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Testing of Formtex CPF liner for protection against early chloride ingress into concrete containing fly ash

We hereby present the results of the above-mentioned assignment. This activity was performed according to our agreement in the Order Confirmation, dated 24 April 2016.

Background
Concrete with binders containing fly ash is often used for infrastructure constructions where low permeability is needed to give a good resistance against aggressive environmental actions, e.g. chloride exposure. However, the use of fly ash as supplementary cementitious material in concrete has the disadvantage that the development of a dense microstructure typically is slower than for other binder types. This results in a concrete with low resistance against chloride ingress at early age but it will develop a high resistance during the first 6 to 12 months. The occurrence of an initial high permeability is particularly true when fly ash is combined with low alkali SR cements as is customary for Danish infrastructure constructions.

It would be very attractive for building owners and contractors if the use of Formtex CPF liner can give a sufficient reduction of the initial permeability of fly ash concrete to prevent a large early chloride ingress. In this case it would prolong the service life which is of interest for the building owners, and it would facilitate earlier exposure to chlorides which is interesting for contactors to shorten the building phase.

Scope
The scope of this assignment is to investigate whether use of Formtex CPF liner can reduce the early chloride ingress into concrete for infrastructure constructions.

Investigations
This investigation of the effect of CPF liner on early chloride ingress includes the following activities:

- Casting of two 0.2 x 0.5 x 1.0 m blocks with identical concrete
- Dry curing of one block and wet curing the other block
- Testing of fresh and hardened concrete properties
- Exposure of both blocks to 2% Cl solution
- Measurement of chloride ingress into exposed blocks

The time schedule for these activities are available in Appendix 1.

Casting of concrete blocks
The concrete mix design for the two blocks are based on a binder composition with 75% CEM I and 25% PFA (pulverized fly ash) and a w/c-ratio of 0.40. Details of the concrete mix design are available in Appendix 2.

The concrete was mixed in a 250 l industrial counter-current mixer (Photo 1) and poured into a mould with plywood on one side and CPF liner on the other side (Photo 2). The mould was separated in the middle with a vertical plywood plate in order to cast two equal concrete blocks measuring 0.2 x 0.5 x 1.0 m each. A copper/constantan thermocouple was inserted to monitor the temperature and the mould was covered with thick plastic.

Supplementary Ø100 x 200 mm concrete cylinders were cast for compressive strength tests.

Curing
The two concrete blocks were demoulded at an age of 8 maturity-days (Photo 3 and photo 4). The bottom part of each block measuring approx. 0.2 x 0.2 x 0.5 m was cut off and sealed in plastic at 20°C to be used later for chloride migrations tests (Photo 5). One block (block I) was cured immersed in tap water and the other block (block II) was cured in dry laboratory climate (Photo 6). Both blocks were cured until an age of 31 maturity-days. The temperature and relative humidity for the dry curing is available in Appendix 3. The concrete temperature and corresponding maturity is available in Appendix 4.

The concrete cylinders were demoulded after one day and cured in a water bath at 20°C until testing.

Testing of fresh and hardened concrete properties
The measured fresh concrete properties were consistency acc. to EN 12350-2, density acc. to EN 12350-6 and air content acc. to EN 12350-7.

The measured hardened concrete properties were compressive strength of cast cylinders acc. to EN 12390-3 at 7 and 28 days after water curing and chloride migration coefficient acc. to NT BUILD 492 at 37 and 182 maturity days after sealed curing in plastic. The chloride migration coefficient was measured on samples from three different situations: a) Surface cast against plywood formwork, b) Bulk concrete from internal position, and c) Surface cast against CPF liner.

Chloride exposure
At the age of 31 maturity days both blocks were submerged in 2% chloride solution made by dissolving NaCl in demineralized water. The temperature of the concrete during exposure was continuously logged (Appendix 4).

Chloride ingress
Concrete cores were drilled after chloride exposure in the laboratory for 76 maturity days and the chloride ingress was measured by determination of chloride profiles acc. to the procedures for profile grinding and chloride analysis described in NT BUILD 443.

Discussion of test results
Fresh and hardened concrete properties
The measured fresh concrete properties are corresponding to results from earlier test with the same mix design reported on the Concrete Expert Centre homepage (www.concreteexpertcentre.dk). The measured compressive strength of 33 MPa at 7 days and 57 MPa at 28 days are higher than earlier data from the Concrete Expert Centre homepage (30 MPa and 44 MPa, respectively).

