Concrete carbonation: experience from the field tests

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Content

- Background
- Field stations
- Carbonation results
  - Effect of air content
  - Effect of w/b ratio
  - Effect of different exposure site
  - Effect of SCM's (fly ash, blast furnace slag)
- Summary

Background

- The purpose of field testing is to assess the durability performance of concrete materials in authentic climate conditions
- Climate conditions are difficult to assess and simulate effectively in standardized laboratory tests where individual condition factors are typically altered one at a time
  - Moisture
  - Temperature
  - Solar radiation
  - Salt exposure
  - Carbon dioxide
  - Ageing of concrete

https://ar-ar.facebook.com/100054645301591/posts/640137242993527/

https://hengitysliitto.videosync.fi/ilmastonmuutos-110520?seek=395

https://www.is.fi/autot/art-2000001938377.html

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Background

- Old durability research projects
  - 1998-2001 Nordic BTB (Durability of de-iced bridge concrete)
  - 2001-2004 EU CONLIFE (High-performance concrete)
  - 2001-2004 EU LIFECON (Life Cycle Management & Sustainability)
  - 2002-2004 Finnish YMP (Environmentally-friendly and Durable concretes)
  - 2007-2008 Finnish DURAFIELD (Concrete durability field testing)
  - 2008-2011 DURAINT (Effect of interacted deterioration parameters on service life of concrete structures in cold environments)
  - 2012-2015 CSLA (Chloride freeze-thaw interaction)
  - 2018-2022 EXACT (Effect of excess air entrainment on behaviour of reinforced concrete structure
  - 2007-2024 BTT (Demanding concrete structures research)

Field station in Espoo

- Established 2002
  - New location 2018 (due to Espoo city construction)
- Freeze/thaw attack without de-icing agents
  - XF3 high water saturation, without de-icing agent
- Corrosion induced by carbonation
  - XC3 moderate humidity
  - XC4 cyclic wet and dry
- Examples of concretes in field
  - YMPYST- project test series (XC4)
    - K35 and K45
    - Fly ash, furnace slag
  - Duraint-project test series (XC3)
    - 23 concretes
    - w/c = 0.36–0.6

https://www.mapcustomizer.com/

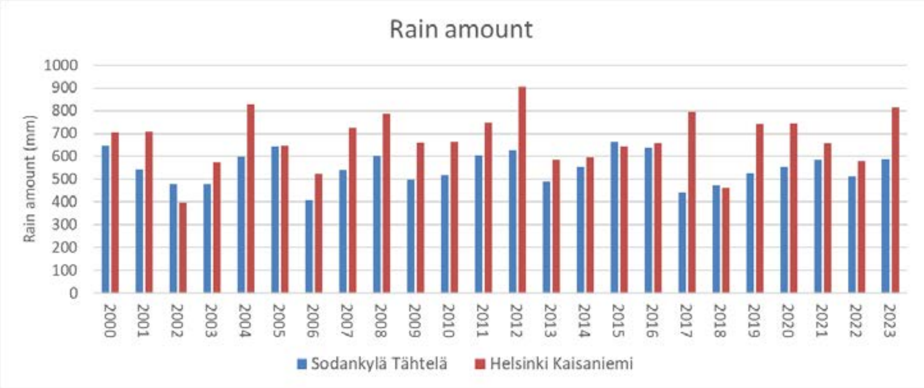
Kotka

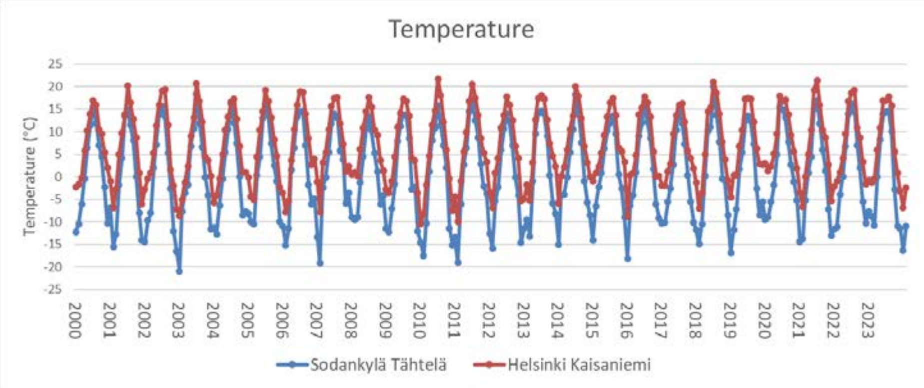
- Established 2008
- Freeze/thaw attack with de-icing agents
  - XF4 high water saturation, with de-icing agent or sea water
- Corrosion induced by chlorides other than from sea water
  - XD3 cyclic wet and dry
- Examples of concretes in field
  - Duraint (w/c 0.42, air entrained bridge concretes)
  - Customers own samples for material development

