	0,030
29	R	13.3.08	3Bf	Yleis-cem.; w/b=0,42;i=1-2 %	CEM II/A-M(S-LL) 42,5 N	0,41	0,41	420	0	0	0	174	1812				Glenium G 51	0,7	Ilma-Parmix	0,000
30	R	13.3.08	3Bg	Yleis-cem.; w/b=0,42;i=4 %	CEM II/A-M(S-LL) 42,5 N	0,41	0,41	420	0	0	0	174	1745				Glenium G 51	0,7	Ilma-Parmix	0,020
31	R	13.3.08	3Bh	Yleis-cem.; w/b=0,42; i=6 %	CEM II/A-M(S-LL) 42,5 N	0,41	0,41	420	0	0	0	174	1691				Glenium G 51	0,6	Ilma-Parmix	0,030
32	R	18.3.08	3Bi	Yleis-cem.; w/b=0,42;i=4 %	CEM II/A-M(S-LL) 42,5 N	0,41	0,41	420	0	0	0	174	1746				Glenium G 51	0,76	Ilma-Parmix	0,060
33	VTT	16.9.09	3Db-REF	Yleis-cem.; w/b=0,51; i=5%	CEM II/A-M(S-LL) 42,5 N	0,51	0,51	333	0	0	0	170	1848	4	10	51	Glenium G 51	0,56	Ilma-Parmix	0,008
34	VTT	17.9.09	3Db -Cu	Yleis-cem.; w/b=0,51; i=5%	CEM II/A-M(S-LL) 42,5 N	0,52	0,52	331	0	0	0	174	1827	4	10	51	Glenium G 51	0,56	Ilma-Parmix	0,008
35	VTT	2.10.09	Cu-mortar	Yleis-cem.; w/b=0,54; i=6%	CEM II/A-M(S-LL) 42,5 N	0,54	0,54	500	0	0	0	270	1370	6	20	80	Glenium G 51	0	Ilma-Parmix	0,010
36	R	22.9.09	5G	Rapid-cem.; w/b=0,42; i=4,5%	CEM II/A-LL 42,5 R	0,42	0,42	378	0	0	0	158	1793				VB-Parmix	2,07	Ilma-Parmix	0,920
37	R	22.9.09	5H	Rapid-cem.; w/b=0,39; i=6,8%	CEM II/A-LL 42,5 R	0,39	0,39	437	0	0	0	169	1644				VB-Parmix	2,08	Ilma-Parmix	1,020
38	R	22.9.09	5J	Rapid-cem.; w/b=0,43; i=2,6%	CEM II/A-LL 42,5 R	0,43	0,43	421	0	0	0	179	1755				VB-Parmix	1,98	Ilma-Parmix	0,170

Aggregate information for concretes mixed at VTT

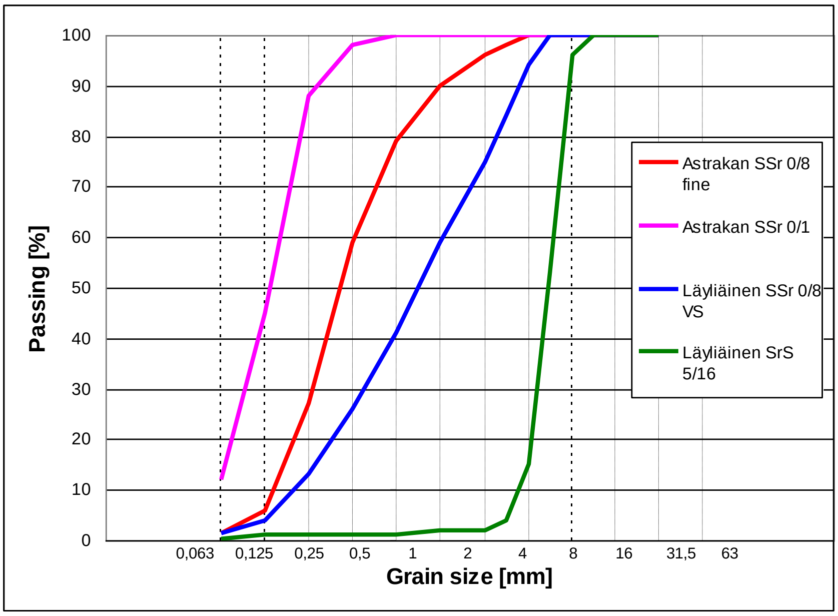
Average values for the aggregates

For each mix a suitable grain size distribution was produced by using below Rudus Oy aggregates. Water absorption was not measured, but the value by Rudus Oy in the below Table A was used. Moisture content was measured at VTT after homogenization procedure.

Table A. Aggregate information. Aggregates used in VTT laboratory concretes.

	Passing (averge) [%]			
Mesh [mm]	Astrakan SSr 0/1	Astrakan SSr 0/8 fine	Läyliäinen SSr 0/8 VS	Läyliäinen SrS 5/16
0,063	11,9	1,3	1,3	0,4
0,125	45	6	4	1
0,25	88	27	13	1
0,5	98	59	26	1
1	100	79	41	1
2	100	90	59	2
4	100	96	75	2
5,6	100	98	84	4
8	100	100	94	15
11,2	100	100	100	53
16	100	100	100	96
22,4	100	100	100	100
31,5	100	100	100	100
45	100	100	100	100
63	100	100	100	100
H-value (about) [By 43] [1)]	931	757	612	319
True density, impregnated surface dry, ρssd [Mg/m^3]	2,69	2,69	2,72	2,75
Water absorption WA24 [%]	0,4	0,4	0,4	0,3
Moisture content (estimated) [%]	10	5	3,6	0,7

1) H-value = ∑Passing-% for meshes [mm]: 0.125, 0.25, 0.5, 1, 2, 4, 8, 16, 31.5 and 63



DuraInt concretes. Fresh concrete properties.

Number	Casting place	Casting date	Short code	Descriptive code	Measurement time [min after water addition] (about)	Basic properties						Air Void Analyzer results (AVA)			
						Slump value [mm]	Tempera-ture [^oC]	SCC Slump-flow/T50 [mm/s]	SCC T50 [s]	Density [kg/m3]	Fresh concrete air content [%]	Air pores < 2 mm [%] (about)	Air pores < 0,3 mm [%]	Specific surface [mm^2/mm^3]	Spacing factor [mm]
1	VTT	25.5.2007	SR1	SR1; 0,42; air=4,5%	10	103				2362	4,5	1,6	1,1	34	0,25
2	VTT	25.5.2007	SR2	SR2; 0,50; air=4,8%	10	65				2353	4,8	2,2	1,5	34	0,22
3	VTT	28.5.2007	SR3	SR3: 0,60; air=6,5%	10	65				2293	6,5	5,4	2,5	23	0,21
4	VTT	28.5.2007	SR4	SR4; 0,50; air=2,3%	10	45				2432	2,3				
5	VTT	28.5.2007	SR5	SR5; 0,50; air=2,4%; +SF	10	70				2420	2,4				
6	VTT	12.9.2007	1A	Perus-cem.; w/b=0,42; i=4-5,5%	25	40				2295	6,5	1,5	0,6	24	0,35
7	R	16.8.2007	2A	SR-cem.; w/b=0,42; i=4-5,5%	10	115	26,0			2357	5,9	4,5		19	0,28
8	R	14.8.2007	3A	Yleis-cem.; w/b=0,42; i=4-5,5%	10	180	27,7			2328	5,9	4,1		20	0,28
9	R	14.8.2007	5A	Rapid-cem.; w/b=0,42; i=4-5,5%	10	140	29,7			2356	5,0	2,8		17	0,40
10	VTT	20.8.2007	6A	Pika-cem.; w/b=0,42; i=4-5,5%	10	80				2314	5,5	2,0	0,4	20	0,49
11	VTT	11.9.2007	7A	Rapid+BFS 50%; w/b=0,42; I=4-5,5%	10	150				2344	6,1	4,8	3,7	39	0,13
12	R	6.9.2007	8A	Rapid-cem.+FA; w/b=0,42; i=4-5,5%	10	170	22,6			2357	5,0	4,0		24	0,25
13	VTT	30.8.2007	3Ba	Yleis-cem.; w/b=0,42; i=1-2%	10	115				2428	2,6				
14	VTT	3.9.2007	3Bb	Yleis-cem.; w/b=0,42; i=3-4%	10	90				2346	4,5	1,6	0,6	20	0,42
15	VTT	3.9.2007	3Bc	Yleis-cem.; w/b=0,42; i=5-6%	10	85				2369	5,3	1,7	0,8	25	0,33
16	VTT	10.9.2007	3Bc2	Yleis-cem.; w/b=0,42; i=6-7%	10	130				2321	7,0	5,6	2,6	24	0,20
17	VTT	4.9.2007	3Bd-SCC1	Yleis-cem.; w/b=0,42; i=3-4%; SCC	10			680	2,9	2365	3,4	2,0	0,2	11	0,75
18	VTT	4.9.2007	3Be-SCC2	Yleis-cem.; w/b=0,42; i=5-6%; SCC	10			750	2,7	2300	5,7	5,1	1,8	20	0,26
19	VTT	13.9.2007	1C	Perus-cem.; w/b=0,50; i=4-5,5%	25	40				2287	6,9	4,3	2,1	24	0,21
20	R	23.8.2007	3C	Yleis-cem.; w/b=0,50; i=4-5,5%	10	120	22,3			2335	5,5	4,0		17	0,32
21	P	20.9.2007	4C	Valko-cem.; w/b=0,50; i=4-5,5%	10	90					5,5				
22	R	28.8.2007	5C	Rapid-cem.; w/b=0,50; i=4-5,5%	10	140	22,8			2370	5,0	3,2		18	0,34
23	P	18.9.2007	6C	Pika-cem.; w/b=0,40; i=4-5,5%	10	130					5,4				
24	R	24.8.2007	3D	Yleis-cem.; w/b=0,50; i=3-4%	10	85	24,2			2395	3,4	2,7		22	0,29
25	VTT	12.9.2007	1E	Perus-cem.; w/b=0,60; i=4-5,5%	25	55				2257	7,3	3,5	1,6	25	0,22
26	R	6.9.2007	3E	Yleis-cem.; w/b=0,60; i=4-5,5%	10	100	18,7			2363	4,3	3,7		19	0,30
27	P	20.9.2007	4E	Valko-cem.; w/b=0,60; i=4-5,5%	10	110					5,5				
28	P	18.9.2007	5E	Rapid-cem.; w/b=0,60; i=4-5,5%	10	140					4,8				
29	R	13.3.2008	3Bf	Yleis-cem.; w/b=0,42;huokostamaton	10	100	23,0			2458	1,7	1,2		8	1,12
30	R	13.3.2008	3Bg	Yleis-cem.; w/b=0,42;I=4 %	10	120	21,0			2451	4,2	2,6		12	0,60
31	R	13.3.2008	3Bh	Yleis-cem.; w/b=0,42; i=6 %	10	150	20,1			2320	6,8	4,6		20	0,27
32	R	18.3.2008	3Bi	Yleis-cem.; w/b=0,42;I=4 %	10	150	20,3			2363	4,9	3,1		18	0,36
33	VTT	16.9.2009	3Db-REF	Yleis-cem.; w/b=0,51; i=5%	10	100					4,6				
34	VTT	17.9.2009	3Db -Cu	Yleis-cem.; w/b=0,51; i=5%	10	90					5,3				
35	VTT	2.10.2009	Cu-mortar	Yleis-cem.; w/b=0,54; i=6%	10	214				2141	6,0				
36	R	22.9.2009	5G	Rapid-cem.; w/b=0,42; i=4,5%	10	120	25,9			2417	4,5				
37	R	22.9.2009	5H	Rapid-cem.; w/b=0,39; i=6,8%	10	220	26,1			2341	6,8				
38	R	22.9.2009	5J	Rapid-cem.; w/b=0,43; i=2,6%	10	210	25,1			2417	2,6				

Air void analysis. Method of measurement.

TESTING INSTRUCTION: **VTT TEST R003-00**

Date: 29.2.2000
One replaces: -

Instruction:

DEFINITION OF THE AIR VOID PARAMETERS OF CONCRETE FROM THIN SECTIONS

CONCRETE, HARDENED
AIR VOID PARAMETERS - AIR CONTENT, SPECIFIC SURFACE AREA AND POWERS SPACING FACTOR
OPTICAL THIN SECTION ANALYSIS

Keywords: Concrete, test method, air content, specific surface area, Powers spacing factor

Contents:

1 SCOPE

This test method describes how to determine the air void parameters of hardened concrete using optical thin section analysis. The air void parameters to be determined are:

- Total air content of the concrete,
- air content of the protective air voids (pores) of the concrete,
- specific surface area of the protective air voids (pores),
- Powers spacing factor of the protective air voids (pores).

In the analysis a converted point count method is used. The analysis is made from the thin sections viewed with a microscope and using a sample shifting table and calculator.

With the method the quality of the air voids of hardened concrete can be estimated.

2 REFERENCES

NT BUILD 381. 1991. Concrete, hardened: air void structure and air content.

ASTM C 457-90. 1990. Standard recommended practice for microscopical determination of air-void content and parameters of the air-void system in hardened concrete.

ASTM C 856. 95 1995. Standard recommended practice for petrographic examination of hardened concrete.

3 DEFINITIONS

Thin section A piece of concrete, impregnated with fluorescent resin, placed in between two glass disks (*slide and cover glass*). The size of the piece is usually about 30 x 50 x 0,025 mm.

Air void (pore) is defined in this analysis as a void contained by the cement paste which intersection length in the level of the upper surface of the thin section is at least 0,020 mm.

Protective air void (pore) is defined in this analysis as a void which intersection length in the level of the upper surface of the thin section is 0,020 - 0,800 mm.

Compaction pore is defined in this analysis as a void which intersection length in the level of the upper surface of the thin section is bigger than 0,800 mm.

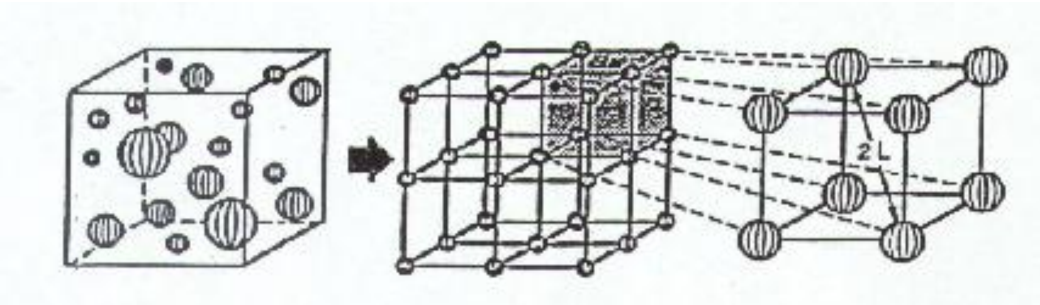
Intersection length of the air void (pore) means in this analysis the length of that segment of a line which will stay inside the air void when the analysis line pierces the void in the level of the upper surface of the thin section.

Air content is the relative share of the air voids contained by the concrete as a % -share of the volume of the concrete (total air content = the total number of optically perceived protective pores and compaction pores).

Specific surface area (α) the relation of the surface area of protective pores to their volume; as unit mm^2/mm^3.

Powers spacing factor (L) is a quantity calculated by the so called Powers equation /NT BUILD 381, ASTM C 458/ and indicates a calculated value as the biggest distance from any given dot of the cement paste to the surface of the nearest protective pore; as unit mm (see the principle in Figure 1).

Paste volume (P) the relative share of the cement paste in concrete - it does not contain the share of air voids; as unit percent by volume.



REALITY
Air voids in cement paste

SIMPLIFIED MODEL

CALCULATION OF THE POWERS SPACING FACTROR (L)

Figure 1. Calculation principle of the Powers spacing factor in normal case in which the relation of the paste volume to the air content (P/A) is at least 4,33.

4 SAMPLES

In the sampling, attention is paid to the representativeness of the sample. One analysis result can represent only one concrete composition and manufacturing method. In the sampling, the following principles are normally followed:

- At least two separate samples are taken, from different parts of the component or specimen to be examined from, both of which at least one thin section is made.
- If the maximum aggregate of the concrete is more than 16 mm, samples will be taken so that in the prepared thin section the paste volume is at least 23% on average.
- The thin sections are made as a piece against the surface of the concrete in a vertical direction in the range of 5 - 35 mm from the surface. This surface has to be the surface to which the freezing exposure is most severe, in other words, usually the outer surface of the structure.
- Usually for large structures where the composition of the concrete can vary especially regarding its air-entrainment and/or the casting conditions and hardening conditions, the sample size and thin section amount are chosen according to a justifiable plan.
- If there are deviations from the previous principles, the deviations and the grounds will be mentioned in the test report (see Chapter 11, h). As an example, a procedure when thin (thickness for example 25 mm) two-layered castings are studied. Then it can be considered suitable to make sections which contain the thickness of the whole surface layer. For the base concrete, the section could then be started immediately under the surface casting. So in this case the surface concrete and the base concrete have to be examined as separate cases.

5 MAKING OF A THIN SECTION

For the analysis, petrographical thin sections are made from the concrete samples. Before the preparation the samples are impregnated in the vacuum with resin containing fluorescent pigment. The impregnated sample is glued to a slide and thinned using diamond cutting and diamond grinding so that the final area of the sample will usually be 30 x 50 mm^2 and the thickness 0,025 mm. The sample area contained by one section can also be smaller than presented here but in that case more than 2 sections (see Chapter 8) will be needed. Finally a cover glass shall be glued over the section. It is essential that in the thin section the concrete is totally impregnated with resin and the thickness of the section is about 0,025 mm in the area of the whole section.

The preparation method of thin sections has been presented in more detail in the standards NT BUILD 381 and ASTM C 856.

6 ANALYSIS METHOD

The thin sections are analysed operating an optical polarisation microscope, sample shifting device and a connected point counter.

The analysis is made adapting the modified point count method which has been presented in the standards NT BUILD 381 and ASTM C 458. In this method the stoppage point is registered for the analysis dot which can be body material, cement paste or pore and the number of the pores cut by the analysis line. Furthermore, the pores are separated into two size classes in the analysis, in other words to the protective pores and compaction pores.

Based on the values determined in the analysis it is possible to calculate the total air content of the concrete, the number of protective pores (from its interception length 0,020

- 0 800 mm pores) and, based on the latter pores, the specific surface area and the Powers spacing factor.

7 MEASUREMENTS

In the analysis, the following analysis parameters are used:

- The magnification of the objective of the microscope has to be 100-fold.
- The analysis level is the level of the upper surface of the section.
- The area to be analysed has to be at least 3000 mm^2 altogether, in other words, the number of the sections has to be at least 2 pieces per concrete composition (see also Chapter 4).
- The number of the analysis dots has to be at least 1500 points altogether.
- The length of the analysis line has to be at least 2300 mm altogether.
- On the analysis line, the distance of analysis dots has to be 1 - 1,5 mm.
- The analysis lines have to be evenly divided to the analysed area.
- The location in depth of pores is checked, if necessary, by focusing for both the stoppage point of analysis dots and the perforations of pores (this means location is checked where an analysis dot or perforation is in the level of the upper surface of the thin section).
- The pores included in the analysis have an intersection length of 0,020 mm as a lower limit.
- The pores are classified in the analysis according to the length of the perforation segments located on the analysis line into pores of 0,020 - 0,800 mm and > 0,800 mm. This separation is made for both the stoppage points of analysis dots and for perforations.

In the analysis, the values are chosen or determined for the following parameters:

I	is the distance of analysis dots (mm),
$\mathbf{S_t}$	is the total number of the analysis dots (=$\mathbf{N_{at}}$ + **Np** + **Nr**, where **Nr is** the number of the analysis dots in the aggregate particles),
$\mathbf{N_T}$	is the number of alignments used in the calculation
$\mathbf{N_{at}}$	is the total number of analysis dots in all the analysed pores (= $\mathbf{N_a}$ + $\mathbf{N_{a>0,8}}$, where $\mathbf{N_{a>0,8}}$ is the number of the analysis dots in the compaction pores which are in accordance with the definition, in other words in the pores – in which perforation length > 0,800 mm),
$\mathbf{N_a}$	is the number of analysis dots in the protective pores which are in accordance with the definition (in other words in the pores with a intersection length of 0,020 - 0,800 mm),
$\mathbf{N_{ai}}$	is the number of perforations in pores with intersection length of 0,020 – 0,800 mm,
$\mathbf{N_p}$	is the number of analysis dots in the cement paste (does not contain analysis dots in the pores > 0,020 mm).

8 CALCULATIONS AND ANALYSIS

For the air void amount, the total number of pores is counted in concrete ($\mathbf{A_{at}}$, %) and furthermore the number of protective pores in concrete (**A**, %). Specific surface area (**α**, mm^2/mm^3) and Powers spacing factor (**L**, mm) are calculated based on the protective pores.