Chloride migration coefficient
The measured chloride migration coefficient values (Table 1) show that the average CMC-value for samples cast against CPF liner is 23% lower than for the samples cast against plywood formwork after 37 maturity days and it is 32% lower after 182 maturity days. The CMC-values for the bulk concrete after 37 maturity days are at the same level as for the samples cast against plywood formwork. After 182 maturity days are the CMC-values for the samples cast against CPF liner approx. 1/3 of the CMC-values for bulk concrete. The corresponding CMC-values for samples cast against plywood formwork are approx. 1/2 of the CMC-values for bulk concrete.

Chloride migration coefficient (CMC) D_{nssm} [x10^{-12} m^2/s] at 37 maturity days	Plywood	Bulk	CPF liner
Core 1	8.7	8.4	7.5
Core 2	9.5	9.2	7.3
Core 3	9.3	10.2	6.4
Average	9.2	9.3	7.1
Chloride migration coefficient (CMC) D_{nssm} [x10^{-12} m^2/s] at 182 maturity days	Plywood	Bulk	CPF liner
Core 1	0.89	1.7	0.55
Core 2	0.72	1.3	0.49
Core 3	0.77	1.5	0.58
Average	0.79	1.5	0.54

Table 1: Chloride migration coefficients acc. to NT BUILD 492 at 37 and 182 maturity days.

Chloride ingress
The measured chloride profiles after submersion in 2% Cl solution for 76 maturity days (Fig. 1 and Fig. 2) show that the chloride ingress is less in samples cast against CPR liner compared to sample cast against plywood formwork. This is true both for wet cured and dry cured samples. The dry cured sample cast against plywood formwork has a very low chloride content in the outmost layer and also rather low chloride contents in the following layers compared to the wet cured sample cast against plywood formwork.

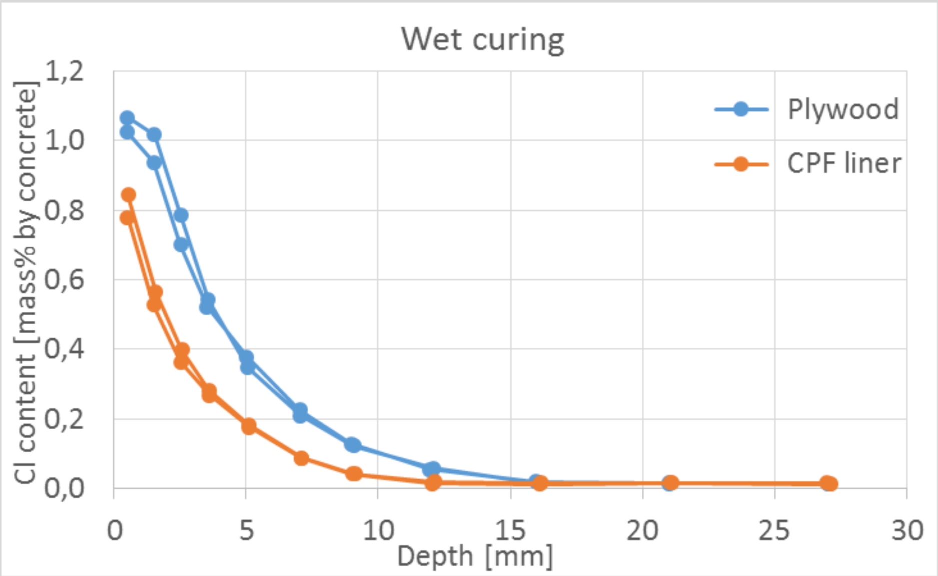

Fig. 1: Chloride ingress into wet cured samples after submersion in 2% Cl solution for 76 maturity days.