Sodankylä

- Established 2001
- Freeze/thaw attack without de-icing agents
  - XF3 high water saturation, without de-icing agent
- Corrosion induced by carbonation
  - XC4 cyclic wet and dry
- Examples of concretes in field
  - CONLIFE (HPC-betonit)
  - YMPYST (same concretes as in Espoo field)

Comparison between field exposures





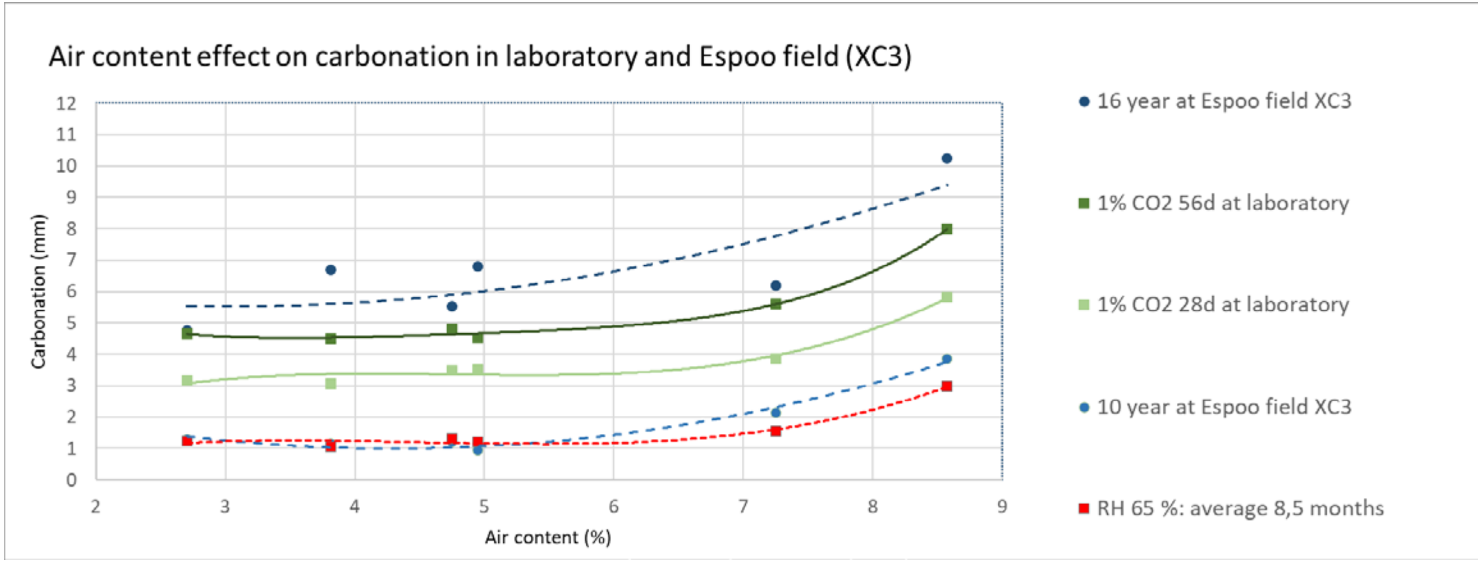
Exposure / information	(symbol)	Kotka HW7	Espoo	Sodankylä	Borås
Freeze/thaw attack, high water saturation, without de-icing agent	XF3		x	x	-
Freeze/thaw attack, high water saturation, with de-icing agent or sea water sea water	XF4	x	-	-	x
Corrosion induced by carbonation, moderate humidity	XC3		x		-
Corrosion induced by carbonation, moderate Cyclic wet and dry	XC4	-	x	x	-
Corrosion induced by chlorides, cyclic wet and dry	XD3	x	-	-	x
Height from the seal level	(m)	20	20	179	-