The number of the protective pores is calculated as follows:

$$A = 100(N_a/S_t) \qquad (\%)$$

The specific surface area of protective pores is calculated as follows:

$\alpha = (400N_{ai})/((S_t - N_T)IA)$ (mm²/mm³)

The amount of the cement paste is calculated as follows:

$P = 100(N_p/S_t)$ (%)

The Powers spacing factor of the protective pores is calculated as follows:

if $P/A \geq 4{,}33$, the following equation is used:

$L = (3/\alpha)(1{,}4(P/A+1)^{1/3}-1)$ (mm)

And if $P/A < 4{,}33$, the following equation is used:

$(L = P/A\alpha)$ (mm)

Air content of the compaction pores (**A_t**) is calculated as follows:

$A_t = 100(N_{at} - N_a)/S_t$ (%)

Correspondingly total air content (**A_{at}**) is calculated as follows:

$A_{at} = 100N_{at}/S_t$ (%)

9 REPORTING OF RESULTS

The following values are reported of as the result of the analysis:

- Total air content of the concrete (**A_{at}**), % of the volume of the concrete - rounded off to the nearest 0,1 %,
- number of protective pores of the concrete (**A**), % of the volume of the concrete - rounded off to the nearest 0,1 %,
- specific surface area of protective pores (**α**), mm^2/mm^3 - rounded off to the nearest 1 mm^2/mm^3,
- Powers spacing factor of protective pores (**L**), mm - rounded off to the nearest 0,01 mm.

If necessary the amount of the cement paste can also be given (**P**), % of the volume of the concrete - rounded off to the nearest 1 %.

If desired, the number of the compaction pores can also be given separately (**$A_{a>0,8}$**), % of the volume of the concrete - rounded off to the nearest 0,1 %.

10 RELIABILITY AND EXACTNESS OF THE RESULTS

The reliability of the value of the Powers spacing factor obtained in the thin section analysis is in relation to the total area that has been analysed and to the analysis amount which the total number of analysis dots and the total length of the analysis line represent. Also the analyst influences the reliability of the result. Only the person with whom a sufficient experience has been stated about the method with parallel analyses can do a reliable analysis.

The width of the analysis results for the structure or component to be examined can be effected by sampling, which has been briefly dealt with in Chapter 4. In each individual case a position regarding what the result represents has to be taken in principle. For example the definition that has been made from the specimen cannot represent a ready structure but only a specimen that has been made from a similar concrete composition.

However, the result is normally indicative at least also for the structure that has been made from a similar concrete composition.

When one experienced analyst makes the analysis using these instructions, the variation of the Powers spacing factor obtained in the analysis is usually under 0,03 mm. This result was obtained when 4 m^2 elements made on the element bed were examined and also examining test cubes made in the laboratory. So this variation also contained the variability of the amount of air-entrainment and quality in the area of the concrete element. If the air-entrainment has an even amount and quality, the variation of the aforementioned Powers spacing factor will be of about 0,01 mm.

When there are big compaction pores in concrete, the total air content obtained in this analysis cannot be considered especially reliable (the standard deviation can be about 2 %). For the actual protective pores the result is relatively reliable also for their total number (standard deviation according to the research results usually under 0,6%). When there are no compaction pores in concrete, the result for the total air content is naturally as reliable as for the number of the protection pores. As an additional remark, the determination of the air content is not an essential point in this method. The quality of air-entrainment is particularly studied with this method described by the specific surface area and Powers spacing factor.

11 TEST REPORT

In the test report at least the following information is reported:

a) Name and address of the test site
b) Date of the commentary and marks
c) The orderer's name and address
d) Identification information of the sample informed by the orderer
e) Information about the sampling (date, the taker of the sample, the sampling locations)
f) Arrival date of the sample
g) Test method (a reference to this test method)
h) Possible deviations from the test method
i) Test results
j) Review of test results, if it has been ordered
k) Date and signatures

Original, in Finnish

Author: Hannele Kuosa	Acceptor: Markku Leivo
Date: 29.2.00	Date: 29.2.00
English translation: Kalle Loimula	Acceptor: Erika Holt
Date: 26.1.11	

Hardened concrete air content. Method of measurement.
Determination of the air content of hardened concrete at early stages of hardening
VTT TESTING INSTRUCTION VTT-S-03974-09e

Keywords: *concrete, test method, air content, hardened, early stages of the hardening*

1. Principle and scope

This test method describes how to determine the total air content of hardened concrete with the water impregnation - pressure treatment method at the early stages of hardening, in other words, usually since the day which follows the casting.

The method is based on the fact that at the early stages of hardening (about 1 d from the casting), the water content of concrete will be high and the compactness is usually still relatively small. The capillary pores and gel pores of the concrete will be nearly totally filled with water or will totally become full of water fast during water absorption. Furthermore, the method is based on the fact that the majority of the air pores do not have time to become full during the short water absorption (about 3 h).

The test scope will usually begin the day following casting. The beginning age can also be later than this, if the concrete has failed to reach the firmness in the early age (for example during 2 days after casting) required for the dismantling of moulds and/or for the loosening of specimens.

Special attention has to be paid to the representativeness of the specimens which are used in the method.

The result which is obtained with this method can be compared with the value of the measured air amount from the concrete mix during a certain time, for instance by test [SFS-EN 12350-8]. Then attention has to be paid to the time of the air content measurement of the mass in relation to the casting time of the specimens, test structure or structure. Attention has to be paid also to the correspondence of compaction techniques.

If information is needed about the air content of a structure being cast, the specimens to be made have to correspond well enough to the structure being cast. Especially the compaction techniques have to correspond to each other. In the method it is also possible to use detachable specimens such as cored cylinders from the test structure or the structure being cast.

The method does not apply to concrete with a water-cement ratio under 0,35 or for concrete which has already been hardened for several days after casting.

2. References

SFS-HANDBOOK 156. Testing concrete 2005.

SFS-EN 12350-7. Testing fresh concrete. Part 7: Air content. Pressure methods. 2000-10-25. 2. edition.

VTT TEST R003-00. Testing specification. Concrete air void structure by thin section analysis. 29.2.2000.

3. Definitions

'The air content of the hardened concrete' refers to the total air content of the concrete as a relative share of the volume of the concrete [vol.-%] which is obtained with the described method. In practice this air content corresponds to the air amount contained by the so-called protective pores and compaction pores of the concrete. This air content does not include the volume of the capillary pores and gel pores.

The air content which is obtained with the method does not precisely correspond to the air content which has been determined for example from hardened concrete thin sections or polished sections with a certain optical method. Especially, correspondence to the total air content given by the thin section analysis described in testing instruction VTT TEST R003-00 is inadequate. This is mainly due to the fact that in the thin section analysis only an indicative value is obtained for the total air content because the sample size (the area of the thin section) is too small to define the total air content.

4. Specimens

In the casting and compaction of the specimens or test structures, one has to take into consideration how they can represent the result of the air content measurement of the mass as well as the real structure being made.

A test beam size of for example 100 x 100 x 500 mm is cast for the assessment. Alternatively, three pieces of 100 mm cubes can be cast. Also, any other concrete object or test structure will apply when it is possible to separate three measurement samples from it by sawing, or by drilling and sawing (wet sawing/drilling). The thickness of the measurement samples should be about 25 mm and area about 100 cm^2.

Three (3) smaller measurement samples (25 ± 2 mm in thickness, area of 100 cm^2) shall be cut from the hardened concrete, for example, from the aforementioned cast test beam. Cutting shall be performed about 1 d after the casting or at the latest when the concrete has reached sufficient strength to perform the cutting.

The measurement samples shall not be cut from the edge of the cast specimen but, for example, starting at least 50 mm away from the edge of the test beam (100 x 100 x 500 mm). However, the surfaces marked off by the short sides (25 mm) of the measurement samples can also be the outer surfaces of the cast specimen.

The selected sections of the specimens are generally chosen so that they represent the hardened concrete, specimen or cast structure as well as possible.

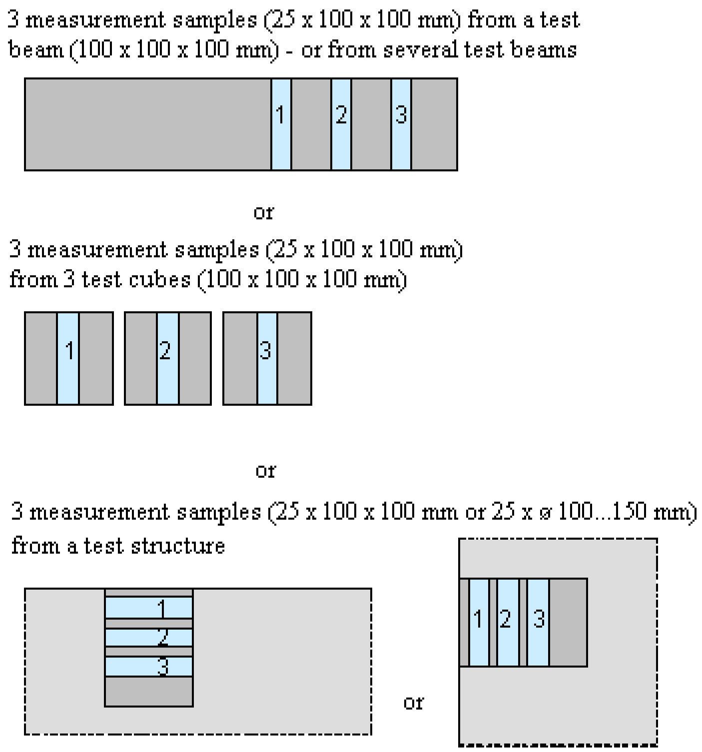


Figure 1. Illustration of the cutting of the three (3) measurement samples. The measurement samples can be cut, for example, from a cast test beam, several test beams, test cubes or test structure. The measurement samples can be cut by wet sawing or by drilling and by wet sawing.

5. Measurements

The measurement samples that were cut to determine the air content of the hardened concrete shall be treated and weighed according to Table 1.

Only sections 2-5 in Table 1 are necessary to determine the air content of the hardened concrete. However, sections 1 and 6 provide additional information about the water content and density of the concrete.

All the weighings are made and the results are recorded with the accuracy at least ±0,01 g. Free water shall always be rubbed away before the air weighing of the wet specimens.

Table 1. Handling of the specimens and weighings to be done. Three (3) specimens/concrete.

1	2	3	4	5	*6*
Q1	Q2	Q3	Q4	Q5	*Q6*
Initial weight in air	Weight in air after 3 ± 0 5 h water absorption	Weight in air after 24 ± 2 h pressure treatment	Weight in water after the pressure release	Weight in air after the pressure release	Weight in air after drying in 105 °C

1) Initial weight means the weight that has been measured after the cutting of the specimens or weight determined after the dismantling of moulds and after the sawing of specimens. This weight is not needed for the definition of the air content and it will not be necessary to measure if one does not want, for example, information about the amount of water or density of the concrete.

2) Water absorption means totally sinking the specimens in water so that they can absorb water freely.

3) The pressure treatment shall begin the same working day when the preceding water absorption has ended. The specimens are pressure treated with water pressure of 15 ± 1,5 MPa. The weighting of the specimens shall be performed as soon as possible after the pressure treatment has ended. Additional water is wiped off from the surfaces of the specimens as fast as possible before the weighings.

4) The pressure release means the discharging of the pressurized water contained by the specimens while they are in water. The time for the pressure release is one day at maximum. A distinctly shorter time will also apply if water does not discharge from the specimens anymore with amounts affecting the exactness of measurings (< 0 01 g during the time required by the air-water weighings). The weight in water means the weight measured by weighing the specimen while submerged in water.

5) The weight of the specimens in air is measured after the water weighings without allowing the specimens to dry in between. Additional water is rubbed off before the weighings.

6) The weight after the drying is not needed for the calculation of the air content. It can be used if one wants, for example, to calculate the dry density of the concrete or the total water content contained by it during the times which correspond to the preceding weighings. The drying is performed in a ventilated heating chamber at the temperature of 105 ± 5ºC. The drying period is so long that it is considered done when the change in the mass of each specimen in the weighings to be done at intervals of one day is under 0,5 % (for example, to specimen 100 x 100 x 25 mm^3 under about 0,3 g.) The specimen is allowed to cool down to normal room temperature before the last and final weighing.

6. Calculations and results

The air content of the hardened concrete (A_{hard}) corresponds to the volume of the amount of water penetrated in the pressure treatment. It is calculated separately for each specimen based on the measurings presented in Chapter 5 with the following equation:

$$A_{hard} = 100\,(Q_{3a} - Q_{2a})/(Q_{5a} - Q_{4w})$$

where
- A_{hard} is the air content of the hardened concrete [%],
- Q_{2a} is the weight in air after water absorption [g],
- Q_{3a} is the weight in air after pressure treatment [g],
- Q_{4w} is the weight in water after pressure release [g],
- Q_{5a} is the weight in air after pressure release [g].

The final result is calculated from the obtained results as an average of the three specimens.

8. Reporting of results

The following information is reported as a result:

a) Name and address of the test site and date of the commentary and labels.

b) The name and address of the orderer.

c) Arrival date of the sample.

d) Identifier information of the concrete informed by the orderer and casting date and time of samples.

e) Air amount of the concrete mix informed by the orderer that has been required or measured if desired and its measuring place and time - for example time after completing the mass. Possibly information about the transport and handling of the mass before casting and information about the compaction method and other essential information which can be significant from the point of view of the total air content of the hardened concrete.

f) As far as possible, information about the test objects and test structures (description, size, compression method) from where the measurement samples were cut out. As unambiguous information as possible about the sampling sections and directions. Form and size of the cut specimens rounded off to the nearest mm.

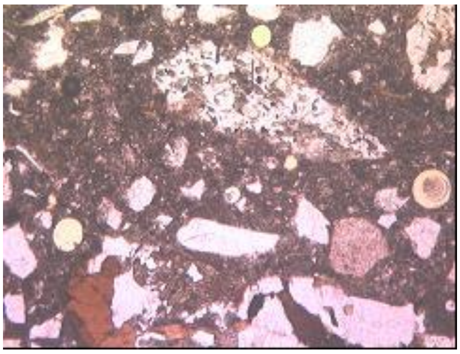
g) Starting time of the air content determination of the hardened concrete. The date and time rounded off to the nearest hour shall be given.
h) Test method (a reference to this process description).
i) Possible deviations from this test method and, from the point of view of interpretation of results possibly noteworthy matters.
j) Test result, in other words air content of the hardened concrete [vol. %] rounded off to the nearest 0,1%.
k) Information about the individual definition results if their difference is greater than 0,5 %-units.
l) If desired, calculatory values based on the initial weight and the weight subsequent to the drying at 105 ^{o}C can be calculated and informed. These values can be initial density, dry density (105 ^{o}C) and the total water content of the concrete at the beginning and the total water content of the concrete at the separate stages of determinations such as after the water absorption.
m) Date and signatures.

Original, in Finnish
Date: 28.5.2009
One replaces: -

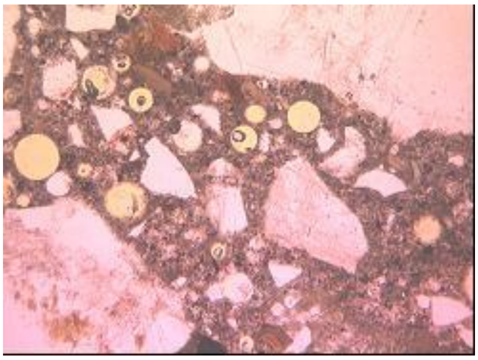
Author: Hannele Kuosa	Acceptor: Markku Leivo
Date: 28.5.09	Date: 28.5.09

English translation: Kalle Loimula	Acceptor: Erika Holt
Date: 26.1.11	Date:

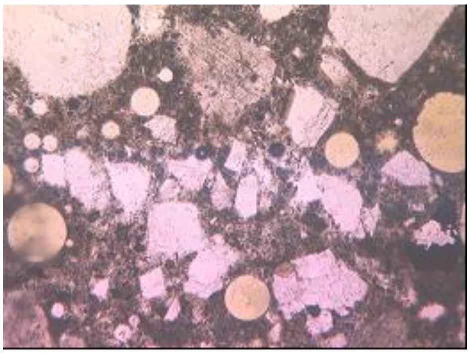
Thin section micrographs. Picture height 1,3 mm.



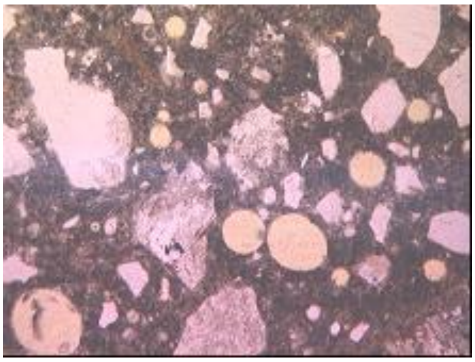
6.1A, CEM II/B-S 42,5 N, air 6,5 %



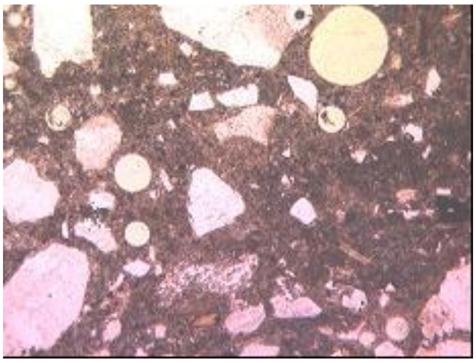
7. 2A, CEM I 42,5 N – SR, air 5,9 %



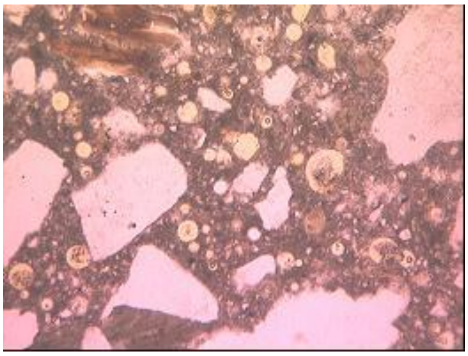
8. 3A, CEM II/A-M(S-LL) 42,5 N, air 5,9 %



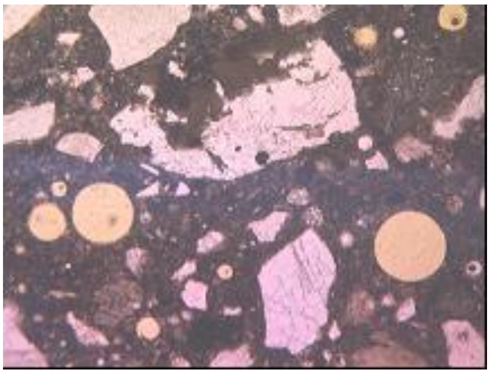
9. 5A, CEM II/A-LL 42,5 R, air 5,0 %



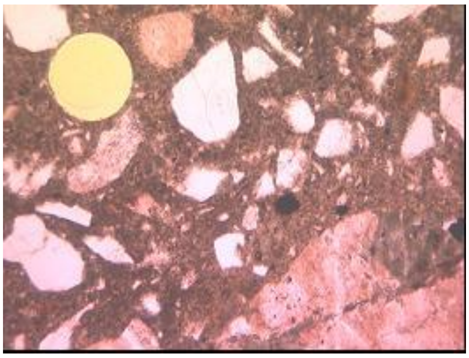
10. 6A, CEM I 52,5 R, air 5,5 %



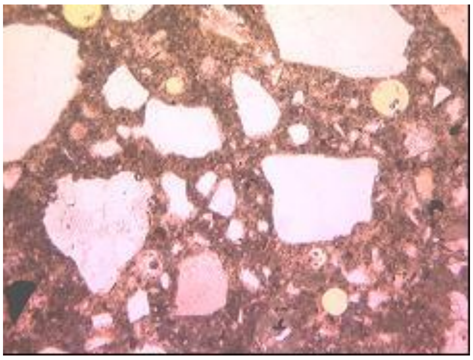
11. 7A, CEM II/A-LL 42,5 R & SLG, air 6,1 %



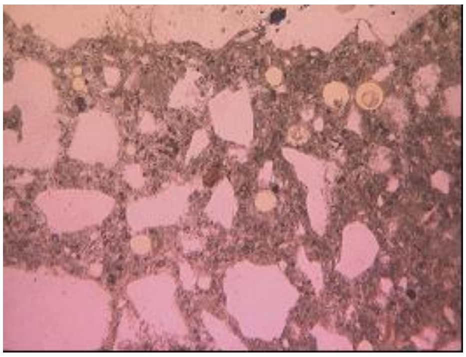
12. 8A, CEM II/A-LL 42,5 R & FA, air 5,0 %



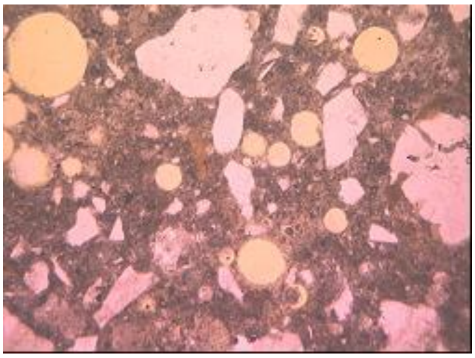
13. 3Ba, CEM II/A-M(S-LL) 42,5 N, air 2,6 %



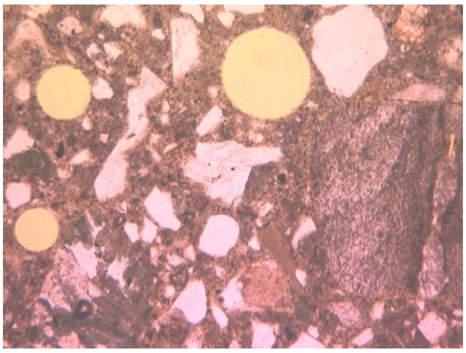
14. 3Bb, CEM II/A-M(S-LL) 42,5 N, air 4,5 %



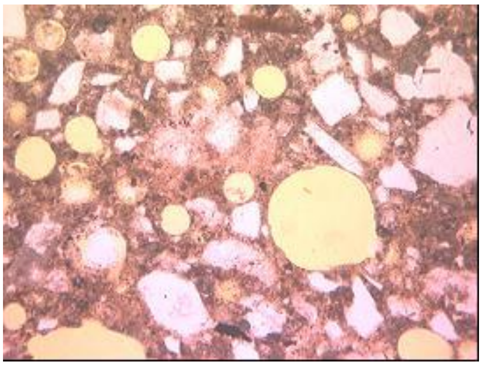
15. 3Bc, CEM II/A-M(S-LL) 42,5 N, air 5,3 %



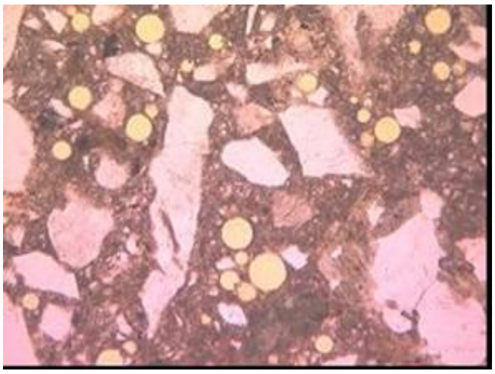
16. 3Bc2, CEM II/A-M(S-LL) 42,5 N, air 7,0 %



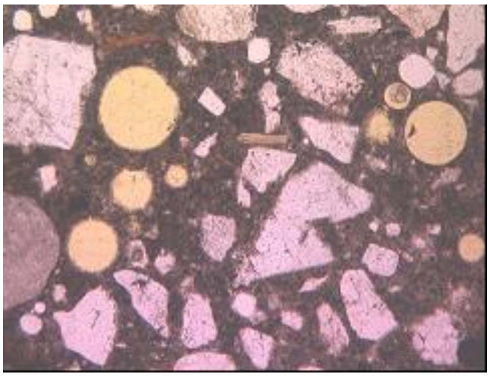
17. 3Bd-SCC1, CEM II/A-M(S-LL) 42,5 N, air 3,4 %



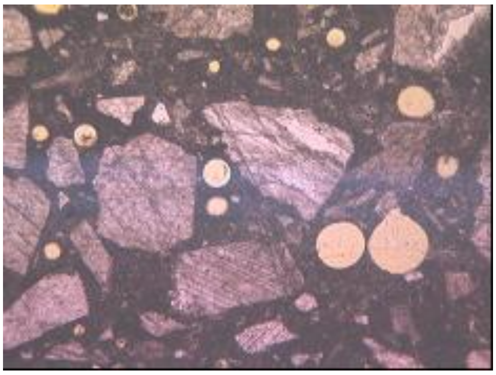
18. 3Be-SCC2, CEM II/A-M(S-LL) 42,5 N, air 5,7 %



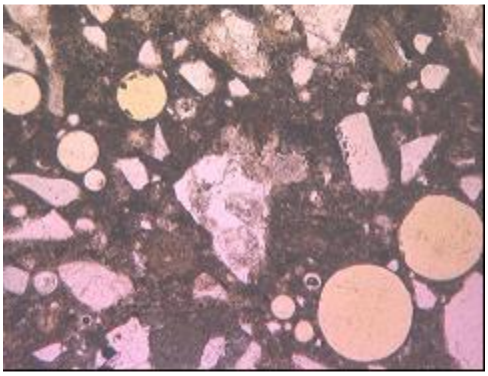
19. 1C, CEM II/B-S 42,5 N, air 6,9 %



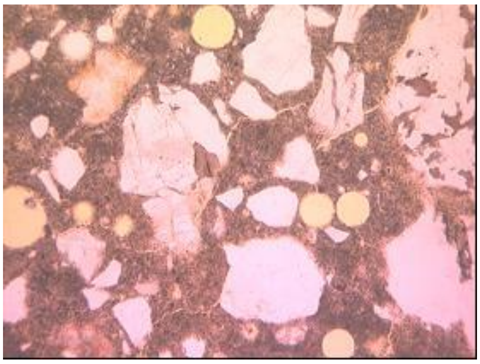
20. 3C, CEM II/A-M(S-LL) 42,5 N, air 5,5 %



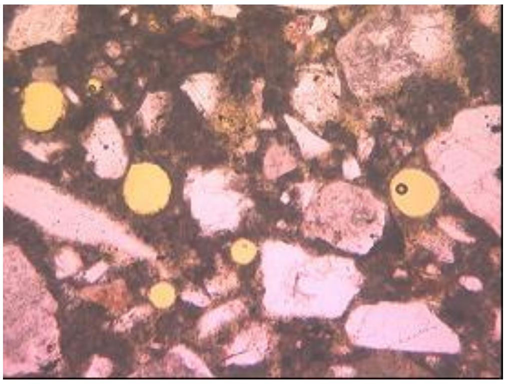
21. 4C, CEM I 52,5 N, air 5,5 %



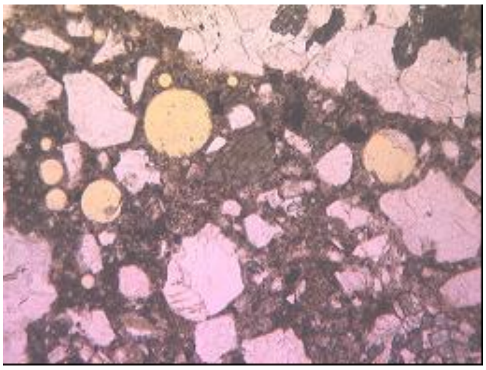
22. 5C, CEM II/A-LL 42,5 R, air 5,0 %



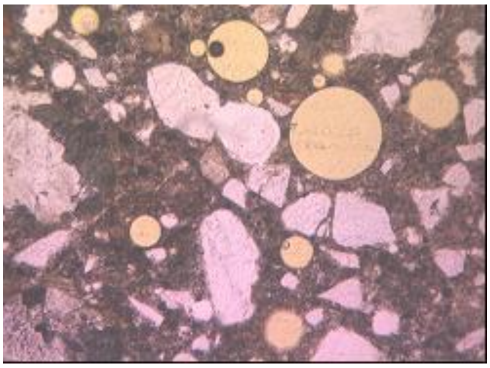
23. 6C, CEM I 52,5 R, air 5,4 %
(microcracks)



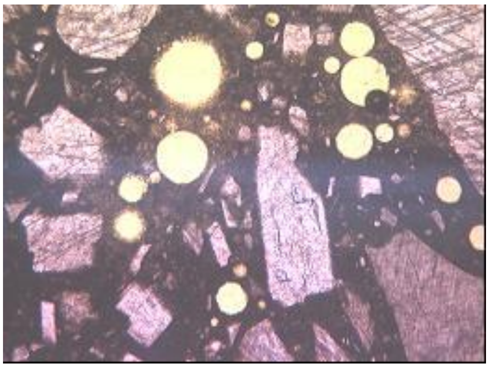
¨24. 3D, CEM II/A-M(S-LL) 42,5 N, air 3,4 %



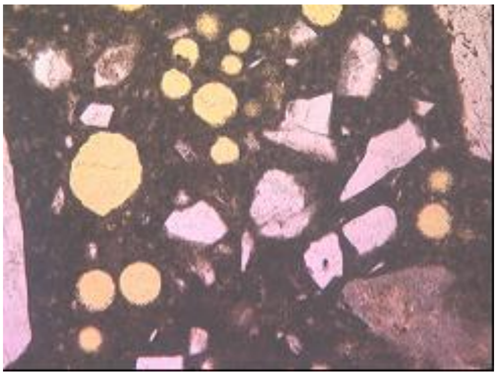
25. 1E, CEM II/B-S 42,5 N, air 7,3 %



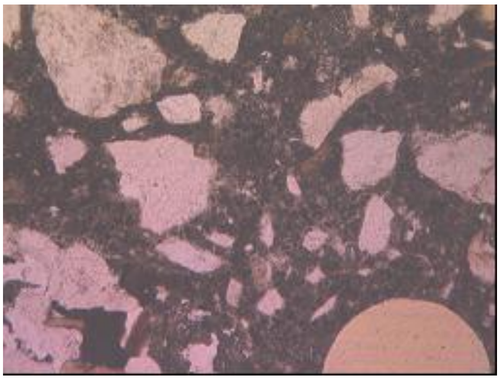
26. 3E, CEM II/A-M(S-LL) 42,5 N, air 4,3 %



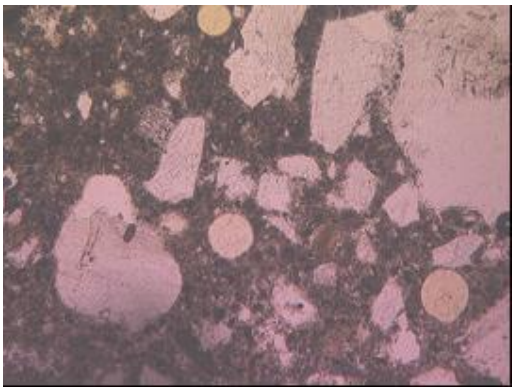
27. 4E, CEM I 52,5 N, air 5,5 %



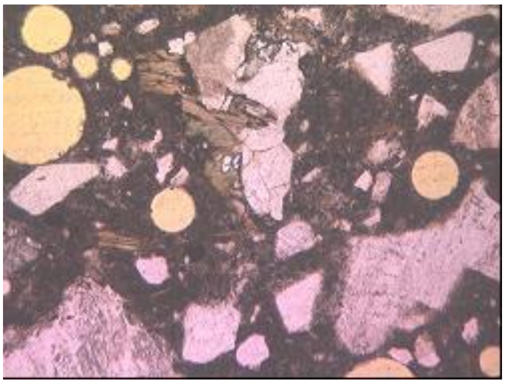
28. 5E, CEM II/A-LL 42,5 R, air 4,8 %



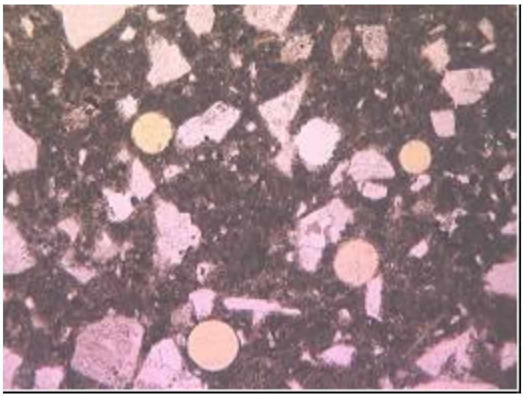
29. 3Bf, CEM II/A-M(S-LL) 42,5 N, air 1,7 %



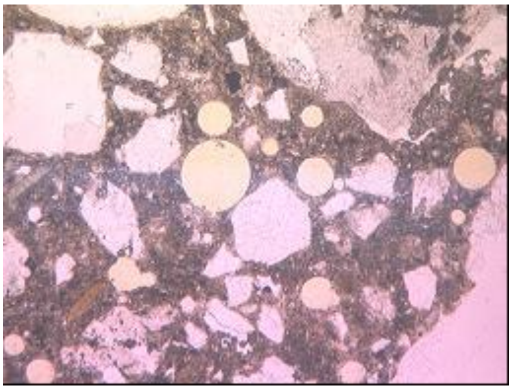
30. 3Bg, CEM II/A-M(S-LL) 42,5 N, air 4,2 %



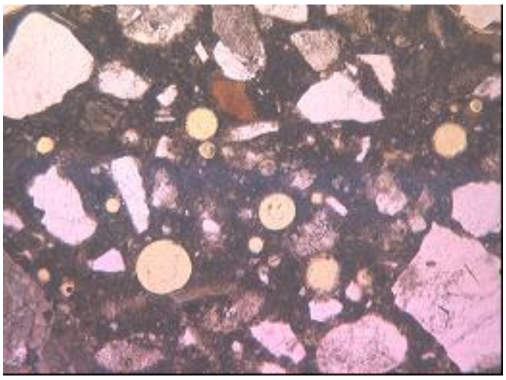
31. 3Bh, CEM II/A-M(S-LL) 42,5 N, air 6,8 %



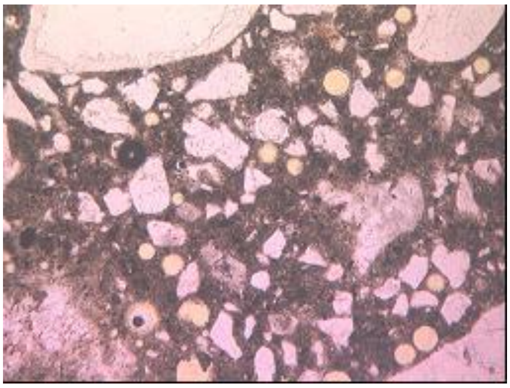
32. 3Bi, CEM II/A-M(S-LL) 42,5 N, air 4,9 %



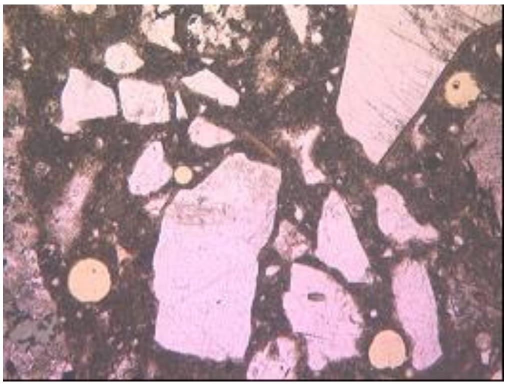
33. 3Db-REF, CEM II/A-M(S-LL) 42,5 N, air 4,6 %



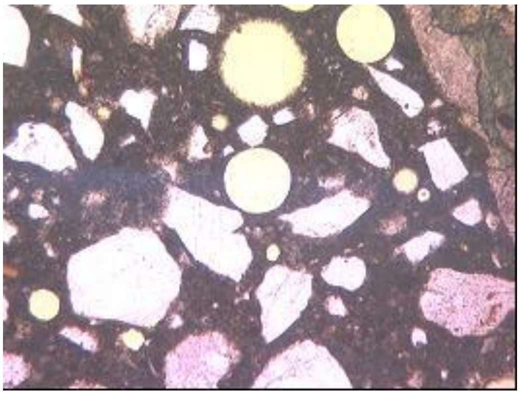
34. 3Db –Cu, CEM II/A-M(S-LL) 42,5 N, air 5,3 %



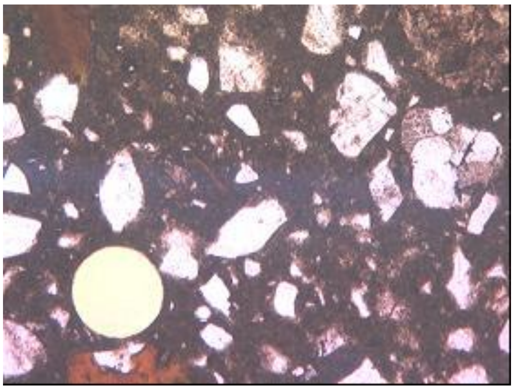
35. Cu-mortar, CEM II/A-M(S-LL) 42,5 N, air 6,0 %



36. 5G, CEM II/A-LL 42,5 R, air 4,5 %



37. 5H, CEM II/A-LL 42,5 R, air 6,8 %



38. 5J, CEM II/A-LL 42,5 R, air 2,6 %

DuraInt concretes. Hardened concrete basic properties.

Number	Casting place	Casting date	Short code	Compressive strength			Pore volumes and density (testing at about 2 d age) [VTT TESTING INSTRUCTION: VTT-S-03974-09]					Thin section results [VTT TEST R003-00]				
				28 d [MPa]	28 d stdev [MPa]	91 d [MPa]	Hardened concrete air pores [%]	Total porosity [%]	Capillary+ gel porosity [%]	Density (wet) [kg/m3]	Density (dry: 105°C) [kg/m3]	Air pores total; about [%]	Air pores <0,800 mm [%]	Air pores <0,300 mm [%]	Specific surface [mm^2/mm^3]	Spacing factor (< 0,800 mm pores) [mm]
1	VTT	25.5.2007	SR1			58,1										
2	VTT	25.5.2007	SR2			51,6										
3	VTT	28.5.2007	SR3			39,4										
4	VTT	28.5.2007	SR4			60,4										
5	VTT	28.5.2007	SR5			61,6										
6	VTT	12.9.2007	1A	56,3	1,6		4,3	17,5	12,9	2558	2422	2,0	1,4	0,8	20,7	0,46
7	R	16.8.2007	2A	46,4	0,3		5,5	18,6	13,1	2531	2392	5,9	4,6	3,5	16,2	0,35
8	R	14.8.2007	3A	38,0	0,8		6,2	20,4	14,2	2513	2361	4,6	3,9	2,8	20,9	0,28
9	R	14.8.2007	5A	41,2	0,3		5,1	18,8	13,7	2533	2387	3,1	2,7	2,2	28,4	0,24
10	VTT	20.8.2007	6A	58,5	4,8		3,8	18,1	14,3	2579	2427	1,9	0,8	0,6	34,2	0,33
11	VTT	11.9.2007	7A	46,0	0,5		7,0	20,0	13,0	2513	2374	4,8	3,2	2,6	36,5	0,18
12	R	6.9.2007	8A	54,6	0,4		4,3	17,9	13,6	2545	2400	3,7	2,1	1,6	26,5	0,30
13	VTT	30.8.2007	3Ba	50,6	1,6		2,7	17,1	14,4	2604	2451	2,6	0,3	0,1	13,7	1,15
14	VTT	3.9.2007	3Bb	46,1	3,7		4,7	19,7	15,0	2551	2391	1,2	0,9	0,7	22,7	0,51
15	VTT	3.9.2007	3Bc	48,9	0,5		4,9	19,1	14,1	2559	2409	1,9	1,8	1,2	21,9	0,38
16	VTT	10.9.2007	3Bc2	39,0	1,3		7,3	20,5	13,3	2513	2372	4,4	3,6	2,7	19,4	0,30
17	VTT	4.9.2007	3Bd-SCC1	51,0	3,2		3,8	18,0	14,2	2580	2429	3,7	2,7	1,3	10,9	0,69
18	VTT	4.9.2007	3Be-SCC2	35,0	0,3		8,6	23,2	14,6	2460	2302	9,8	8,4	5,9	12,1	0,34
19	VTT	13.9.2007	1C	45,5	3,0		5,6	18,8	13,2	2538	2397	3,9	3,4	3,3	26,6	0,22
20	R	23.8.2007	3C	40,1	1,9		4,8	19,5	14,7	2523	2367	4,6	3,2	2,0	20,8	0,28
21	P	20.9.2007	4C	46,3	0,9		4,3	16,9	12,6	2522	2389	7,7	4,0	3,1	20,7	0,29
22	R	28.8.2007	5C	44,9	1,6		4,5	19,2	14,6	2541	2385	3,7	2,6	1,8	12,8	0,51
23	P	18.9.2007	6C	50,3	1,4		4,4	18,3	13,9	2502	2354	3,9	3,5	2,9	23,3	0,29
24	R	24.8.2007	3D	44,5	0,2		3,5	18,1	14,6	2581	2427	3,4	2,2	1,8	35,8	0,21
25	VTT	12.9.2007	1E	32,8	0,2		4,9	19,8	15,0	2536	2376	5,3	3,1	2,4	22,6	0,26
26	R	6.9.2007	3E	35,5	0,7		4,2	18,9	14,8	2554	2397	2,2	2,0	1,6	25,1	0,28
27	P	20.9.2007	4E	39,5	1,5		4,6	18,0	13,4	2511	2369	4,3	3,6	3,1	25,1	0,25
28	P	18.9.2007	5E	41,2	0,8		3,8	18,4	14,7	2510	2354	3,8	2,5	1,4	16,1	0,41
29	R	13.3.2008	3Bf	64,0	0,8		2,3	15,7	13,4	2616	2475	1,9	0,7	0,2	12,0	0,98
30	R	13.3.2008	3Bg	57,2	0,2		3,4	17,4	14,0	2594	2446	2,4	1,2	0,6	23,2	0,41
31	R	13.3.2008	3Bh	46,3	3,0		5,9	19,5	13,7	2534	2388	3,1	2,2	1,7	23,5	0,31
32	R	18.3.2008	3Bi	52,8	1,2		4,0	19,2	15,3	3	2412	4,4	2,6	2,0	16,4	0,44
33	VTT	16.9.2009	3Db-REF	36,5	0,9							3,3	2,8	2	24,3	0,27
34	VTT	17.9.2009	3Db -Cu	40,2	0,6							3,7	3,1	2,5	27,4	0,21
35	VTT	2.10.2009	Cu-mortar	30,8	1,5							4	3,8	2,7	31,1	0,22
36	R	22.9.2009	5G	61,7	0,6							2,8	1,5	0,8	20,2	0,42
37	R	22.9.2009	5H	59,2	3,6							1,7	1,5	1,2	30,2	0,28
38	R	22.9.2009	5J	64,2	1,5							0,9	0,4	0,1	16,9	0,84

Timing for field specimen casting, curing and start of field testing.