Carbonation results (lab & field)

Carbonation results (Espoo, XC3 moderate humidity)

Effect of air content

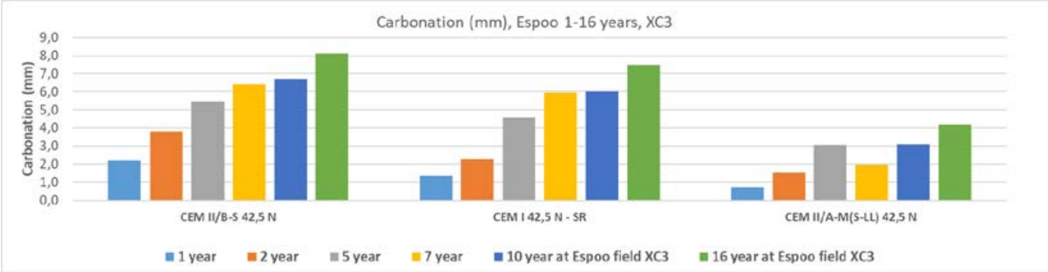
- CEM II/A-M(S-LL) 42.5 N (Yleissementti)
- Air content vary from 2.7 % to 8.6 %



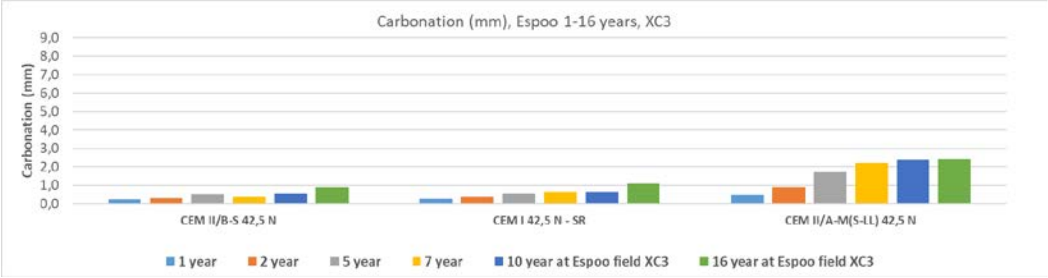
Carbonation results (field)

Carbonation results (Espoo, XC3 moderate humidity)
Effect of w/b ratio

Perus-cem.; w/b=0,42; i=4-5,5%	CEM II/B-S 42,5 N
SR-cem.; w/b=0,42; i=4-5,5%	CEM I 42,5 N - SR
Yleis-cem.; w/b=0,42; i=4-5,5%	CEM II/A-M(S-LL) 42,5 N



w/b ratio ~0.6



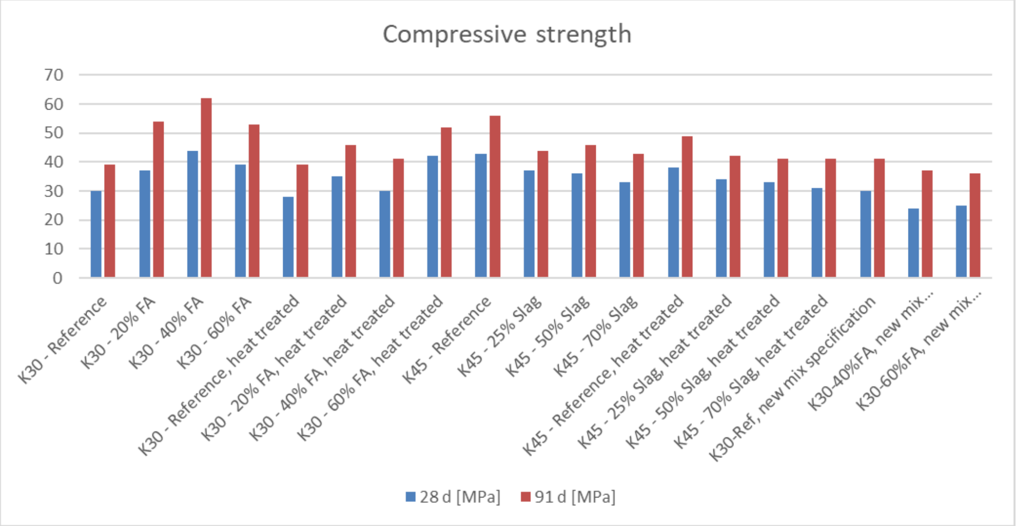
w/b ratio ~0.42

Effect of different exposure sites
Carbonation results (YMPYST Espoo & Sodankylä)
XC4 cyclic wet and dry