				Chloride penetration				Carbonation			Frost-salt					Frost				
				Specimen 300x300x500 mm^3		1st salting		Specimen 100x100x500 mm^3			Specimen cubes 150x1050x150 mm^3			Specimen 150x150x75 mm^2		Specimen cubes 150x1050x150 mm^3			Specimen 150x150x75 mm2	
Number	Casting place	Casting date	Short code	Demoulding and to field/outdoors	Surface treatment	Date	Age about [months]	Demoulding and to water at 1 d age	To RH 65 % laboratoey climate at 7 d age	To field sheltered (Otaniemi) at 25 - 32 d age	Demoulding and to water at 1 d age	To RH 65 % laboratory climate at 7 d age	Sawing vertically in 2 halves (h 75 mm) at 21 d	Measurements (frequency, ultrasound and volume)	To the field	Demoulding and to water at 1 d age	To RH 65 % laboratoey climate at 7 d age	Sawing vertically in 2 halves (h 75 mm) at 21 d	Measurements (frequency, ultrasound and volume)	To the field
1	VTT	25.5.07	SR1																	
2	VTT	25.5.07	SR2																	
3	VTT	28.5.07	SR3																	
4	VTT	28.5.07	SR4																	
5	VTT	28.5.07	SR5																	
6	VTT	12.9.07	1A	10.10.07		11.11.07	2,0	13.9.07	19.9.07	8.10.07	13.9.07	19.9.07	3.10.07	17.10.07	24.10.07					
7	R	16.8.07	2A	6.9.07		11.11.07	2,9	17.8.07	23.8.07	13.9.07	17.8.07	23.8.07	6.9.07	3.10.07	10.10.07					
8	R	14.8.07	3A	6.9.09		11.11.07	3,0	15.8.07	21.8.07	11.9.07	15.8.07	21.8.07	4.9.07	3.10.07	10.10.07					
9	R	14.8.07	5A	6.9.09		11.11.07	3,0	15.8.07	21.8.07	11.9.07	15.8.07	21.8.07	4.9.07	3.10.07	10.10.07					
10	VTT	20.8.07	6A	13.9.07		11.11.07	2,8	21.8.07	27.8.07	17.9.07	21.8.07	27.8.07	10.9.07	3.10.07	10.10.07					
11	VTT	11.9.07	7A	10.10.07		11.11.07	2,0	12.9.07	18.9.07	8.10.07	12.9.07	18.9.07	2.10.07	17.10.07	24.10.07					
12	R	6.9.07	8A	27.9.07		11.11.07	2,2	7.9.07	13.9.07	1.10.07	7.9.07	13.9.07	27.9.07	17.10.07	24.10.07					
13	VTT	30.8.07	3Ba					31.8.07	6.9.07	1.10.07	31.8.07	6.9.07	20.9.07	17.10.07	24.10.07					
14	VTT	3.9.07	3Bb					4.9.07	10.9.07	1.10.07	4.9.07	10.9.07	24.9.07	17.10.07	24.10.07					
15	VTT	3.9.07	3Bc					4.9.07	10.9.07	1.10.07	4.9.07	10.9.07	24.9.07	17.10.07	24.10.07					
16	VTT	10.9.07	3Bc2					11.9.07	17.9.07	8.10.07	11.9.07	17.9.07	1.10.07	17.10.07	24.10.07					
17	VTT	4.9.07	3Bd-SCC1					5.9.07	11.9.07	1.10.07	5.9.07	11.9.07	25.9.07	17.10.07	24.10.07					
18	VTT	4.9.07	3Be-SCC2					5.9.07	11.9.07	1.10.07	5.9.07	11.9.07	25.9.07	17.10.07	24.10.07					
19	VTT	13.9.07	1C	10.10.07		11.11.07	2,0	14.9.07	20.9.07	8.10.07	14.9.07	20.9.07	4.10.07	17.10.07	24.10.07					
20	R	23.8.07	3C	13.9.07		11.11.07	2,7	24.8.07	30.8.07	20.9.07	24.8.07	30.8.07	13.9.07	3.10.07	10.10.07					
21	P	20.9.07	4C					21.9.07	27.9.07	17.10.07						21.9.07	27.9.07	11.10.07	17.10.07	24.10.10
22	R	28.8.07	5C	20.9.07		11.11.07	2,5	29.8.07	4.9.07	25.9.07	29.8.07	4.9.07	18.9.07	3.10.07	10.10.07	29.8.07	4.9.07	18.9.07	3.10.07	10.10.07
23	P	18.9.07	6C	10.10.07		11.11.07	1,8	19.9.07	25.9.07	17.10.07						19.9.07	25.9.07	9.10.07	17.10.07	24.10.07
24	R	24.8.07	3D	13.9.07	24.9.07	11.11.07	2,6	25.8.07	31.8.07	21.9.07										
25	VTT	12.9.07	1E					13.9.07	19.9.07	8.10.07						13.9.07	19.9.07	3.10.07	17.10.07	24.10.07
26	R	6.9.07	3E					7.9.07	13.9.07	1.10.07						7.9.07	13.9.07	27.9.07	17.10.07	24.10.07
27	P	20.9.07	4E					21.9.07	27.9.07	17.10.07						21.9.07	27.9.07	11.10.07	17.10.07	24.10.07
28	P	18.9.07	5E					19.9.07	25.9.07	17.10.07						19.9.07	25.9.07	9.10.07	17.10.07	24.10.07
29	R	13.3.08	3Bf								14.3.08	20.3.08	20.3.08	10.6.08	13.6.07					
30	R	13.3.08	3Bg								14.3.08	20.3.08	20.3.08	10.6.08	13.6.07					
31	R	13.3.08	3Bh								14.3.08	20.3.08	20.3.08	10.6.08	13.6.07					
32	R	18.3.08	3Bi								19.3.08	25.3.08	25.3.08	10.6.08	13.6.07					
33	VTT	16.9.09	3Db-REF	28.10.09			1,9													
34	VTT	17.9.09	3Db -Cu	28.10.09	1.10.09		1,8													
35	VTT	2.10.09	Cu-mortar	28.10.09			1,0													
36	R	22.9.09	5G	28.10.09			1,7													
37	R	22.9.09	5H	28.10.09			1,7													
38	R	22.9.09	5J	28.10.09			1,7													

Field chloride profiles after the 1st winter season 2007-08.
Measured values [% of concrete].

1 year - No. 6, 1A, w/b = 0.41, CEM II/B-S 42,5 N		1 year - No. 7, 2A, w/b = 0.42, CEM I 42,5 N - SR		1 year - No. 8, 3A, w/b = 0.42, CEM II/A-M(S-LL) 42,5 N		1 year - No. 8, 3A3 - 6 m from highway lane		1 year - No. 8, 3A5 - 8 m from highway lane		1 year - No. 8, 3A7 - 10 m from highway lane		1 year - No. 9, 5A, w/b = 0.42, CEM II/A-LL 42,5 R		1 year - No. 9, 5A3 - 6 m from highway lane		1 year - No. 9, 5A5 - 8 m from highway lane		1 year - No. 9, 5A7 - 10 m from highway lane	
Depth [mm]	Cl [w.-% of concrete]	Depth [mm]	Cl [w.-% of concrete]	Depth [mm]	Cl [w.-% of concrete]	Depth [mm]	Cl [w.-% of concrete]	Depth [mm]	Cl [w.-% of concrete]	Depth [mm]	Cl [w.-% of concrete]	Depth [mm]	Cl [w.-% of concrete]	Depth [mm]	Cl [w.-% of concrete]	Depth [mm]	Cl [w.-% of concrete]	Depth [mm]	Cl [w.-% of concrete]
0,5	0,060	0,5	0,038	0,5	0,028	0,5	0,028	0,5	0,017	0,5	0,016	0,5	0,030	0,5	0,036	0,5	0,045	0,5	0,021
1,5	0,052	1,5	0,045	1,5	0,035	1,5	0,026	1,5	0,015	1,5	0,015	1,5	0,040	1,5	0,013	1,5	0,017	1,5	0,018
3,0	0,043	3,0	0,036	3,0	0,033	3,0	0,020	3,0	0,018	3,0	0,015	3,0	0,034	3,0	0,021	3,0	0,021	3,0	0,016
5,0	0,030	5,0	0,025	5,0	0,028	5,0	0,015	5,0	0,016	5,0	0,012	5,0	0,032	5,0	0,019	5,0	0,017	5,0	0,013
7,0	0,022	7,0	0,022	7,0	0,024	7,0	0,022	7,5	0,011	7,0	0,011	7,0	0,023	6,7	0,017	7,4	0,008	7,6	0,012
9,0	0,012	9,0	0,017	9,0	0,016	9,0	0,015	13,6	0,016	9,0	0,018	9,0	0,016	12,6	0,013	12,8	0,013	14,6	0,017
11,0	0,015	11,0	0,022	11,0	0,016	11,0	0,013	19,2	0,014	11,0	0,014	11,0	0,016	18,4	0,011	18,4	0,010	21,2	0,011
13,0	0,015	13,0	0,012	13,0	0,018	13,0	0,012	25,1	0,016	13,0	0,018	13,0	0,011	25,3	0,013	19,1	0,009	27,8	0,014
15,0	0,013	15,0	0,018	15,0	0,014	15,0	0,011	31,2	0,014	15,0	0,017	15,0	0,011	32,5	0,012	20,7	0,010	34,3	0,015
17,0	0,013	17,0	0,015	17,0	0,016	17,0	0,011			17,0	0,014	17,0	0,016						
20,0	0,016	20,0	0,015	20,0	0,016	20,0	0,013			20,0	0,019	20,0	0,015						

1 year - No. 10, 6A, w/b = 0.42, CEM I 52,5 R		1 year - No. 11, 7A, w/b = 0.42, CEM II/A-LL 42,5 R & Finnsementti SLG KJ400		1 year - No. 12, 8A, w/b = 0.45,CEM II/A-LL 42,5 R & FA [EN 450-1. 2005] Fineness N, Class A		1 year - No.19, 1C, w/b = 0.47, CEM II/A-M(S-LL) 42,5 N		1 year - No. 20, 3C, w/b = 0.49, CEM II/A-M(S-LL) 42,5 N		1 year - No. 22, 5C, w/b = 0.51, CEM II/A-LL 42,5 R		1 year - No. 23, w/b = 0.40, 6C, CEM I 52,5 R	
Depth [mm]	Cl [w.-% of concrete]	Depth [mm]	Cl [w.-% of concrete]	Depth [mm]	Cl [w.-% of concrete]	Depth [mm]	Cl [w.-% of concrete]	Depth [mm]	Cl [w.-% of concrete]	Depth [mm]	Cl [w.-% of concrete]	Depth [mm]	Cl [w.-% of concrete]
0,5	0,039	0,5	0,067	0,5	0,043	0,5	0,046	0,5	0,049	0,5	0,051	0,5	0,049
1,5	0,053	1,5	0,061	1,5	0,046	1,5	0,053	1,5	0,038	1,5	0,053	1,5	0,050
3,0	0,032	3,0	0,040	3,0	0,031	3,0	0,046	3,0	0,036	3,0	0,049	3,0	0,038
5,0	0,023	5,0	0,021	5,0	0,027	5,0	0,030	5,0	0,033	5,0	0,033	5,0	0,026
7,0	0,018	7,0	0,016	6,8	0,017	7,0	0,017	7,4	0,017	7,0	0,021	6,5	0,017
9,0	0,019	9,0	0,013	12,7	0,013	9,0	0,012	12,9	0,010	9,0	0,019	8,3	0,009
11,0	0,017	11,0	0,015	18,8	0,012	11,0	0,010	18,8	0,014	11,0	0,014	13,8	0,011
13,0	0,015	13,0	0,016	25,2	0,016	13,0	0,014	24,3	0,009	13,0	0,019	19,7	0,010
15,0	0,022	15,0	0,015	31,8	0,014	15,0	0,009	30,5	0,007	15,0	0,010	25,8	0,010
17,0	0,017	17,0	0,014			17,0	0,009			17,0	0,011	33,0	0,009
20,0	0,017	20,0	0,016			20,0	0,010			20,0	0,013		

1 year - no. 24 - w/b 0.50 - CEM II/A-M(S-LL) 42,5 N - 3D 3 - impregnation		1 year - no. 24 - w/b 0.50 - CEM II/A-M(S-LL) 42,5 N - 3D 6 - impregnation		1 year - no. 24 - w/b 0.50 - CEM II/A-M(S-LL) 42,5 N - 3D 9 - impregnation		1 year - no. 24 - w/b 0.50 - CEM II/A-M(S-LL) 42,5 N - 3D 12 - form lining		1 year - no. 24 - w/b 0.50 - CEM II/A-M(S-LL) 42,5 N - 3D 15 - form lining		1 year - no. 24 - w/b 0.50 - CEM II/A-M(S-LL) 42,5 N - 3D 18 - form lining		1 year - no. 24 - w/b 0.50 - CEM II/A-M(S-LL) 42,5 N - 3D REFERENCE	
Depth [mm]	Cl [w.-% of concrete]	Depth [mm]	Cl [w.-% of concrete]	Depth [mm]	Cl [w.-% of concrete]	Depth [mm]	Cl [w.-% of concrete]	Depth [mm]	Cl [w.-% of concrete]	Depth [mm]	Cl [w.-% of concrete]	Depth [mm]	Cl [w.-% of concrete]
0,5	0,021	0,5	0,030	0,5	0,032	0,5	0,026	0,5	0,033	0,5	0,035	0,5	0,050
1,5	0,016	1,5	0,018	1,5	0,020	1,5	0,027	1,5	0,028	1,5	0,035	1,5	0,036
3,0	0,009	3,0	0,011	3,0	0,018	3,0	0,019	3,0	0,024	3,0	0,028	3,0	0,029
5,0	0,010	5,0	0,015	5,0	0,017	5,0	0,024	5,0	0,018	5,0	0,019	5,0	0,032
7,0	0,019	7,0	0,016	7,0	0,014	7,0	0,014	7,0	0,016	7,0	0,013	7,0	0,016
9,0	0,012	9,0	0,015	11,3	0,009	13,3	0,010	9,0	0,016	13,3	0,009	12,9	0,010
11,5	0,009	11,5	0,009	16,4	0,010	19,7	0,004	10,9	0,006	19,6	0,014	18,7	0,009
17,9	0,014	18,4	0,007	23,0	0,011	25,3	0,012	16,5	0,015	26,2	0,007	26,2	0,011
24,9	0,012	24,8	0,012	30,3	0,015	32,6	0,006	23,2	0,013	33,2	0,011	34,1	0,012

Field chloride profiles after the 1st winter season 2007-08.
Calculated values [% of cement].

1 year - No. 6, 1A, w/b = 0.41, CEM II/B-S 42,5 N		1 year - No. 7, 2A, w/b = 0.42, CEM I 42,5 N - SR		1 year - No. 8, 3A, w/b = 0.42, CEM II/A-M(S-LL) 42,5 N		1 year - No. 8, 3A3 - 6 m from highway lane		1 year - No. 8, 3A5 - 8 m from highway lane		1 year - No. 8, 3A7 - 10 m from highway lane		1 year - No. 9, 5A, w/b = 0.42, CEM II/A-LL 42,5 R		1 year - No. 9, 5A3 - 6 m from highway lane		1 year - No. 9, 5A5 - 8 m from highway lane		1 year - No. 9, 5A7 - 10 m from highway lane	
Depth [mm]	Cl [w.-% of cement]	Depth [mm]	Cl [w.-% of cement]	Depth [mm]	Cl [w.-% of cement]	Depth [mm]	Cl [w.-% of cement]	Depth [mm]	Cl [w.-% of cement]	Depth [mm]	Cl [w.-% of cement]	Depth [mm]	Cl [w.-% of cement]	Depth [mm]	Cl [w.-% of cement]	Depth [mm]	Cl [w.-% of cement]	Depth [mm]	Cl [w.-% of cement]
0,5	0,334	0,5	0,225	0,5	0,146	0,5	0,145	0,5	0,089	0,5	0,083	0,5	0,161	0,5	0,199	0,5	0,249	0,5	0,117
1,5	0,290	1,5	0,264	1,5	0,185	1,5	0,138	1,5	0,080	1,5	0,079	1,5	0,215	1,5	0,072	1,5	0,094	1,5	0,100
3,0	0,241	3,0	0,213	3,0	0,171	3,0	0,102	3,0	0,095	3,0	0,079	3,0	0,183	3,0	0,116	3,0	0,116	3,0	0,089
5,0	0,168	5,0	0,147	5,0	0,145	5,0	0,080	5,0	0,084	5,0	0,065	5,0	0,171	5,0	0,104	5,0	0,096	5,0	0,073
7,0	0,120	7,0	0,127	7,0	0,127	7,0	0,112	7,5	0,060	7,0	0,057	7,0	0,121	6,7	0,093	7,4	0,043	7,6	0,068
9,0	0,067	9,0	0,098	9,0	0,083	9,0	0,076	13,6	0,085	9,0	0,095	9,0	0,084	12,6	0,073	12,8	0,070	14,6	0,091
11,0	0,086	11,0	0,127	11,0	0,086	11,0	0,065	19,2	0,074	11,0	0,075	11,0	0,088	18,4	0,062	18,4	0,054	21,2	0,060
13,0	0,086	13,0	0,073	13,0	0,093	13,0	0,062	25,1	0,082	13,0	0,093	13,0	0,061	25,3	0,073	19,1	0,050	27,8	0,076
15,0	0,070	15,0	0,106	15,0	0,075	15,0	0,055	31,2	0,075	15,0	0,089	15,0	0,057	32,5	0,066	20,7	0,058	34,3	0,084
17,0	0,075	17,0	0,090	17,0	0,083	17,0	0,058			17,0	0,071	17,0	0,084						
20,0	0,090	20,0	0,086	20,0	0,083	20,0	0,066			20,0	0,100	20,0	0,083						

1 year - No. 10, 6A, w/b = 0.42, CEM I 52,5 R		1 year - No. 11, 7A, w/b = 0.42, CEM II/A-LL 42,5 R & Finnsementti SLG KJ400		1 year - No. 12, 8A, w/b = 0.45,CEM II/A-LL 42,5 R & FA [EN 450-1. 2005] Fineness N, Class A		1 year - No.19, 1C, w/b = 0.47, CEM II/A-M(S-LL) 42,5 N		1 year - No. 20, 3C, w/b = 0.49, CEM II/A-M(S-LL) 42,5 N		1 year - No. 22, 5C, w/b = 0.51, CEM II/A-LL 42,5 R		1 year - No. 23, w/b = 0.40, 6C, CEM I 52,5 R	
Depth [mm]	Cl [w.-% of cement]	Depth [mm]	Cl [w.-% of cement]	Depth [mm]	Cl [w.-% of cement]	Depth [mm]	Cl [w.-% of cement]	Depth [mm]	Cl [w.-% of cement]	Depth [mm]	Cl [w.-% of cement]	Depth [mm]	Cl [w.-% of cement]
0,5	0,210	0,5	0,349	0,5	0,215	0,5	0,302	0,5	0,332	0,5	0,338	0,5	0,248
1,5	0,286	1,5	0,317	1,5	0,230	1,5	0,349	1,5	0,257	1,5	0,354	1,5	0,252
3,0	0,173	3,0	0,206	3,0	0,157	3,0	0,300	3,0	0,245	3,0	0,323	3,0	0,193
5,0	0,124	5,0	0,109	5,0	0,136	5,0	0,195	5,0	0,226	5,0	0,221	5,0	0,130
7,0	0,098	7,0	0,084	6,8	0,085	7,0	0,111	7,4	0,115	7,0	0,138	6,5	0,085
9,0	0,102	9,0	0,069	12,7	0,064	9,0	0,079	12,9	0,069	9,0	0,125	8,3	0,046
11,0	0,094	11,0	0,080	18,8	0,061	11,0	0,065	18,8	0,096	11,0	0,092	13,8	0,053
13,0	0,079	13,0	0,084	25,2	0,078	13,0	0,093	24,3	0,059	13,0	0,125	19,7	0,049
15,0	0,117	15,0	0,077	31,8	0,068	15,0	0,056	30,5	0,050	15,0	0,064	25,8	0,049
17,0	0,090	17,0	0,073			17,0	0,061			17,0	0,073	33,0	0,046
20,0	0,090	20,0	0,084			20,0	0,065			20,0	0,087		

1 year - no. 24 - w/b 0.50 - CEM II/A-M(S-LL) 42,5 N - 3D 3 - impregnation		1 year - no. 24 - w/b 0.50 - CEM II/A-M(S-LL) 42,5 N - 3D 6 - impregnation		1 year - no. 24 - w/b 0.50 - CEM II/A-M(S-LL) 42,5 N - 3D 9 - impregnation		1 year - no. 24 - w/b 0.50 - CEM II/A-M(S-LL) 42,5 N - 3D 12 - form lining		1 year - no. 24 - w/b 0.50 - CEM II/A-M(S-LL) 42,5 N - 3D 15 - form lining		1 year - no. 24 - w/b 0.50 - CEM II/A-M(S-LL) 42,5 N - 3D 18 - form lining		1 year - no. 24 - w/b 0.50 - CEM II/A-M(S-LL) 42,5 N - 3D REFERENCE	
Depth [mm]	Cl [w.-% of cement]	Depth [mm]	Cl [w.-% of cement]	Depth [mm]	Cl [w.-% of cement]	Depth [mm]	Cl [w.-% of cement]	Depth [mm]	Cl [w.-% of cement]	Depth [mm]	Cl [w.-% of cement]	Depth [mm]	Cl [w.-% of cement]
0,5	0,145	0,5	0,205	0,5	0,221	0,5	0,180	0,5	0,227	0,5	0,241	0,5	0,342
1,5	0,111	1,5	0,126	1,5	0,138	1,5	0,187	1,5	0,193	1,5	0,241	1,5	0,246
3,0	0,062	3,0	0,077	3,0	0,125	3,0	0,130	3,0	0,164	3,0	0,192	3,0	0,203
5,0	0,067	5,0	0,106	5,0	0,116	5,0	0,163	5,0	0,126	5,0	0,131	5,0	0,222
7,0	0,131	7,0	0,111	7,0	0,094	7,0	0,100	7,0	0,111	7,0	0,092	7,0	0,112
9,0	0,082	9,0	0,106	11,3	0,060	13,3	0,070	9,0	0,111	13,3	0,059	12,9	0,069
11,5	0,060	11,5	0,060	16,4	0,070	19,7	0,027	10,9	0,045	19,6	0,098	18,7	0,064
17,9	0,095	18,4	0,051	23,0	0,074	25,3	0,080	16,5	0,107	26,2	0,049	26,2	0,078
24,9	0,085	24,8	0,080	30,3	0,103	32,6	0,041	23,2	0,088	33,2	0,078	34,1	0,083

Field chloride profiles after the 1st winter season 2009-10.
Measured values [% of concrete].

1 year - No. 33, 3Db-1 REF, CEM II/A-LL 42,5 R		1 year - No. 34, 3Db-5 Cu, CEM II/A-LL 42,5 R		1 year - No. 35, 3Db-3 Cu mortar, CEM II/A-LL 42,5 R		1 year - No. 36, 5G1, w/b = 0.42, CEM II/A-LL 42,5 R		1 year - No. 37, 5H1, w/b = 0.39, CEM II/A-LL 42,5 R		1 year - No. 38, 5J1, w/b = 0.43, CEM II/A-LL 42,5 R	
Depth [mm]	Cl [w.-% of concrete]	Depth [mm]	Cl [w.-% of concrete]	Depth [mm]	Cl [w.-% of concrete]	Depth [mm]	Cl [w.-% of concrete]	Depth [mm]	Cl [w.-% of concrete]	Depth [mm]	Cl [w.-% of concrete]
0,5	0,03	0,5	0,009	0,5	0,007	0,5	0,019	0,5	0,025	0,5	0,025
1,5	0,027	1,5	0,014	1,5	0,000	1,5	0,028	1,5	0,033	1,5	0,038
3,0	0,022	3,0	0,026	3,0	0,017	3,0	0,030	3,0	0,034	3,0	0,043
5,0	0,037	5,0	0,028	5,0	0,046	5,0	0,019	5,0	0,022	5,0	0,027
7,2	0,025	6,8	0,020	7,4	0,028	7,4	0,016	7,5	0,013	7,0	0,018
12,9	0,018	12,0	0,014	12,8	0,008	13,5	0,011	13,8	0,013	12,7	0,011
19,4	0,009	17,5	0,013	18,3	0,014	19,3	0,007	19,8	0,010	18,8	0,009

Field chloride profiles after the 1st winter season 2009-10.
Calculated values [% of cement]

1 year - No. 33, 3Db-1 REF, CEM II/A-LL 42,5 R		1 year - No. 34, 3Db-5 Cu, CEM II/A-LL 42,5 R		1 year - No. 35, 3Db-3 Cu mortar, CEM II/A-LL 42,5 R		1 year - No. 36, 5G1, w/b = 0.42, CEM II/A-LL 42,5 R		1 year - No. 37, 5H1, w/b = 0.39, CEM II/A-LL 42,5 R		1 year - No. 38, 5J1, w/b = 0.43, CEM II/A-LL 42,5 R	
Depth [mm]	Cl [w.-% of cement/binding material]	Depth [mm]	Cl [w.-% of cement/binding material]	Depth [mm]	Cl [w.-% of cement/binding material]	Depth [mm]	Cl [w.-% of cement/binding material]	Depth [mm]	Cl [w.-% of cement/binding material]	Depth [mm]	Cl [w.-% of cement/binding material]
0,5	0,203	0,5	0,061	0,5	0,028	0,5	0,113	0,5	0,125	0,5	0,135
1,5	0,183	1,5	0,094	1,5	0,000	1,5	0,167	1,5	0,165	1,5	0,205
3,0	0,149	3,0	0,175	3,0	0,067	3,0	0,179	3,0	0,170	3,0	0,232
5,0	0,251	5,0	0,189	5,0	0,182	5,0	0,113	5,0	0,110	5,0	0,146
7,2	0,169	6,8	0,135	7,4	0,111	7,4	0,097	7,5	0,064	7,0	0,099
12,9	0,122	12,0	0,094	12,8	0,032	13,5	0,064	13,8	0,064	12,7	0,062
19,4	0,061	17,5	0,088	18,3	0,056	19,3	0,043	19,8	0,050	18,8	0,047

Field chloride profiles after the 3rd winter season 2009-10.
Measured values [% of concrete].

3 years - No. 6, 1A, w/b = 0.41, CEM II/B-S 42,5 N		3 years - No. 7, 2A, w/b = 0.42, CEM I 42,5 N - SR		3 years - No. 8, 3A, w/b = 0.42, CEM II/A-M(S-LL) 42,5 N		3 years - No. 8, 3A3 - 6 m from highway lane		3 years - No. 8, 3A5 - 8 m from highway lane		3 years - No. 8, 3A7 - 10 m from highway lane		3 years - No. 9, 5A, w/b = 0.42, CEM II/A-LL 42,5 R		3 years - No. 9, 5A3 - 6 m from highway lane		3 years - No. 9, 5A5 - 8 m from highway lane		3 years - No. 9, 5A7 - 10 m from highway lane	
Depth [mm]	Cl [w.-% of concrete]	Depth [mm]	Cl [w.-% of concrete]	Depth [mm]	Cl [w.-% of concrete]	Depth [mm]	Cl [w.-% of concrete]	Depth [mm]	Cl [w.-% of concrete]	Depth [mm]	Cl [w.-% of concrete]	Depth [mm]	Cl [w.-% of concrete]	Depth [mm]	Cl [w.-% of concrete]	Depth [mm]	Cl [w.-% of concrete]	Depth [mm]	Cl [w.-% of concrete]
0,5	0,063	0,3	0,051	0,5	0,033	0,5	0,015	0,5	0,020	0,5	0,009	0,5	0,043	0,5	0,015	0,5	0,006	0,5	0,014
1,5	0,048	1,3	0,045	1,5	0,053	1,5	0,008	1,5	0,016	1,5	0,008	1,5	0,042	1,5	0,012	1,5	0,013	1,5	0,011
3,0	0,041	3,0	0,047	3,0	0,037	3,0	0,010	3,0	0,016	3,0	0,005	3,0	0,048	3,0	0,018	3,0	0,009	3,0	0,010
5,0	0,022	5,0	0,032	5,0	0,026	5,0	0,007	5,0	0,016	5,0	0,006	5,0	0,034	5,0	0,014	5,0	0,006	5,0	0,005
7,3	0,013	7,0	0,019	7,4	0,016	7,7	0,010	7,6	0,010	7,3	0,010	7,3	0,021	7,5	0,015	7,0	0,012	6,9	0,014
12,9	0,010	12,3	0,009	13,6	0,009	14,2	0,009	13,4	0,010	12,1	0,012	11,8	0,014	12,7	0,015	11,9	0,009	12,0	0,011
18,2	0,009	18,1	0,005	19,6	0,008	19,7	0,006	19,2	0,011	18,1	0,008	18,2	0,012	17,8	0,009	18,3	0,009	18,3	0,011

3 years - No. 10, 6A, w/b = 0.42, CEM I 52,5 R		3 years - No. 11, 7A, w/b = 0.42, CEM II/A-LL 42,5 R & Finnsementti SLG KJ400		3 years - No. 12, 8A, w/b = 0.45,CEM II/A-LL 42,5 R & FA [EN 450-1. 2005] Fineness N, Class A		3 years - No.19, 1C, w/b = 0.47, CEM II/A-M(S-LL) 42,5 N		3 years - No. 20, 3C, w/b = 0.49, CEM II/A-M(S-LL) 42,5 N		3 years - No. 22, 5C, w/b = 0.51, CEM II/A-LL 42,5 R		3 years - No. 23, w/b = 0.40, 6C, CEM I 52,5 R	
Depth [mm]	Cl [w.-% of concrete]	Depth [mm]	Cl [w.-% of concrete]	Depth [mm]	Cl [w.-% of concrete]	Depth [mm]	Cl [w.-% of concrete]	Depth [mm]	Cl [w.-% of concrete]	Depth [mm]	Cl [w.-% of concrete]	Depth [mm]	Cl [w.-% of concrete]
0,5	0,055	0,5	0,065	0,5	0,062	0,5	0,052	0,5	0,049	0,5	0,071	0,5	0,059
1,5	0,047	1,5	0,089	1,5	0,079	1,5	0,069	1,5	0,044	1,5	0,060	1,5	0,060
3,0	0,030	3,0	0,064	3,0	0,063	3,0	0,050	3,0	0,055	3,0	0,045	3,0	0,056
5,0	0,025	5,0	0,033	5,0	0,040	5,0	0,050	5,0	0,044	5,0	0,034	5,0	0,041
7,3	0,017	7,4	0,021	7,1	0,026	7,9	0,018	7,0	0,030	7,4	0,020	7,6	0,024
13,2	0,011	12,3	0,014	11,8	0,012	13,5	0,013	12,6	0,017	13,2	0,015	12,4	0,013
18,9	0,011	17,8	0,009	17,8	0,010	19,3	0,005	18,8	0,012	18,9	0,012	17,7	0,008

1 year - no. 24 - w/b 0.50 - CEM II/A-M(S-LL) 42,5 N - 3D 3 - impregnation		1 year - no. 24 - w/b 0.50 - CEM II/A-M(S-LL) 42,5 N - 3D 6 - impregnation		1 year - no. 24 - w/b 0.50 - CEM II/A-M(S-LL) 42,5 N - 3D 9 - impregnation		1 year - no. 24 - w/b 0.50 - CEM II/A-M(S-LL) 42,5 N - 3D 12 - form lining		1 year - no. 24 - w/b 0.50 - CEM II/A-M(S-LL) 42,5 N - 3D 15 - form lining		1 year - no. 24 - w/b 0.50 - CEM II/A-M(S-LL) 42,5 N - 3D 18 - form lining		1 year - no. 24 - w/b 0.50 - CEM II/A-M(S-LL) 42,5 N - 3D REFERENCE	
Depth [mm]	Cl [w.-% of concrete]	Depth [mm]	Cl [w.-% of concrete]	Depth [mm]	Cl [w.-% of concrete]	Depth [mm]	Cl [w.-% of concrete]	Depth [mm]	Cl [w.-% of concrete]	Depth [mm]	Cl [w.-% of concrete]	Depth [mm]	Cl [w.-% of concrete]
0,5	0,049	0,5	0,021	0,5	0,023	0,5	0,040	0,5	0,047	0,5	0,047	0,5	0,030
1,5	0,027	1,5	0,015	1,5	0,017	1,5	0,031	1,5	0,047	1,5	0,036	1,5	0,053
3,0	0,011	3,0	0,012	3,0	0,011	3,0	0,018	3,0	0,043	3,0	0,018	3,0	0,056
5,0	0,007	5,0	0,009	5,0	0,009	5,0	0,014	5,0	0,032	5,0	0,021	5,0	0,046
7,4	0,008	7,4	0,008	7,4	0,008	7,1	0,014	7,4	0,016	7,0	0,017	7,8	0,031
12,4	0,008	12,2	0,008	12,0	0,010	12,4	0,008	13,2	0,011	12,5	0,011	13,8	0,018
17,5	0,010	18,2	0,007	17,9	0,008	18,8	0,007	19,0	0,008	18,4	0,012	19,2	0,015

Field chloride profiles after the 3rd winter season 2009-10.

Calculated values [% of cement].

3 years - No. 6, 1A, w/b = 0.41, CEM II/B-S 42,5 N		3 years - No. 7, 2A, w/b = 0.42, CEM I 42,5 N - SR		3 years - No. 8, 3A, w/b = 0.42, CEM II/A-M(S-LL) 42,5 N - 4.5 m from highway line		3 years - No. 8, 3A3 - 6 m from highway lane		3 years - No. 8, 3A5 - 8 m from highway lane	
Depth [mm]	Cl [w.-% of cement/binding material]	Depth [mm]	Cl [w.-% of cement/binding material]	Depth [mm]	Cl [w.-% of cement/binding material]	Depth [mm]	Cl [w.-% of cement/binding material]	Depth [mm]	Cl [w.-% of cement/binding material]
0,5	0,349	0,5	0,299	0,5	0,172	0,5	0,078	0,5	0,104
1,5	0,266	1,3	0,264	1,5	0,277	1,5	0,042	1,5	0,083
3,0	0,227	3,0	0,276	3,0	0,193	3,0	0,052	3,0	0,083
5,0	0,122	5,0	0,188	5,0	0,136	5,0	0,037	5,0	0,083
7,3	0,073	7,0	0,110	7,4	0,083	7,7	0,055	7,6	0,054
12,9	0,054	12,3	0,053	13,6	0,047	14,2	0,047	13,4	0,052
18,2	0,050	18,1	0,029	19,6	0,044	19,7	0,033	19,2	0,058

3 years - No. 8, 3A7 - 10 m from highway lane		3 years - No. 9, 5A, w/b = 0.42, CEM II/A-LL 42,5 R - 4.5 m from highway line		3 years - No. 9, 5A3 - 6 m from highway lane		3 years - No. 9, 5A5 - 8 m from highway lane		3 years - No. 9, 5A7 - 10 m from highway lane	
Depth [mm]	Cl [w.-% of cement/binding material]	Depth [mm]	Cl [w.-% of cement/binding material]	Depth [mm]	Cl [w.-% of cement/binding material]	Depth [mm]	Cl [w.-% of cement/binding material]	Depth [mm]	Cl [w.-% of cement/binding material]
0,5	0,047	0,5	0,231	0,5	0,083	0,5	0,033	0,5	0,077
1,5	0,042	1,5	0,226	1,5	0,066	1,5	0,072	1,5	0,061
3,0	0,026	3,0	0,258	3,0	0,100	3,0	0,050	3,0	0,055
5,0	0,031	5,0	0,183	5,0	0,077	5,0	0,033	5,0	0,028
7,3	0,053	7,3	0,114	7,5	0,083	7,0	0,068	6,9	0,075
12,1	0,060	11,8	0,073	12,7	0,083	11,9	0,052	12,0	0,060
18,1	0,042	18,2	0,065	17,8	0,052	18,3	0,052	18,3	0,059

1 year - no. 24 - w/b 0.50 - CEM II/A-M(S-LL) 42,5 N - 3D 3 - impregnation		1 year - no. 24 - w/b 0.50 - CEM II/A-M(S-LL) 42,5 N - 3D 6 - impregnation		1 year - no. 24 - w/b 0.50 - CEM II/A-M(S-LL) 42,5 N - 3D 9 - impregnation		1 year - no. 24 - w/b 0.50 - CEM II/A-M(S-LL) 42,5 N - 3D 12 - form lining		1 year - no. 24 - w/b 0.50 - CEM II/A-M(S-LL) 42,5 N - 3D 15 - form lining		1 year - no. 24 - w/b 0.50 - CEM II/A-M(S-LL) 42,5 N - 3D 18 - form lining		1 year - no. 24 - w/b 0.50 - CEM II/A-M(S-LL) 42,5 N - 3D REFERENCE	
Depth [mm]	Cl [w.-% of cement/binding material]	Depth [mm]	Cl [w.-% of cement/binding material]	Depth [mm]	Cl [w.-% of cement/binding material]	Depth [mm]	Cl [w.-% of cement/binding material]	Depth [mm]	Cl [w.-% of cement/binding material]	Depth [mm]	Cl [w.-% of cement/binding material]	Depth [mm]	Cl [w.-% of cement/binding material]
0,5	0,339	0,5	0,145	0,5	0,159	0,5	0,277	0,5	0,325	0,5	0,325	0,5	0,207
1,5	0,187	1,5	0,104	1,5	0,118	1,5	0,214	1,5	0,325	1,5	0,249	1,5	0,367
3,0	0,076	3,0	0,083	3,0	0,076	3,0	0,124	3,0	0,297	3,0	0,124	3,0	0,387
5,0	0,048	5,0	0,062	5,0	0,062	5,0	0,097	5,0	0,221	5,0	0,145	5,0	0,318
7,4	0,053	7,4	0,058	7,4	0,058	7,1	0,094	7,4	0,108	7,0	0,117	7,8	0,214
12,4	0,058	12,2	0,053	12,0	0,067	12,4	0,055	13,2	0,079	12,5	0,079	13,8	0,127
17,5	0,072	18,2	0,048	17,9	0,056	18,8	0,050	19,0	0,055	18,4	0,084	19,2	0,103

3 years - No. 10, 6A, w/b = 0.42, CEM I 52,5 R		3 years - No. 11, 7A, w/b = 0.42, CEM II/A-LL 42,5 R & Finnsementti SLG KJ400		3 years - No. 12, 8A, w/b = 0.45,CEM II/A-LL 42,5 R & FA [EN 450-1. 2005] Fineness N, Class A		3 years - No.19, 1C, w/b = 0.47, CEM II/A-M(S-LL) 42,5 N		3 years - No. 20, 3C, w/b = 0.49, CEM II/A-M(S-LL) 42,5 N		3 years - No. 22, 5C, w/b = 0.51, CEM II/A-LL 42,5 R		3 years - No. 23, w/b = 0.40, 6C, CEM I 52,5 R	
Depth [mm]	Cl [w.-% of cement/binding material]	Depth [mm]	Cl [w.-% of cement/binding material]	Depth [mm]	Cl [w.-% of cement/binding material]	Depth [mm]	Cl [w.-% of cement/binding material]	Depth [mm]	Cl [w.-% of cement/binding material]	Depth [mm]	Cl [w.-% of cement/binding material]	Depth [mm]	Cl [w.-% of cement/binding material]
0,5	0,297	0,5	0,337	0,5	0,310	0,5	0,341	0,5	0,332	0,5	0,473	0,5	0,298
1,5	0,254	1,5	0,462	1,5	0,395	1,5	0,453	1,5	0,298	1,5	0,400	1,5	0,303
3,0	0,162	3,0	0,332	3,0	0,315	3,0	0,328	3,0	0,372	3,0	0,300	3,0	0,282
5,0	0,135	5,0	0,171	5,0	0,200	5,0	0,328	5,0	0,298	5,0	0,227	5,0	0,207
7,3	0,091	7,4	0,110	7,1	0,130	7,9	0,116	7,0	0,202	7,4	0,134	7,6	0,119
13,2	0,062	12,3	0,070	11,8	0,061	13,5	0,088	12,6	0,113	13,2	0,102	12,4	0,063
18,9	0,062	17,8	0,049	17,8	0,050	19,3	0,034	18,8	0,080	18,9	0,079	17,7	0,039

Carbonation at 1 % CO_2, RH 60 % and T = 21 ^oC (carbonation time 28 d and 56 d) and coefficient for carbonation (k, at 56 d)