- Different exposure (temperature, precipitation, humidity)
- Two strength classes in YMPYST project
- K30- selected for ready-mix concrete industry
  - The fly ash amounts used were 20 %, 40 %, and 60 %
- K45- selected for precast concrete
  - Granulated blast furnace slag 25 %, 50 %, and 70 %
- Air entrained (6% target)
  - All 8 mixes tested after both normal curing and heat-treated curing.
  - Total of 19 different concretes (2x8, +3)

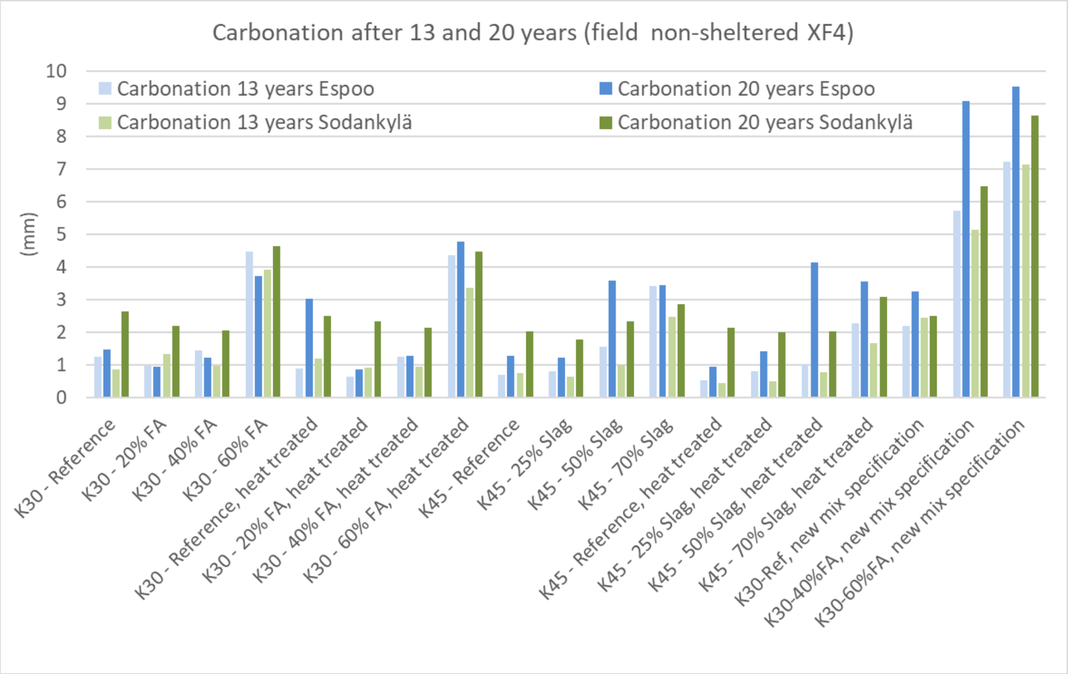
Effect of different exposure
Carbonation results (YMPYST Espoo & Sodankylä)
XC4 cyclic wet and dry (w/b ratio 0.5-0.6)