						Average [mm]		Standard deviation [mm]		Coefficient of variation [%]		k (1 % CO_2 for 56 d) [mm/d^0,5]
Number	Casting place	Casting date	Short code	Descriptive code		28 d	56 d	28 d	56 d	28 d	56 d	
6	VTT	12.9.07	1A	Perus-cem.; w/b=0,42; i=4-5,5%		2,7	3,6	0,5	0,6	18	16	0,5
7	R	16.8.07	2A	SR-cem.; w/b=0,42; i=4-5,5%		2,1	3,6	0,6	0,5	30	14	0,5
8	R	14.8.2007	3A	Yleis-cem.; w/b=0,42; i=4-5,5%		3,4	5,5	0,6	0,7	18	12	0,7
9	R	14.8.2007	5A	Rapid-cem.; w/b=0,42; i=4-5,5%		3,0	5,0	0,5	0,8	16	15	0,7
10	VTT	20.8.2007	6A	Pika-cem.; w/b=0,42; i=4-5,5%		1,6	2,6	0,4	0,4	23	16	0,3
11	VTT	11.9.2007	7A	Rapid+BFS 50%; w/b=0,42; I=4-5,5%		3,9	5,7	0,5	0,6	13	10	0,8
12	R	6.9.2007	8A	Rapid-cem.+FA; w/b=0,42; i=4-5,5%		3,0	4,7	0,3	0,8	11	16	0,6
13	VTT	30.8.2007	3Ba	Yleis-cem.; w/b=0,42; i=1-2%		3,2	4,6	0,4	0,8	12	17	0,6
14	VTT	3.9.2007	3Bb	Yleis-cem.; w/b=0,42; i=3-4%		3,5	4,8	0,3	0,5	9	11	0,6
15	VTT	3.9.2007	3Bc	Yleis-cem.; w/b=0,42; i=5-6%		3,5	4,5	0,4	0,5	11	11	0,6
16	VTT	10.9.2007	3Bc2	Yleis-cem.; w/b=0,42; i=6-7%		3,9	5,6	0,5	0,6	12	10	0,8
17	VTT	4.9.2007	3Bd-SCC1	Yleis-cem.; w/b=0,42; i=3-4%; SCC		3,1	4,5	0,3	0,5	11	11	0,6
18	VTT	4.9.2007	3Be-SCC2	Yleis-cem.; w/b=0,42; i=5-6%; SCC		5,8	8,0	0,9	1,0	16	13	1,1
19	VTT	13.9.2007	1C	Perus-cem.; w/b=0,50; i=4-5,5%		3,8	5,9	0,6	0,7	15	13	0,8
20	R	23.8.2007	3C	Yleis-cem.; w/b=0,50; i=4-5,5%		3,9	6,0	1,1	1,1	27	18	0,8
21	P	20.9.2007	4C	Valko-cem.; w/b=0,50; i=4-5,5%		2,1	2,7	0,6	0,4	28	14	0,4
22	R	28.8.2007	5C	Rapid-cem.; w/b=0,50; i=4-5,5%		3,8	5,4	0,5	0,9	12	16	0,7
23	P	18.9.2007	6C	Pika-cem.; w/b=0,40; i=4-5,5% 1)		1,9	4,0	0,4	1,0	19	25	0,5
24	R	24.8.2007	3D	Yleis-cem.; w/b=0,50; i=3-4%		3,8	5,2	0,8	1,0	20	20	0,7
25	VTT	12.9.2007	1E	Perus-cem.; w/b=0,60; i=4-5,5%		7,9	10,5	1,1	1,1	13	10	1,4
26	R	6.9.2007	3E	Yleis-cem.; w/b=0,60; i=4-5,5%		5,8	7,1	0,6	1,1	10	15	0,9
27	P	20.9.2007	4E	Valko-cem.; w/b=0,60; i=4-5,5%		3,1	4,3	0,9	0,8	28	18	0,6
28	P	18.9.2007	5E	Rapid-cem.; w/b=0,60; i=4-5,5%		4,1	6,4	0,6	1,0	13	15	0,8
					average (for all)	3,6	5,2	0,6	0,7	0,7	17	15
					average for w/b ca 0,42	3,2	4,8	0,5	0,7	0,6	16	14
					average for w/b 0,46 - 0,60 (ca 0.52)	4,3	5,9	0,7	0,9	0,8	19	16

1) w/b was initially planned to be 0.50, but was changed to 0.40

Carbonation at laboratory at RH 65 % after about 8.3 months and at field after about 9 and 26 months.

					at RH 65 % LABORATORY CLIMATIC ROOM about 8.3 months			FIELD CARBONATION about 268 d (ca 9 month); 21.8.-27.9.08 until 5.6.08 (= 1st measurement date)			FIELD CARBONATION about 770 d (26 months) 2007 - until September 2009 (= 2nd measurement time)		
Number	Casting place	Casting date	Short code	Descriptive code	Carbonation at RH 65 %: average 8,3 months (7,7…9,0 months) [mm]	Standard deviation (RH 65 %) [mm]	$k_{(RH65\%\ about\ 8,3\ months)}$ [mm/d^0,5]	Field carbonation depth (268 d) [mm] (September 2007 - May 2008)	Standard deviation (268 d) [mm]	$k_{(field\ 268\ d)}$	Field carbonation depth (772 d) [mm] (2007-09)	Standard deviation (772 d) [mm]	$k_{(field\ 772\ d)}$
6	VTT	12.9.07	1A	Perus-cem.; w/b=0,42; i=4-5,5%	0,73	0,32	0,05	0,24	0,17	0,01	0,31	0,36	0,01
7	R	16.8.07	2A	SR-cem.; w/b=0,42; i=4-5,5%	0,69	0,14	0,04	0,27	0,07	0,02	0,37	0,09	0,01
8	R	14.8.2007	3A	Yleis-cem.; w/b=0,42; i=4-5,5%	1,34	0,22	0,08	0,49	0,28	0,03	0,90	0,17	0,03
9	R	14.8.2007	5A	Rapid-cem.; w/b=0,42; i=4-5,5%	1,10	0,30	0,07	0,39	0,11	0,02	0,72	0,52	0,03
10	VTT	20.8.2007	6A	Pika-cem.; w/b=0,42; i=4-5,5%	0,42	0,09	0,03	0,18	0,04	0,01	0,10	0,00	0,00
11	VTT	11.9.2007	7A	Rapid+BFS 50%; w/b=0,42; I=4-5,5%	1,86	0,37	0,12	0,66	0,22	0,04	0,77	0,28	0,03
12	R	6.9.2007	8A	Rapid-cem.+FA; w/b=0,42; i=4-5,5%	1,25	0,22	0,08	0,35	0,17	0,02	0,36	0,09	0,01
13	VTT	30.8.2007	3Ba	Yleis-cem.; w/b=0,42; i=1-2%	1,24	0,17	0,08	0,29	0,18	0,02	0,75	0,70	0,03
14	VTT	3.9.2007	3Bb	Yleis-cem.; w/b=0,42; i=3-4%	1,32	0,20	0,08	0,24	0,10	0,01	0,89	0,42	0,03
15	VTT	3.9.2007	3Bc	Yleis-cem.; w/b=0,42; i=5-6%	1,21	0,22	0,08	0,23	0,11	0,01	0,43	0,07	0,02
16	VTT	10.9.2007	3Bc2	Yleis-cem.; w/b=0,42; i=6-7%	1,55	0,39	0,10	0,43	0,09	0,03	1,04	0,46	0,04
17	VTT	4.9.2007	3Bd-SCC1	Yleis-cem.; w/b=0,42; i=3-4%; SCC	1,06	0,16	0,07	0,20	0,00	0,01	0,38	0,10	0,01
18	VTT	4.9.2007	3Be-SCC2	Yleis-cem.; w/b=0,42; i=5-6%; SCC	2,99	0,58	0,19	0,59	0,08	0,04	1,46	0,56	0,05
19	VTT	13.9.2007	1C	Perus-cem.; w/b=0,50; i=4-5,5%	1,76	0,22	0,11	0,53	0,16	0,03	1,02	0,43	0,04
20	R	23.8.2007	3C	Yleis-cem.; w/b=0,50; i=4-5,5%	1,83	0,39	0,11	0,54	0,32	0,03	0,69	0,48	0,02
21	P	20.9.2007	4C	Valko-cem.; w/b=0,50; i=4-5,5%	0,54	0,21	0,04	0,27	0,19	0,02	0,34	0,26	0,01
22	R	28.8.2007	5C	Rapid-cem.; w/b=0,50; i=4-5,5%	1,72	0,25	0,11	0,32	0,08	0,02	0,91	0,30	0,03
23	P	18.9.2007	6C	Pika-cem.; w/b=0,40; i=4-5,5%	0,60	0,13	0,04	0,11	0,10	0,01	0,89	0,58	0,03
24	R	24.8.2007	3D	Yleis-cem.; w/b=0,50; i=3-4%	1,45	0,58	0,09	0,40	0,26	0,02	1,03	0,26	0,04
25	VTT	12.9.2007	1E	Perus-cem.; w/b=0,60; i=4-5,5%	3,66	0,69	0,24	2,18	0,64	0,14	3,82	0,70	0,14
26	R	6.9.2007	3E	Yleis-cem.; w/b=0,60; i=4-5,5%	2,40	0,56	0,15	1,37	0,82	0,08	2,28	0,66	0,08
27	P	20.9.2007	4E	Valko-cem.; w/b=0,60; i=4-5,5%	1,37	0,79	0,09	0,73	0,13	0,05	1,53	1,06	0,05
28	P	18.9.2007	5E	Rapid-cem.; w/b=0,60; i=4-5,5%	1,84	0,28	0,12	0,57	0,13	0,04	0,95	0,18	0,03

Com

Comment 1:

Calculated coefficients for carbonation (k) are based on individual precise carbonation times for each concrete (see Appendix 13).

Comment 2:

Calculated coefficients (k-values) for laboratory and field carbonation cannot be directly compared because of different temperature, humidity and CO_2-content.

Carbonation of different specimen surfaces (beams 100 x 100 x 500 mm^3: casting, side and bottom surfaces).

Number	at 1 % CO_2 for 28 d			at 1 % CO_2 for 56 d			at RH 65 % LABORATORY CLIMATIC ROOM about 8.3 months						Field carbonation depth (268 d) [mm] (2007-08: September…May)						FIELD CARBONATION about 770 d (26 months) 2007 - until september 2009 (= 2nd measurement time)					
	Casting surface average [mm]	Side surface average [mm]	Bottom surface average [mm]	Casting surface average [mm]	Side surface average [mm]	Bottom surface average [mm]	Casting surface average [mm]	Side surface average [mm]	Bottom surface average [mm]	Casting surface standard deviation [mm]	Side surface standard deviation [mm]	Bottom surface average standard deviation [mm]	Casting surface average [mm]	Side surface average [mm]	Bottom surface average [mm]	Casting surface standard deviation [mm]	Side surface standard deviation [mm]	Bottom surface average standard deviation [mm]	Casting surface average [mm]	Side surface average [mm]	Bottom surface average [mm]	Casting surface standard deviation [mm]	Side surface standard deviation [mm]	Bottom surface average standard deviation [mm]
6	2,9	2,7	2,3	3,6	3,4	4,0	0,9	0,8	0,4	0,0	0,4	0,0	0,4	0,3	0,0	0,1	0,1	0,0	0,8	0,2	0,0	0,0	0,3	0,0
7	2,2	2,2	1,9	3,6	3,8	3,2	0,8	0,6	0,7	0,2	0,1	0,1	0,2	0,3	0,3	0,0	0,1	0,0	0,3	0,4	0,4	0,0	0,1	0,1
8	3,4	3,3	3,8	5,3	5,8	5,0	1,4	1,3	1,5	0,2	0,2	0,3	0,7	0,5	0,2	0,1	0,3	0,0	0,8	0,9	1,0	0,2	0,2	0,1
9	2,8	3,1	2,9	4,7	5,5	4,3	1,4	1,1	0,8	0,0	0,3	0,1	0,4	0,4	0,3	0,1	0,1	0,0	0,9	1,0	0,0	0,4	0,3	0,0
10	1,4	1,5	1,9	2,4	2,5	2,7	0,4	0,5	0,4	0,1	0,1	0,1	0,2	0,2	0,2	0,0	0,1	0,0	0,1	0,1	0,1	0,0	0,0	0,0
11	4,0	4,0	3,8	5,8	5,7	5,6	1,4	2,1	1,9	0,0	0,3	0,1	0,7	0,5	0,8	0,1	0,3	0,1	0,9	0,8	0,5	0,3	0,2	0,1
12	3,1	3,1	2,9	4,3	5,1	4,2	1,3	1,2	1,3	0,1	0,3	0,2	0,4	0,4	0,2	0,0	0,2	0,0	0,5	0,4	0,3	0,1	0,1	0,1
13	3,1	3,4	2,8	4,5	5,1	3,9	1,2	1,4	1,0	0,0	0,1	0,1	0,5	0,4	0,0	0,1	0,1	0,0	1,7	0,6	0,0	0,7	0,1	0,0
14	3,6	3,5	3,4	5,2	4,6	4,9	1,4	1,2	1,6	0,1	0,1	0,1	0,1	0,3	0,2	0,0	0,0	0,0	1,5	0,6	0,8	0,4	0,2	0,0
15	3,4	3,4	3,8	4,4	4,7	4,3	1,2	1,2	1,3	0,1	0,3	0,1	0,2	0,3	0,1	0,0	0,1	0,0	0,4	0,5	0,5	0,1	0,1	0,1
16	3,8	4,0	3,6	5,6	5,7	5,4	1,4	1,5	1,8	0,3	0,2	0,6	0,4	0,4	0,5	0,0	0,1	0,0	0,9	1,3	0,6	0,1	0,5	0,2
17	3,1	3,0	3,1	4,6	4,6	4,2	1,2	1,0	1,0	0,1	0,2	0,1	0,2	0,2	0,2	0,0	0,0	0,0	0,3	0,5	0,4	0,1	0,1	0,1
18	4,6	6,4	5,9	6,6	8,6	8,1	2,1	3,5	2,9	0,1	0,2	0,2	0,6	0,6	0,5	0,1	0,1	0,1	0,8	1,9	1,1	0,1	0,4	0,0
19	4,5	3,6	3,6	6,5	5,7	5,6	1,8	1,8	1,7	0,3	0,3	0,1	0,8	0,5	0,4	0,1	0,1	0,0	0,7	1,4	0,7	0,1	0,4	0,2
20	5,4	3,7	3,1	7,6	5,6	5,3	2,2	1,9	1,3	0,1	0,3	0,1	0,6	0,8	0,0	0,1	0,1	0,0	1,0	0,9	0,0	0,4	0,3	0,0
21	2,3	2,5	1,3	2,7	2,9	2,4	0,8	0,5	0,3	0,1	0,2	0,0	0,5	0,2	0,2	0,1	0,2	0,0	0,6	0,4	0,0	0,2	0,1	0,0
22	3,7	3,9	3,7	5,8	5,7	4,4	1,5	1,8	1,9	0,0	0,2	0,4	0,4	0,3	0,3	0,0	0,1	0,0	0,7	1,1	0,8	0,2	0,3	0,1
23	1,7	2,1	1,8	4,5	4,0	3,7	0,6	0,7	0,4	0,0	0,1	0,0	0,2	0,1	0,0	0,0	0,1	0,0	1,0	0,6	1,3	0,2	0,7	0,2
24	4,6	3,8	3,1	6,0	5,3	4,0	2,3	1,3	0,8	0,1	0,2	0,2	0,8	0,4	0,1	0,1	0,1	0,0	0,8	1,2	1,0	0,1	0,2	0,3
25	8,9	7,9	6,9	11,8	10,2	9,9	4,3	3,7	2,9	0,3	0,6	0,3	2,7	2,3	1,4	0,4	0,5	0,1	4,6	3,7	3,2	0,3	0,6	0,4
26	5,9	5,9	5,5	7,7	7,4	5,8	3,0	2,2	2,1	0,1	0,6	0,2	1,8	1,7	0,4	0,1	0,9	0,0	3,1	2,3	1,5	0,6	0,2	0,2
27	4,2	2,7	2,9	4,9	4,4	3,5	2,6	1,0	0,9	0,2	0,4	0,3	0,8	0,8	0,5	0,1	0,1	0,1	2,6	1,8	0,0	0,4	0,5	0,0
28	4,5	4,0	4,0	6,7	6,5	5,8	2,1	1,8	1,7	0,4	0,2	0,1	0,6	0,6	0,4	0,1	0,1	0,0	1,0	1,0	0,9	0,2	0,2	0,1
average for all w/b-ratios	3,8	3,6	3,4	5,4	5,3	4,8	1,6	1,5	1,3	0,1	0,2	0,2	0,6	0,5	0,3	0,1	0,2	0,0	1,1	1,0	0,6	0,2	0,3	0,1
average for w/b ca 0,42	3,1	3,3	3,1	4,7	4,9	4,5	1,2	1,3	1,2	0,1	0,2	0,1	0,4	0,3	0,3	0,0	0,1	0,0	0,8	0,7	0,5	0,2	0,2	0,1
average for w/b 0,46 - 0,60 (ca 0.52)	4,9	4,2	3,8	6,6	6,0	5,2	2,3	1,8	1,5	0,2	0,3	0,2	1,0	0,8	0,4	0,1	0,2	0,0	1,7	1,5	0,9	0,3	0,3	0,1

Freeze-thaw without de-icing salt (frost). Laboratory testing results. (Information on air content and air pore structure is included)
Standard, Aged 1 year and carbonated (1.20 – 1.26 years, ca. 1.22 years) and Aged > year NOT carbonated (1.53 – 1.59 years, ca. 1.55 years)

Num-ber	Casting place	Casting date	Short code	Cement type	Descriptive code	Standard frost scaling (water) [kg/m²]						Standard - Internal (water) (RDM$_{UPTT}$ = 100 $(t_0/t_n)^2$ [%]						Fresh concrete air [%]	Hardened concrete: Air pores <0,300 mm [%]	Hardened concrete: Spacing factor (< 0,800 mm pores) [mm]
						0	7	14	28	42	56	0	7	14	28	42	56			
21	P	20.9.07	4C	21. CEM I 52,5 N (w/b 0.46)	Valko-cem.; w/b=0,50; i=4-5,5%	0,000	0,010	0,014	0,020	0,024	0,028	100	95	96	99	104	110	5,50	3,10	0,29
22	R	28.8.07	5C	22. CEM II/A-LL 42,5 R (w/b 0.51)	Rapid-cem.; w/b=0,50; i=4-5,5%	0,000	0,003	0,011	0,013	0,017	0,020	100	102	103	106	107	107	5,00	1,80	0,51
25	VTT	12.9.07	1E	25. CEM II/B-S 42,5 N (w/b 0.60)	Perus-cem.; w/b=0,60; i=4-5,5%	0,000	0,008	0,010	0,011	0,012	0,013	100	100	102	103	104	106	7,30	2,40	0,26
26	R	6.9.07	3E	26. CEM II/A-M(S-LL) 42,5 N (w/b 0.58)	Yleis-cem.; w/b=0,60; i=4-5,5%	0,000	0,003	0,004	0,006	0,010	0,013	100	99	100	102	102	102	4,30	1,60	0,28
27	P	20.9.07	4E	27. CEM I 52,5 N (w/b 0.54)	Valko-cem.; w/b=0,60; i=4-5,5%	0,000	0,010	0,011	0,016	0,019	0,023	100	94	95	99	102	107	5,50	3,10	0,25
28	P	18.9.07	5E	28. CEM II/A-LL 42,5 R (w/b 0.54)	Rapid-cem.; w/b=0,60; i=4-5,5%	0,000	0,002	0,006	0,034	0,217	0,259	100	98	98	101	100	101	4,80	1,40	0,41

7,30	high, presumably extra compaction pores

Num-ber	Casting place	Casting date	Short code	Cement type	Descriptive code	Aged 1 year and carbonated - frost scaling [kg/m²]						Aged 1 year and carbonated - Internal (water) (RDM$_{UPTT}$ = 100 $(t_0/t_n)^2$ [%]						Fresh concrete air [%]	Air pores <0,300 mm [%]	Spacing factor (< 0,800 mm pores) [mm]
						0	7	14	28	42	56	0	7	14	28	42	56			
21	P	20.9.07	4C	21. CEM I 52,5 N (w/b 0.46)	Valko-cem.; w/b=0,50; i=4-5,5%	0,000	0,005	0,011	0,017	0,019	0,020	100	104	109	113	115	119	5,50	3,10	0,29
22	R	28.8.07	5C	22. CEM II/A-LL 42,5 R (w/b 0.51)	Rapid-cem.; w/b=0,50; i=4-5,5%	0,000	0,006	0,009	0,011	0,189	0,406	100	103	106	109	110	111	5,00	1,80	0,51
25	VTT	12.9.07	1E	25. CEM II/B-S 42,5 N (w/b 0.60)	Perus-cem.; w/b=0,60; i=4-5,5%	0,000	0,007	0,008	0,009	0,029	0,029	100	105	106	107	107	106	7,30	2,40	0,26
26	R	6.9.07	3E	26. CEM II/A-M(S-LL) 42,5 N (w/b 0.58)	Yleis-cem.; w/b=0,60; i=4-5,5%	0,000	0,004	0,007	0,157	0,336	0,401	100	102	106	107	107	110	4,30	1,60	0,28
27	P	20.9.07	4E	27. CEM I 52,5 N (w/b 0.54)	Valko-cem.; w/b=0,60; i=4-5,5%	0,000	0,005	0,006	0,012	0,013	0,013	100	111	113	115	116	117	5,50	3,10	0,25
28	P	18.9.07	5E	28. CEM II/A-LL 42,5 R (w/b 0.54)	Rapid-cem.; w/b=0,60; i=4-5,5%	0,000	0,004	0,004	0,012	0,024	0,031	100	104	106	109	111	112	4,80	1,40	0,41

0,189	Average(0,162; 0,377; 0,027)
0,406	Average(0,363; 0,454; 0,402)
0,157	Average(0,438; 0,025; 0,009)
0,336	Average(0,492; 0,052; 0,463)
0,401	Average(0,504; 0,054; 0,646)
7,30	high, presumably extra compaction pores

Num-ber	Casting place	Casting date	Short code	Cement type	Descriptive code	Aged >1 year NOT carbonated - frost scaling [kg/m²]						Aged >1 year NOT carbonated - Internal (water) (RDM$_{UPTT}$ = 100 $(t_0/t_n)^2$ [%]						Fresh concrete air [%]	Air pores <0,300 mm [%]	Spacing factor (< 0,800 mm pores) [mm]
						0	7	14	28	42	56	0	7	14	28	42	56			
21	P	20.9.07	4C	21. CEM I 52,5 N (w/b 0.46)	Valko-cem.; w/b=0,50; i=4-5,5%	0,000	0,010	0,017	0,024	0,027	0,030	100	106	112	116	118	120	5,50	3,10	0,29
22	R	28.8.07	5C	22. CEM II/A-LL 42,5 R (w/b 0.51)	Rapid-cem.; w/b=0,50; i=4-5,5%	0,000	0,002	0,005	0,008	0,011	0,056	100	103	105	106	106	108	5,00	1,80	0,51
25	VTT	12.9.07	1E	25. CEM II/B-S 42,5 N (w/b 0.60)	Perus-cem.; w/b=0,60; i=4-5,5%	0,000	0,003	0,006	0,011	0,016	0,020	100	108	109	110	111	111	7,30	2,40	0,26
26	R	6.9.07	3E	26. CEM II/A-M(S-LL) 42,5 N (w/b 0.58)	Yleis-cem.; w/b=0,60; i=4-5,5%	0,000	0,008	0,013	0,017	0,020	0,026	100	104	105	107	107	108	4,30	1,60	0,28
27	P	20.9.07	4E	27. CEM I 52,5 N (w/b 0.54)	Valko-cem.; w/b=0,60; i=4-5,5%	0,000	0,009	0,014	0,019	0,024	0,027	100	106	107	108	109	111	5,50	3,10	0,25
28	P	18.9.07	5E	28. CEM II/A-LL 42,5 R (w/b 0.54)	Rapid-cem.; w/b=0,60; i=4-5,5%	0,000	0,008	0,011	0,017	0,022	0,031	100	105	107	109	110	110	4,80	1,40	0,41

7,30	high, presumably extra compaction pores

Freeze-thaw without de-icing salt (frost). Field testing results. (Information on air content and air pore structure is included)

Num-ber	Casting place	Casting date	Short code	Cement type	Descriptive code	Frost SPRING 2008 (1 WINTER)				Frost SEPTEMBER 2008 (1 WINTER + 1 SUMMER)				Fresh concrete air [%]	Hardened concrete	
						ΔV(autumn 07 Spring 08) [%] (+ is increase)	Standard internal (RDMUPTT = (t0/tn)^2*100 [%] Spring 08	RDMFF = (fn/f0)^2x100 [%] Spring 08	RDM(average (UP&FF) [%] Spring 08	ΔV(autumn 07 - autumn 08) [%] September 08 (+ is increase)	Standard internal (RDMUPTT = (t0/tn)^2*100 [%] Sept.08	RDMFF = (fn/f0)^2x100 [%] Sept.08	RDM(average (UP&FF) [%] Sept.08		Air pores <0,300 mm [%]	Spacing factor (< 0,800 mm pores) [mm]
21	P	20.9.07	4C	CEM I 52,5 N (w/b 0.46)	Valko-cem.; w/b=0,50; i=4-5,5%	0,05	95,6	97,0	96,3	0,12	97,4	98,2	97,8	5,50	3,10	0,29
22	R	28.8.07	5C	CEM II/A-LL 42,5 R (w/b 0.51)	Rapid-cem.; w/b=0,50; i=4-5,5%	-0,01	98,4	99,7	99,1	-0,14	101,5	101,4	101,4	5,00	1,80	0,51
25	VTT	12.9.07	1E	CEM II/B-S 42,5 N (w/b 0.60)	Perus-cem.; w/b=0,60; i=4-5,5%	-0,15	101,0	98,3	99,6	-0,12	102,8	103,3	103,0	7,30	2,40	0,26
26	R	6.9.07	3E	CEM II/A-M(S-LL) 42,5 N (w/b 0.58)	Yleis-cem.; w/b=0,60; i=4-5,5%	-0,01	98,2	98,8	98,5	0,07	100,8	100,7	100,7	4,30	1,60	0,28
27	P	20.9.07	4E	CEM I 52,5 N (w/b 0.54)	Valko-cem.; w/b=0,60; i=4-5,5%	0,02	96,5	97,6	97,1	0,10	98,2	99,2	98,7	5,50	3,10	0,25
28	P	18.9.07	5E	CEM II/A-LL 42,5 R (w/b 0.54)	Rapid-cem.; w/b=0,60; i=4-5,5%	0,01	97,6	99,3	98,4	0,12	99,0	100,7	99,8	4,80	1,40	0,41

Num-ber	Casting place	Casting date	Short code	Cement type	Descriptive code	Frost SPRING 2009 (2 WINTERS)				Frost SPRING 2010 (3 WINTERS)				Fresh concrete air [%]	Hardened concrete	
						ΔV(autumn 07 - Spring 09 [%] (+ is increase)	Standard internal (RDMUPTT = (t0/tn)^2*100 Spring 09	RDMFF = (fn/f0)^2x100 [%] Spring 09	RDM(average (UP&FF) [%] Spring 09	ΔV(autumn 07 - Spring 10 [%] (+ is increase)	Standard internal (RDMUPTT = (t0/tn)^2*100 [%] Spring 10	RDMFF = (fn/f0)^2x100 [%] Spring 10	RDM(average (UP&FF) [%] Spring 10		Air pores <0,300 mm [%]	Spacing factor (< 0,800 mm pores) [mm]
21	P	20.9.07	4C	CEM I 52,5 N (w/b 0.46)	Valko-cem.; w/b=0,50; i=4-5,5%	-0,10	97,2	98,3	97,8	-0,29	95,8	99,0	97,4	5,50	3,10	0,29
22	R	28.8.07	5C	CEM II/A-LL 42,5 R (w/b 0.51)	Rapid-cem.; w/b=0,50; i=4-5,5%	-0,13	100,0	102,6	101,3	-0,37	102,3	104,0	103,2	5,00	1,80	0,51
25	VTT	12.9.07	1E	CEM II/B-S 42,5 N (w/b 0.60)	Perus-cem.; w/b=0,60; i=4-5,5%	-0,27	102,6	104,8	103,7	-0,49	104,0	107,9	106,0	7,30	2,40	0,26
26	R	6.9.07	3E	CEM II/A-M(S-LL) 42,5 N (w/b 0.58)	Yleis-cem.; w/b=0,60; i=4-5,5%	-0,12	97,1	101,3	99,2	-0,36	101,6	103,5	102,5	4,30	1,60	0,28
27	P	20.9.07	4E	CEM I 52,5 N (w/b 0.54)	Valko-cem.; w/b=0,60; i=4-5,5%	-0,13	98,0	100,8	99,4	-0,27	95,7	101,2	98,5	5,50	3,10	0,25
28	P	18.9.07	5E	CEM II/A-LL 42,5 R (w/b 0.54)	Rapid-cem.; w/b=0,60; i=4-5,5%	-0,10	100,0	100,4	100,2	-0,34	100,4	103,5	102,0	4,80	1,40	0,41

Freeze-thaw with de-icing salt (frost-salt). Laboratory testing results. (Information on air content and air pore structure is included).

Standard testing method.

Num-ber	Casting place	Casting date	Short code	Cement type	Descriptive code	Standard frost-salt scaling [kg/m2]						Standard internal (salt) (RDM_{UPTT} = 100 $(t0/tn)^2$ [%]						Fresh concrete air [%]	Hardened concrete: Air pores <0,300 mm [%]	Hardened concrete: Spacing factor (< 0,800 mm pores) [mm]
						0	7	14	28	42	56	0	7	14	28	42	56			
6	VTT	12.9.07	1A	6. CEM II/B-S 42,5 N (w/b 0.41)	Perus-cem.; w/b=0,42; i=4-5,5%	0,00	0,044	0,062	0,098	0,142	0,195	100	101	101	101	104	104	6,5	0,8	0,46
7	R	16.8.07	2A	7. CEM I 42,5 N - SR (w/b 0.42)	SR-cem.; w/b=0,42; i=4-5,5%	0,00	0,015	0,030	0,037	0,042	0,045	100	105	105	109	109	110	5,9	3,5	0,35
8	R	14.8.07	3A	8. CEM II/A-M(S-LL) 42,5 N (w/b 0.42)	Yleis-cem.; w/b=0,42; i=4-5,5%	0,00	0,151	0,173	0,186	0,194	0,202	100	97	100	102	103	107	5,9	2,8	0,28
9	R	14.8.07	5A	9. CEM II/A-LL 42,5 R (w/b 0.42)	Rapid-cem.; w/b=0,42; i=4-5,5%	0,00	0,072	0,144	0,183	0,195	0,205	100	101	103	104	106	109	5,0	2,2	0,24
10	VTT	20.8.07	6A	10. CEM I 52,5 R (w/b 0.42)	Pika-cem.; w/b=0,42; i=4-5,5%	0,00	0,026	0,048	0,057	0,066	0,075	100	100	99	102	103	104	5,5	0,6	0,33
11	VTT	11.9.07	7A	11. CEM II/A-LL 42,5 R & SLG (w/b 0.42)	Rapid+BFS 50%; w/b=0,42; I=4-5,5%	0,00	0,052	0,131	0,201	0,281	0,320	100	98	97	99	98	99	6,1	2,6	0,18
12	R	6.9.07	8A	12. CEM II/A-LL 42,5 R & FA (w/b 0.45)	Rapid-cem.+FA; w/b=0,42; i=4-5,5%	0,00	0,033	0,054	0,091	0,117	0,158	100	101	102	102	103	105	5,0	1,6	0,30
13	VTT	30.8.07	3Ba	13. CEM II/A-M(S-LL) 42,5 N (w/b 0.42, air 2.6 %)	Yleis-cem.; w/b=0,42; i=1-2% (no air entr.)	0,00	0,973	1,921	2,263	3,059	3,500	100	99	99	97	86	30	2,6	0,1	1,15
14	VTT	3.9.07	3Bb	14. CEM II/A-M(S-LL) 42,5 N (w/b 0.42, air 4.5 %)	Yleis-cem.; w/b=0,42; i=3-4%	0,00	0,540	1,050	1,547	1,651	1,750	100	100	99	101	102	90	4,5	0,7	0,51
15	VTT	3.9.07	3Bc	15. CEM II/A-M(S-LL) 42,5 N (w/b 0.42, air 5.3 %)	Yleis-cem.; w/b=0,42; i=5-6%	0,00	0,337	0,560	0,723	0,756	0,840	100	99	99	100	100	90	5,3	1,2	0,38
16	VTT	10.9.07	3Bc2	16. CEM II/A-M(S-LL) 42,5 N (w/b 0.42, air 7.0 %)	Yleis-cem.; w/b=0,42; i=6-7%	0,00	0,044	0,057	0,078	0,089	0,096	100	98	99	101	102	103	7,0	2,7	0,30
17	VTT	4.9.07	3Bd-SCC1	17. CEM II/A-M(S-LL) 42,5 N (w/b 0.42 air 3.4 %)	Yleis-cem.; w/b=0,42; i=3-4%; SCC	0,00	0,364	0,807	1,250	1,321	1,400	100	99	99	98	99	90	3,4	1,3	0,69
18	VTT	4.9.07	3Be-SCC2	18. CEM II/A-M(S-LL) 42,5 N (w/b 0.42, air 5.7 %)	Yleis-cem.; w/b=0,42; i=5-6%; SCC	0,00	0,025	0,071	0,106	0,118	0,128	100	99	99	100	100	99	5,7	5,9	0,34
19	VTT	13.9.07	1C	19. CEM II/B-S 42,5 N (w/b 0.47)	Perus-cem.; w/b=0,50; i=4-5,5%	0,00	0,007	0,015	0,023	0,031	0,039	100	98	98	99	102	102	6,9	3,3	0,22
20	R	23.8.07	3C	20. CEM II/A-M(S-LL) 42,5 N (w/b 0.49)	Yleis-cem.; w/b=0,50; i=4-5,5%	0,00	0,041	0,061	0,070	0,079	0,084	100	99	100	102	103	103	5,5	2,0	0,28
22	R	28.8.07	5C	22. CEM II/A-LL 42,5 R (w/b 0.51)	Rapid-cem.; w/b=0,50; i=4-5,5%	0,00	0,172	0,321	0,519	0,612	0,636	100	99	100	103	105	105	5,0	1,8	0,51
23	P	18.9.07	6C	23. CEM I 52,5 R (w/b 0.40)	Pika-cem.; w/b=0,40; i=4-5,5%	0,00	0,113	0,175	0,260	0,294	0,390	100	97	98	98	100	101	5,4	2,9	0,29
29	R	13.3.08	3Bf	29. CEM II/A-M(S-LL) 42,5 N (w/b 0.41, air 1.7 %)	Yleis-cem.; w/b=0,42;(no airentr.)	0,000	0,695	1,388	2,359	2,627	2,740	100	100	100	95	82	50	1,7	0,2	0,98
30	R	13.3.08	3Bg	30. CEM II/A-M(S-LL) 42,5 N (w/b 0.41, air 4.2 %)	Yleis-cem.; w/b=0,42;I=4 %	0,000	0,269	0,359	0,420	0,453	0,496	100	100	99	100	100	101	4,2	0,6	0,41
31	R	13.3.08	3Bh	31. CEM II/A-M(S-LL) 42,5 N (w/b 0.41, air 6.8 %)	Yleis-cem.; w/b=0,42; i=6 %	0,000	0,116	0,162	0,193	0,216	0,236	100	100	100	101	104	105	6,8	1,7	0,31
32	R	18.3.08	3Bi	32. CEM II/A-M(S-LL) 42,5 N (w/b 0.41, air 4.9 %)	Yleis-cem.; w/b=0,42;I=4 %	0,000	0,137	0,205	0,247	0,286	0,305	100	100	101	102	102	104	4,9	2,0	0,44

extrapolation, no real value, too much scaling

no value, too much scaling

Freeze-thaw with de-icing salt (frost-salt). Laboratory testing results. (Information on air content and air pore structure is included).
Aged ca. 1 year (1.2 – 1.3 years, average 1.25 years) and carbonated.

Num-ber	Casting place	Casting date	Short code	Cement type	Descriptive code	Aged 1 year and carbonated - frost-salt scaling [kg/m^2]						Aged 1 year and carbonated - Internal (salt) (RDM$_{UPTT}$ = 100 $(t_0/t_n)^2$ [%]						Fresh concrete air [%]	Air pores <0,300 mm [%]	Spacing factor (< 0,800 mm pores) [mm]
						0	7	14	28	42	56	0	7	14	28	42	56			
6	VTT	12.9.07	1A	6. CEM II/B-S 42,5 N (w/b 0.41)	Perus-cem.; w/b=0,42; i=4-5,5%	0,00	0,141	0,29	0,437	0,474	0,501	100	101	102	104	104	105	6,5	0,8	0,46
7	R	16.8.07	2A	7. CEM I 42,5 N - SR (w/b 0.42)	SR-cem.; w/b=0,42; i=4-5,5%	0,00	0,105	0,306	0,472	0,521	0,532	100	103	104	107	110	112	5,9	3,5	0,35
8	R	14.8.07	3A	8. CEM II/A-M(S-LL) 42,5 N (w/b 0.42)	Yleis-cem.; w/b=0,42; i=4-5,5%	0,00	0,038	0,151	0,299	0,395	0,422	100	103	105	108	111	112	5,9	2,8	0,28
9	R	14.8.07	5A	9. CEM II/A-LL 42,5 R (w/b 0.42)	Rapid-cem.; w/b=0,42; i=4-5,5%	0,00	0,065	0,227	0,452	0,489	0,726	100	103	105	109	112	113	5,0	2,2	0,24
10	VTT	20.8.07	6A	10. CEM I 52,5 R (w/b 0.42)	Pika-cem.; w/b=0,42; i=4-5,5%	0,00	0,327	0,782	1,217	1,486	1,549	100	102	104	107	110	111	5,5	0,6	0,33
11	VTT	11.9.07	7A	11. CEM II/A-LL 42,5 R & SLG (w/b 0.42)	Rapid+BFS 50%; w/b=0,42; I=4-5,5%	0,00	0,129	0,276	0,389	0,422	0,442	100	98	97	98	98	98	6,1	2,6	0,18
12	R	6.9.07	8A	12. CEM II/A-LL 42,5 R & FA (w/b 0.45)	Rapid-cem.+FA; w/b=0,42; i=4-5,5%	0,00	0,269	0,543	0,746	0,790	0,801	100	102	104	106	104	106	5,0	1,6	0,30
13	VTT	30.8.07	3Ba	13. CEM II/A-M(S-LL) 42,5 N (w/b 0.42, air 2.6 %)	Yleis-cem.; w/b=0,42; i=1-2%,(no air entr.)	0,00	0,281	1,160	8,314	10	12	100	94	67	10	10	10	2,6	0,1	1,15
14	VTT	3.9.07	3Bb	14. CEM II/A-M(S-LL) 42,5 N (w/b 0.42, air 4.5 %)	Yleis-cem.; w/b=0,42; i=3-4%	0,00	0,119	0,781	1,416	1,580	1,633	100	103	105	108	108	110	4,5	0,7	0,51
15	VTT	3.9.07	3Bc	15. CEM II/A-M(S-LL) 42,5 N (w/b 0.42, air 5.3 %)	Yleis-cem.; w/b=0,42; i=5-6%	0,00	0,098	0,505	1,084	1,212	1,274	100	101	105	107	107	104	5,3	1,2	0,38
16	VTT	10.9.07	3Bc2	16. CEM II/A-M(S-LL) 42,5 N (w/b 0.42, air 7.0 %)	Yleis-cem.; w/b=0,42; i=6-7%	0,00	0,039	0,101	0,162	0,177	0,182	100	103	104	107	110	112	7,0	2,7	0,30
17	VTT	4.9.07	3Bd-SCC1	17. CEM II/A-M(S-LL) 42,5 N (w/b 0.42 air 3.4 %)	Yleis-cem.; w/b=0,42; i=3-4%; SCC	0,00	0,025	0,160	0,530	0,546	0,553	100	102	103	104	107	108	3,4	1,3	0,69
18	VTT	4.9.07	3Be-SCC2	18. CEM II/A-M(S-LL) 42,5 N (w/b 0.42, air 5.7 %)	Yleis-cem.; w/b=0,42; i=5-6%; SCC	0,00	0,010	0,022	0,059	0,061	0,062	100	102	106	109	111	111	5,7	5,9	0,34
19	VTT	13.9.07	1C	19. CEM II/B-S 42,5 N (w/b 0.47)	Perus-cem.; w/b=0,50; i=4-5,5%	0,00	0,443	0,674	0,809	0,841	0,850	100	103	106	106	109	110	6,9	3,3	0,22
20	R	23.8.07	3C	20. CEM II/A-M(S-LL) 42,5 N (w/b 0.49)	Yleis-cem.; w/b=0,50; i=4-5,5%	0,00	0,205	0,564	0,814	0,834	0,865	100	104	106	109	109	109	5,5	2,0	0,28
22	R	28.8.07	5C	22. CEM II/A-LL 42,5 R (w/b 0.51)	Rapid-cem.; w/b=0,50; i=4-5,5%	0,00	0,745	1,271	1,529	1,618	1,776	100	106	106	110	109	111	5,0	1,8	0,51
23	P	18.9.07	6C	23. CEM I 52,5 R (w/b 0.40)	Pika-cem.; w/b=0,40; i=4-5,5%	0,00	0,122	0,277	0,405	0,450	0,492	100	101	104	107	111	111	5,4	2,9	0,29
29	R	13.3.08	3Bf	29. CEM II/A-M(S-LL) 42,5 N (w/b 0.41, air 1.7 %)	Yleis-cem.; w/b=0,42;(no air-entr.)	**Not determined**												1,7	0,2	0,98
30	R	13.3.08	3Bg	30. CEM II/A-M(S-LL) 42,5 N (w/b 0.41, air 4.2 %)	Yleis-cem.; w/b=0,42;I=4 %													4,2	0,6	0,41
31	R	13.3.08	3Bh	31. CEM II/A-M(S-LL) 42,5 N (w/b 0.41, air 6.8 %)	Yleis-cem.; w/b=0,42; i=6 %													6,8	1,7	0,31
32	R	18.3.08	3Bi	32. CEM II/A-M(S-LL) 42,5 N (w/b 0.41, air 4.9 %)	Yleis-cem.; w/b=0,42;I=4 %													4,9	2,0	0,44

	extrapolation, no real value, too much scaling
10	specimen destroyed

Freeze-thaw with de-icing salt (frost-salt). Laboratory testing results. (Information on air content and air pore structure is included).

Aged > 1 year (1.53 – 1.63 years, average 1.58 years) NOT carbonated.