Descriptive code	Cement type		28 d [MPa]	91 d [MPa]
K30 - Reference	Rapid CEM	CEM II/A-LL 42,5 R	30	39
K30 - 20% FA	Rapid CEM	CEM II/A-LL 42,5 R	37	54
K30 - 40% FA	Rapid CEM	CEM II/A-LL 42,5 R	44	62
K30 - 60% FA	Rapid CEM	CEM II/A-LL 42,5 R	39	53
K30 - Reference, heat treated	Rapid CEM	CEM II/A-LL 42,5 R	28	39
K30 - 20% FA, heat treated	Rapid CEM	CEM II/A-LL 42,5 R	35	46
K30 - 40% FA, heat treated	Rapid CEM	CEM II/A-LL 42,5 R	30	41
K30 - 60% FA, heat treated	Rapid CEM	CEM II/A-LL 42,5 R	42	52
K45 - Reference	Pikasementti	CEM I 52,5 R	43	56
K45 - 25% Slag	Pikasementti	CEM I 52,5 R	37	44
K45 - 50% Slag	Pikasementti	CEM I 52,5 R	36	46
K45 - 70% Slag	Pikasementti	CEM I 52,5 R	33	43
K45 - Reference, heat treated	Pikasementti	CEM I 52,5 R	38	49
K45 - 25% Slag, heat treated	Pikasementti	CEM I 52,5 R	34	42
K45 - 50% Slag, heat treated	Pikasementti	CEM I 52,5 R	33	41
K45 - 70% Slag, heat treated	Pikasementti	CEM I 52,5 R	31	41
K30-Ref, new mix specification	Rapid CEM	CEM II/A-LL 42,5 R	30	41
K30-40%FA, new mix specification	Rapid CEM	CEM II/A-LL 42,5 R	24	37
K30-60%FA, new mix specification	Rapid CEM	CEM II/A-LL 42,5 R	25	36



Effect of different exposure

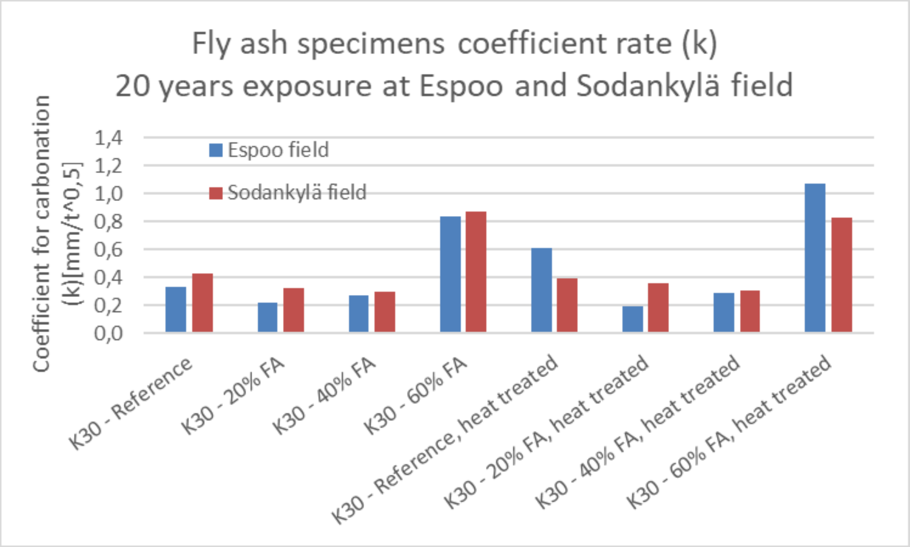
Carbonation results (YMPYST Espoo & Sodankylä)
XC4 cyclic wet and dry

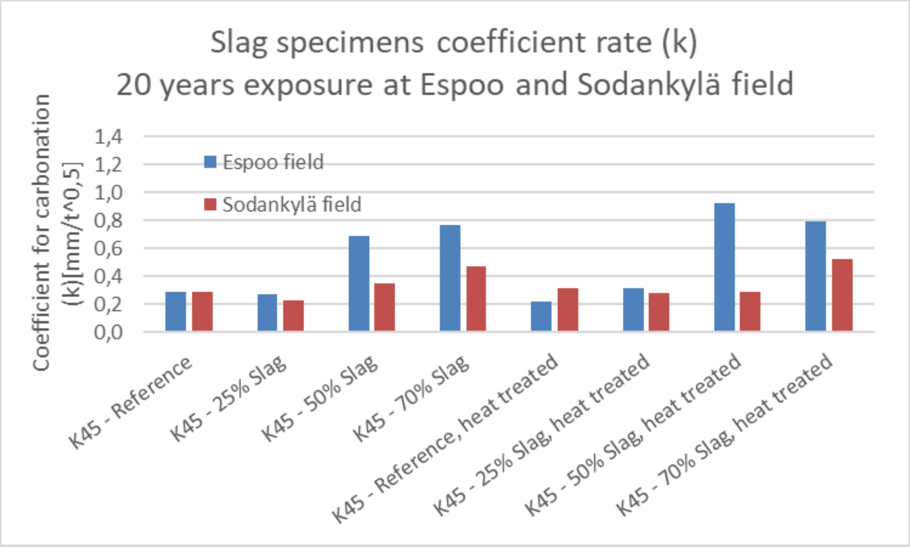


Effect of different exposure and SCM's

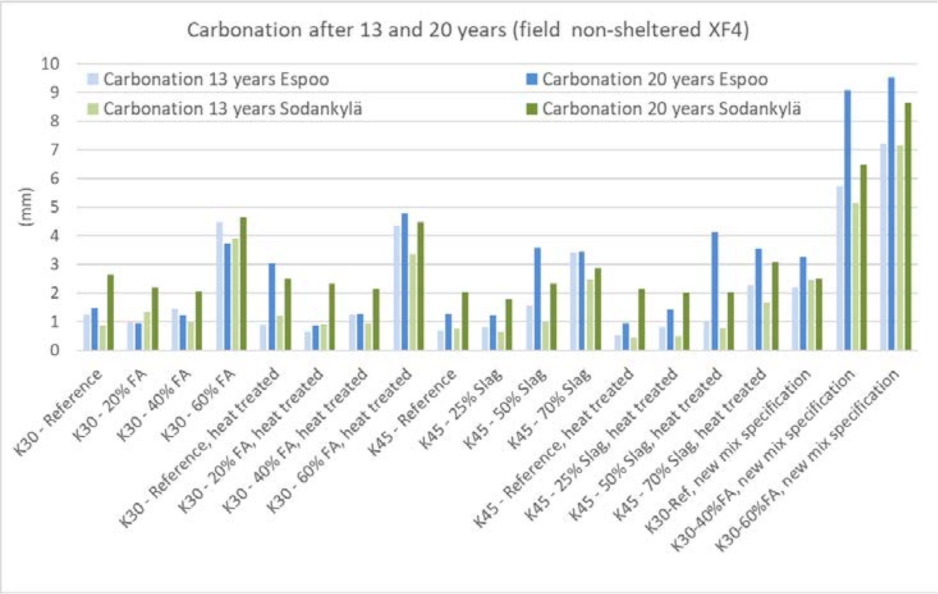
Carbonation results (YMPYST Espoo & Sodankylä)

XC4 cyclic wet and dry





Effect of different exposure and SCM’s
Carbonation results (YMPYST Espoo & Sodankylä)
XC4 cyclic wet and dry



$k = x/\sqrt{t}$

Residual service life in 2024 with 25mm concrete cover (years)			
Carbonation in 20 years	Coefficient rate	Total service life	Residual service life in 2024
(mm)	k = x/√t	t=(25mm/k)^2	t-(2024-2003)
5	1,12	500	**479**
10	2,24	125	**104**

Exposure class	Minimum value of concrete cover for a working life of 50 years [mm]		Minimum value of concrete cover for a working life of 100 years [mm]	
	Reinforcing steel	Prestressing steel	Reinforcement	Prestressing steel
X0	10	10	10	10
XC1	10	20	10	20
XC2	20	30	25	35
XC3, XC4	25	35	30	40
XS1, XD1	30	40	35	45
XS2, XD2	35	45	40	50
XS3, XD3	40	50	45	55

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Summary

- Carbonation is slow process especially with good quality concrete
- With high dosages of SCM's carbonation is higher

- Field data can be used in several ways
  - as a reference to improve accelerated laboratory performance tests
  - development of novel laboratory tests
  - to calibrate service life models

- Suggestions for future research
  - To predict which binders could be used after >10 years and expose those at field stations now

Thank you!

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-Finnish Construction Industries (RT)
-Finnish Transport Infrastructure Agency (Väylä)
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-Finnsementti Oy
-City of Helsinki, Espoo, Vantaa, Tampere, Turku

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