Num-ber	Casting place	Casting date	Short code	Cement type	Descriptive code	Aged >1 year NOT carbonated - frost-salt scaling [kg/m^2]						Aged >1 year NOT carbonated - Internal (salt) (RDM$_{UPTT}$ = 100 $(t_0/t_n)^2$ [%]						Fresh concrete air [%]	Air pores <0,300 mm [%]	Spacing factor (< 0,800 mm pores) [mm]
						0	7	14	28	42	56	0	7	14	28	42	56			
6	VTT	12.9.07	1A	6. CEM II/B-S 42,5 N (w/b 0.41)	Perus-cem.; w/b=0,42; i=4-5,5%	0,000	0,045	0,063	0,074	0,083	0,095	100	107	107	110	112	112	6,5	0,8	0,46
7	R	16.8.07	2A	7. CEM I 42,5 N - SR (w/b 0.42)	SR-cem.; w/b=0,42; i=4-5,5%	0,000	0,037	0,063	0,079	0,086	0,092	100	104	105	109	109	111	5,9	3,5	0,35
8	R	14.8.07	3A	8. CEM II/A-M(S-LL) 42,5 N (w/b 0.42)	Yleis-cem.; w/b=0,42; i=4-5,5%	0,000	0,033	0,040	0,080	0,086	0,088	100	102	105	109	111	114	5,9	2,8	0,28
9	R	14.8.07	5A	9. CEM II/A-LL 42,5 R (w/b 0.42)	Rapid-cem.; w/b=0,42; i=4-5,5%	0,000	0,071	0,120	0,216	0,261	0,271	100	102	105	110	112	112	5,0	2,2	0,24
10	VTT	20.8.07	6A	10. CEM I 52,5 R (w/b 0.42)	Pika-cem.; w/b=0,42; i=4-5,5%	0,000	0,094	0,228	0,540	0,816	0,984	100	101	103	106	108	110	5,5	0,6	0,33
11	VTT	11.9.07	7A	11. CEM II/A-LL 42,5 R & SLG (w/b 0.42)	Rapid+BFS 50%; w/b=0,42; I=4-5,5%	0,000	0,007	0,014	0,021	0,032	0,044	100	101	100	101	102	103	6,1	2,6	0,18
12	R	6.9.07	8A	12. CEM II/A-LL 42,5 R & FA (w/b 0.45)	Rapid-cem.+FA; w/b=0,42; i=4-5,5%	0,000	0,025	0,050	0,067	0,079	0,085	100	102	102	105	106	109	5,0	1,6	0,30
13	VTT	30.8.07	3Ba	13. CEM II/A-M(S-LL) 42,5 N (w/b 0.42, air 2.6 %)	Yleis-cem.; w/b=0,42; i=1-2% (no air entr.)	0,000	0,508	4,269	9,244	12	15	100	102	72	10	10	10	2,6	0,1	1,15
14	VTT	3.9.07	3Bb	14. CEM II/A-M(S-LL) 42,5 N (w/b 0.42, air 4.5 %)	Yleis-cem.; w/b=0,42; i=3-4%	0,000	0,152	0,380	0,914	1,182	1,828	100	103	105	108	105	70	4,5	0,7	0,51
15	VTT	3.9.07	3Bc	15. CEM II/A-M(S-LL) 42,5 N (w/b 0.42, air 5.3 %)	Yleis-cem.; w/b=0,42; i=5-6%	0,000	0,086	0,184	0,279	0,363	0,626	100	101	103	105	105	109	5,3	1,2	0,38
16	VTT	10.9.07	3Bc2	16. CEM II/A-M(S-LL) 42,5 N (w/b 0.42, air 7.0 %)	Yleis-cem.; w/b=0,42; i=6-7%	0,000	0,018	0,028	0,034	0,037	0,039	100	103	104	108	111	110	7,0	2,7	0,30
17	VTT	4.9.07	3Bd-SCC1	17. CEM II/A-M(S-LL) 42,5 N (w/b 0.42 air 3.4 %)	Yleis-cem.; w/b=0,42; i=3-4%; SCC	0,000	0,040	0,108	0,424	0,812	1,103	100	101	102	104	105	107	3,4	1,3	0,69
18	VTT	4.9.07	3Be-SCC2	18. CEM II/A-M(S-LL) 42,5 N (w/b 0.42, air 5.7 %)	Yleis-cem.; w/b=0,42; i=5-6%; SCC	0,000	0,012	0,018	0,021	0,024	0,028	100	101	105	109	109	112	5,7	5,9	0,34
19	VTT	13.9.07	1C	19. CEM II/B-S 42,5 N (w/b 0.47)	Perus-cem.; w/b=0,50; i=4-5,5%	0,000	0,052	0,090	0,121	0,148	0,190	100	101	104	106	111	112	6,9	3,3	0,22
20	R	23.8.07	3C	20. CEM II/A-M(S-LL) 42,5 N (w/b 0.49)	Yleis-cem.; w/b=0,50; i=4-5,5%	0,000	0,058	0,115	0,170	0,180	0,187	100	106	110	113	114	115	5,5	2,0	0,28
22	R	28.8.07	5C	22. CEM II/A-LL 42,5 R (w/b 0.51)	Rapid-cem.; w/b=0,50; i=4-5,5%	0,000	0,109	0,178	0,304	0,357	0,376	100	104	105	108	107	108	5,0	1,8	0,51
23	P	18.9.07	6C	23. CEM I 52,5 R (w/b 0.40)	Pika-cem.; w/b=0,40; i=4-5,5%	0,000	0,136	0,194	0,292	0,378	0,460	100	101	103	106	108	110	5,4	2,9	0,29
29	R	13.3.08	3Bf	29. CEM II/A-M(S-LL) 42,5 N (w/b 0.41, air 1.7 %)	Yleis-cem.; w/b=0,42;(no air-entr.)	Not determined												1,7	0,2	0,98
30	R	13.3.08	3Bg	30. CEM II/A-M(S-LL) 42,5 N (w/b 0.41, air 4.2 %)	Yleis-cem.; w/b=0,42;I=4 %													4,2	0,6	0,41
31	R	13.3.08	3Bh	31. CEM II/A-M(S-LL) 42,5 N (w/b 0.41, air 6.8 %)	Yleis-cem.; w/b=0,42; i=6 %													6,8	1,7	0,31
32	R	18.3.08	3Bi	32. CEM II/A-M(S-LL) 42,5 N (w/b 0.41, air 4.9 %)	Yleis-cem.; w/b=0,42;I=4 %													4,9	2,0	0,44

(red value)	extrapolation, no real value, too much scaling
1,103	average for 2 specimen
10	specimen destroyed
70	Average(109; 80; 22)

Freeze-thaw with de-icing salt (frost-salt). Field testing results.

Num-ber	Casting place	Casting date	Short code	Cement type	Descriptive code	Frost-salt SPRING 2008 (1 WINTER)			
						ΔV(autumn 07 Spring 08) [%] (+ is increase)	Standard internal (RDMUPTT = (t0/tn)^2*100 [%] Spring 08	RDMFF = (fn/f0)^2x100 [%] Spring 08	RDM(average (UP&FF) [%] Spring 08
6	VTT	12.9.07	1A	6. CEM II/B-S 42,5 N (w/b 0.41)	Perus-cem.; w/b=0,42; i=4-5,5%	0,07	102,5	102,2	102,4
7	R	16.8.07	2A	7. CEM I 42,5 N - SR (w/b 0.42)	SR-cem.; w/b=0,42; i=4-5,5%	0,09	102,3	102,0	102,1
8	R	14.8.07	3A	8. CEM II/A-M(S-LL) 42,5 N (w/b 0.42)	Yleis-cem.; w/b=0,42; i=4-5,5%	0,14	102,0	101,3	101,7
9	R	14.8.07	5A	9. CEM II/A-LL 42,5 R (w/b 0.42)	Rapid-cem.; w/b=0,42; i=4-5,5%	0,10	104,2	101,7	103,0
10	VTT	20.8.07	6A	10. CEM I 52,5 R (w/b 0.42)	Pika-cem.; w/b=0,42; i=4-5,5%	0,06	105,5	101,4	103,4
11	VTT	11.9.07	7A	11. CEM II/A-LL 42,5 R & SLG (w/b 0.42)	Rapid+BFS 50%; w/b=0,42; I=4-5,5%	0,09	101,6	101,3	101,4
12	R	6.9.07	8A	12. CEM II/A-LL 42,5 R & FA (w/b 0.45)	Rapid-cem.+FA; w/b=0,42; i=4-5,5%	0,13	102,5	101,4	102,0
13	VTT	30.8.07	3Ba	13. CEM II/A-M(S-LL) 42,5 N (w/b 0.42, air 2.6 %)	Yleis-cem.; w/b=0,42; i=1-2% (no air entr.)	0,20	101,9	101,9	101,9
14	VTT	3.9.07	3Bb	14. CEM II/A-M(S-LL) 42,5 N (w/b 0.42, air 4.5 %)	Yleis-cem.; w/b=0,42; i=3-4%	0,24	102,1	101,6	101,8
15	VTT	3.9.07	3Bc	15. CEM II/A-M(S-LL) 42,5 N (w/b 0.42, air 5.3 %)	Yleis-cem.; w/b=0,42; i=5-6%	0,17	102,1	101,9	102,0
16	VTT	10.9.07	3Bc2	16. CEM II/A-M(S-LL) 42,5 N (w/b 0.42, air 7.0 %)	Yleis-cem.; w/b=0,42; i=6-7%	0,10	103,2	102,0	102,6
17	VTT	4.9.07	3Bd-SCC1	17. CEM II/A-M(S-LL) 42,5 N (w/b 0.42 air 3.4 %)	Yleis-cem.; w/b=0,42; i=3-4%; SCC	0,18	103,1	101,9	102,5
18	VTT	4.9.07	3Be-SCC2	18. CEM II/A-M(S-LL) 42,5 N (w/b 0.42, air 5.7 %)	Yleis-cem.; w/b=0,42; i=5-6%; SCC	0,18	103,9	102,8	103,4
19	VTT	13.9.07	1C	19. CEM II/B-S 42,5 N (w/b 0.47)	Perus-cem.; w/b=0,50; i=4-5,5%	0,04	101,9	100,1	101,0
20	R	23.8.07	3C	20. CEM II/A-M(S-LL) 42,5 N (w/b 0.49)	Yleis-cem.; w/b=0,50; i=4-5,5%	0,11	100,8	101,2	101,0
22	R	28.8.07	5C	22. CEM II/A-LL 42,5 R (w/b 0.51)	Rapid-cem.; w/b=0,50; i=4-5,5%	0,12	101,8	99,3	100,6
23	P	18.9.07	6C	23. CEM I 52,5 R (w/b 0.40)	Pika-cem.; w/b=0,40; i=4-5,5%	0,13	101,0	100,1	100,6
29	R	13.3.08	3Bf	29. CEM II/A-M(S-LL) 42,5 N (w/b 0.41, air 1.7 %)	Yleis-cem.; w/b=0,42;(no air-entr.)	(Casting 2008, 1st measurement 2009, see page 2)			
30	R	13.3.08	3Bg	30. CEM II/A-M(S-LL) 42,5 N (w/b 0.41, air 4.2 %)	Yleis-cem.; w/b=0,42;I=4 %				
31	R	13.3.08	3Bh	31. CEM II/A-M(S-LL) 42,5 N (w/b 0.41, air 6.8 %)	Yleis-cem.; w/b=0,42; i=6 %				
32	R	18.3.08	3Bi	32. CEM II/A-M(S-LL) 42,5 N (w/b 0.41, air 4.9 %)	Yleis-cem.; w/b=0,42;I=4 %				

Freeze-thaw with de-icing salt (frost-salt). Field testing results.

Num-ber	Casting place	Casting date	Short code	Cement type	Descriptive code	Frost-salt SPRING 2009 (2 WINTERS)				Frost-salt SPRING 2010 (3 WINTERS)			
						ΔV(autumn 07 - Spring 09 [%] (+ is increase)	Standard internal (RDMUPTT = (t0/tn)^2*100 Spring 09	RDMFF = (fn/f0)^2x100 [%] Spring 09	RDM(average (UP&FF) [%] Spring 09	ΔV(autumn 07 - Spring 10 [%] (+ is increase)	Standard internal (RDMUPTT = (t0/tn)^2*100 [%] Spring 10	RDMFF = (fn/f0)^2x100 [%] Spring 10	RDM(average (UP&FF) [%] Spring 10
6	VTT	12.9.07	1A	6. CEM II/B-S 42,5 N (w/b 0.41)	Perus-cem.; w/b=0,42; i=4-5,5%	-0,16	103,8	104,5	104,2	-0,06	104,1	105,6	104,8
7	R	16.8.07	2A	7. CEM I 42,5 N - SR (w/b 0.42)	SR-cem.; w/b=0,42; i=4-5,5%	-0,21	104,0	104,5	104,2	-0,21	102,5	104,9	103,7
8	R	14.8.07	3A	8. CEM II/A-M(S-LL) 42,5 N (w/b 0.42)	Yleis-cem.; w/b=0,42; i=4-5,5%	-0,11	106,5	105,9	106,2	-0,03	104,4	107,2	105,8
9	R	14.8.07	5A	9. CEM II/A-LL 42,5 R (w/b 0.42)	Rapid-cem.; w/b=0,42; i=4-5,5%	-0,14	104,4	105,5	105,0	-0,11	105,9	107,2	106,6
10	VTT	20.8.07	6A	10. CEM I 52,5 R (w/b 0.42)	Pika-cem.; w/b=0,42; i=4-5,5%	-0,18	106,6	105,0	105,8	-0,09	106,8	105,5	106,2
11	VTT	11.9.07	7A	11. CEM II/A-LL 42,5 R & SLG (w/b 0.42)	Rapid+BFS 50%; w/b=0,42; I=4-5,5%	-0,15	103,3	103,0	103,2	-0,11	103,9	104,3	104,1
12	R	6.9.07	8A	12. CEM II/A-LL 42,5 R & FA (w/b 0.45)	Rapid-cem.+FA; w/b=0,42; i=4-5,5%	-0,14	103,6	105,0	104,3	-0,08	104,2	105,5	104,9
13	VTT	30.8.07	3Ba	13. CEM II/A-M(S-LL) 42,5 N (w/b 0.42, air 2.6 %)	Yleis-cem.; w/b=0,42; i=1-2% (no air entr.)	-0,06	103,2	106,4	104,8	0,07	104,0	106,3	105,2
14	VTT	3.9.07	3Bb	14. CEM II/A-M(S-LL) 42,5 N (w/b 0.42, air 4.5 %)	Yleis-cem.; w/b=0,42; i=3-4%	-0,03	103,2	106,0	104,6	0,02	103,4	106,7	105,1
15	VTT	3.9.07	3Bc	15. CEM II/A-M(S-LL) 42,5 N (w/b 0.42, air 5.3 %)	Yleis-cem.; w/b=0,42; i=5-6%	-0,02	104,5	105,4	104,9	0,04	100,7	106,5	103,6
16	VTT	10.9.07	3Bc2	16. CEM II/A-M(S-LL) 42,5 N (w/b 0.42, air 7.0 %)	Yleis-cem.; w/b=0,42; i=6-7%	-0,16	106,0	106,1	106,0	-0,09	103,3	107,3	105,3
17	VTT	4.9.07	3Bd-SCC1	17. CEM II/A-M(S-LL) 42,5 N (w/b 0.42 air 3.4 %)	Yleis-cem.; w/b=0,42; i=3-4%; SCC	-0,14	105,7	105,6	105,6	-0,02	105,4	107,0	106,2
18	VTT	4.9.07	3Be-SCC2	18. CEM II/A-M(S-LL) 42,5 N (w/b 0.42, air 5.7 %)	Yleis-cem.; w/b=0,42; i=5-6%; SCC	-0,16	104,6	106,5	105,6	-0,04	104,2	108,1	106,2
19	VTT	13.9.07	1C	19. CEM II/B-S 42,5 N (w/b 0.47)	Perus-cem.; w/b=0,50; i=4-5,5%	-0,25	103,6	103,9	103,7	-0,14	104,2	105,2	104,7
20	R	23.8.07	3C	20. CEM II/A-M(S-LL) 42,5 N (w/b 0.49)	Yleis-cem.; w/b=0,50; i=4-5,5%	-0,26	104,4	104,0	104,2	-0,10	101,6	105,4	103,5
22	R	28.8.07	5C	22. CEM II/A-LL 42,5 R (w/b 0.51)	Rapid-cem.; w/b=0,50; i=4-5,5%	-0,22	101,0	102,5	101,8	-0,05	101,0	103,3	102,2
23	P	18.9.07	6C	23. CEM I 52,5 R (w/b 0.40)	Pika-cem.; w/b=0,40; i=4-5,5%	-0,12	104,1	102,1	103,1	0,00	104,8	104,2	104,5

Num-ber	Casting place	Casting date	Short code	Cement type	Descriptive code	Frost-salt SPRING 2009 (1 WINTER)				Frost-salt SPRING 2010 (2 WINTERS)			
						ΔV(Spring 08 - Spring 09 [%] (+ is increase)	Standard internal (RDMUPTT = (t0/tn)^2*100 Spring 09	RDMFF = (fn/f0)^2x100 [%] Spring 09	RDM(average (UP&FF) [%] Spring 09	ΔV(Spring 08 - Spring 10 [%] (+ is increase)	Standard internal (RDMUPTT = (t0/tn)^2*100 [%] Spring 10	RDMFF = (fn/f0)^2x100 [%] Spring 10	RDM(average (UP&FF) [%] Spring 10
29	R	13.3.08	3Bf	29. CEM II/A-M(S-LL) 42,5 N (w/b 0.41, air 1.7 %)	Yleis-cem.; w/b=0,42;(no air-entr.)	-0,23	105,2	103,3	104,2	-0,05	105,7	105,4	105,5
30	R	13.3.08	3Bg	30. CEM II/A-M(S-LL) 42,5 N (w/b 0.41, air 4.2 %)	Yleis-cem.; w/b=0,42;I=4 %	-0,28	110,0	104,4	107,2	-0,15	107,7	105,7	106,7
31	R	13.3.08	3Bh	31. CEM II/A-M(S-LL) 42,5 N (w/b 0.41, air 6.8 %)	Yleis-cem.; w/b=0,42; i=6 %	-0,30	106,7	104,8	105,8	-0,11	105,2	107,0	106,1
32	R	18.3.08	3Bi	32. CEM II/A-M(S-LL) 42,5 N (w/b 0.41, air 4.9 %)	Yleis-cem.; w/b=0,42;I=4 %	-0,30	103,7	104,1	103,9	-0,18	104,2	106,0	105,1

VTT Document Management System (DOHA)

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Customer / extranet user registration and how to start

1. Registration process starts when Your project manager in VTT asks VTT IT support to create a New Extranet User
2. When a New Extranet User is created Doha e-mails ” VTT Document Management System Terms of Use” to New Extranet User
3. Customer / extranet user accepts Terms of Use by e-mailing "I agree" mail to Your project manager in VTT
4. When a customer / extranet user sends "I agree" mail he accepts that his name, company etc. can be seen by any other user in VTT Doha system or by any other user in his projects in Doha
5. Your project manager in VTT e-mails to extranet user **one user id and two passwords** (extranet login password and doha login password) and www link to Doha http://www.vtt.fi/project
6. Extranet User logs in through VTT firewall with extranet password and in Doha system with Documentum password (= doha login password)
7. Read carefully the instructions "How to Start" and make necessary installations and settings before first login.http://www.vtt.fi/project/how_to_start.htm

Example mail:

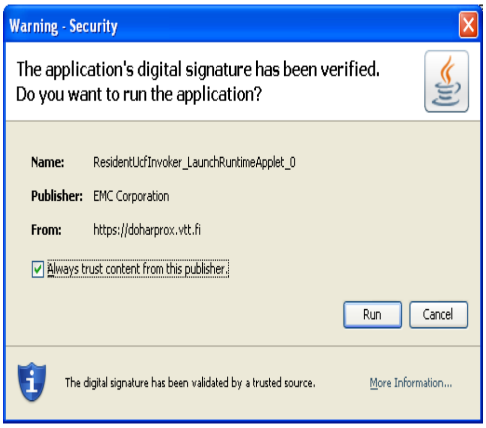
You have been added to VTT Project Document project (VTT-TESTI,seppo.sorsa,KT-admin,24012008)
Browse yourself to http://www.vtt.fi/project and read the help pages.

Your first user id and password for extranet login is:
user id: exttesttepp, password: VX56qrs5

Your Documentum login id is:
user id: exttesttepp, password: nhN445iW

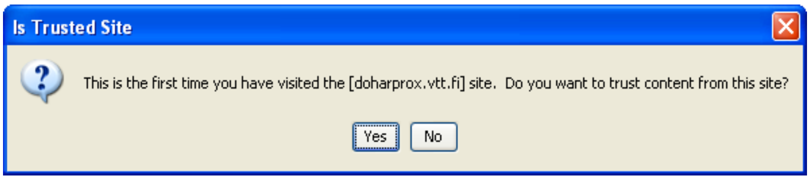
When Extranet-user logs in Doha for the first time the systen shows to him Warning – Security window.

Choose ”Always trust content from this publisher” and then **Run.** If You choose ”Cancel”, You can still check in the system but not all actions are in use.



When You make edit, export- import or check-out actions for the first time. Choose ”Yes”. After that You can use the system normally

If You Choose ”No” then You can’t use import, edit, export, check-out or checkin actions



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