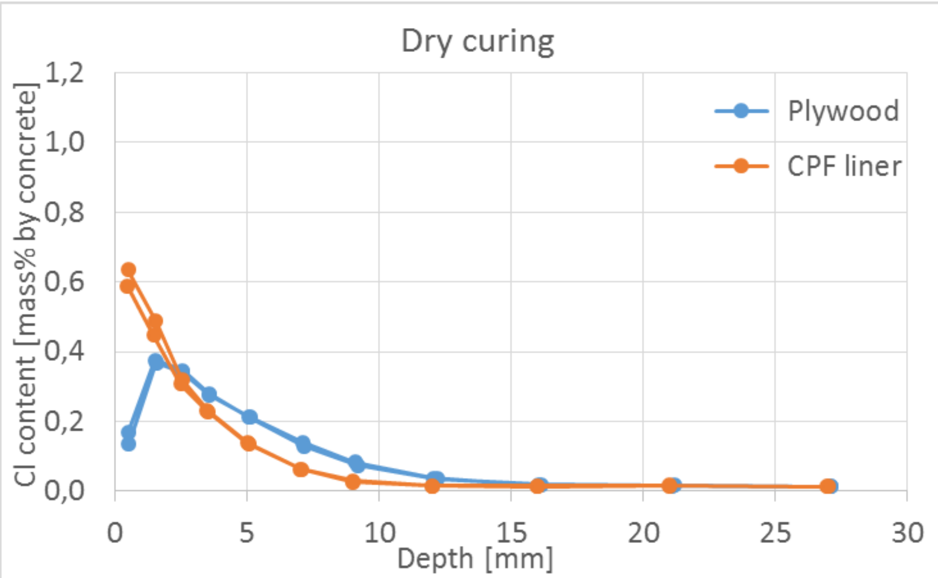

Fig. 2: Chloride ingress into dry cured samples after submersion in 2% Cl solution for 76 maturity days.

This phenomenon is most likely caused by carbonation of the outmost concrete during the dry curing period. The chloride binding capacity is drastically reduced when concrete carbonates. The dry cured samples cast against CPF liner do not show the same effect, although the chloride content are generally somewhat lower than for wet cured samples cast against CPF liner. The explanation for this is most likely due to a more dense concrete in the outer layer as an effect of the CPF liner. This dense concrete is less prone to carbonation and drying out during the dry curing period.

The chloride penetration parameters for the chloride profiles have been estimated (Table 2) acc. to the principles in NT BUILD 443. These values have to be used with caution as they are only representing the actual exposure regime and exposure time. These values cannot be regarding as constants. The curve-fits on the two chloride profiles determined for the wet cured samples cast against plywood formwork are not representing the part of the profile between 7 mm and 12 mm depth very well. The measured chloride contents are underestimated by the curve-fits in this region, which results in too low values for D_e and $K_{0.05}$.

Chloride penetration parameters	C_s mass% of CO	C_i mass% of CO	D_e $x10^{-12}$ m^2/s	$K_{0.05}$ mm/year^{½}
Wet curing - Plywood - a	1.335	0.013	1.7	23
Wet curing - Plywood - b	1.160	0.013	2.1	24
Wet curing - CPF liner - a	0.776	0.013	1.3	18
Wet curing - CPF liner - b	0.702	0.013	1.4	18
Dry curing - Plywood - a	0.478	0.013	3.2	25
Dry curing - Plywood - b	0.467	0.013	3.5	26
Dry curing - CPF liner - a	0.697	0.013	1.1	16
Dry curing - CPF liner - b	0.615	0.013	1.2	16

Table 2: Chloride penetration parameters estimated by curve-fitting on chloride profiles acc. to the principles in NT BUILD 443.

The actual penetration depths of 0.05% chloride content (Table 3) have been estimated by linear interpolation on the measured chloride profiles. These values show that the penetration depths are higher in the wet cured samples than in the corresponding dry cured samples. At this time there is no explanation for that as one might expect the opposite due to an additional contribution from capillary suction in the dry cured samples when they are submerged in the chloride solution. Further investigations by e.g. petrographic analysis could clarify this.

Penetration depth of 0.05% Cl $x_{0.05}$ [mm] after 76 maturity days exposure	Plywood	CPF liner
Wet curing - a	12.9	8.7
Wet curing - b	12.5	8.7
Dry curing - a	11.1	7.8
Dry curing - b	11.2	7.7

Table 3: Chloride penetration depth of 0.05 %Cl by concrete estimated by linear interpolation on chloride profiles.

The effect of the CPF liner is an average reduction of penetration depth of 0.05 %Cl from 12.7 mm to 8.7 mm (31% reduction) for wet cured samples and from 11.2 mm to 7.8 mm (30% reduction) for dry cured samples.

Conclusions
The effect of CPF liner on early chloride penetration into concrete with high fly ash content has been investigated by a comparative study with plywood formwork as reference.

The main conclusion is that use of formwork with CPF liner will significantly reduce the chloride ingress into concrete compared to formwork of plywood, and thereby giving a good potential for extending the service life of chloride exposed concrete structures.

After submersion of concrete samples with an age of 31 maturity days in 2 %Cl solution for 76 maturity days the penetration depth of 0.05 %Cl content was reduced approx. 30% for both wet cured and dry cured samples. The average penetration was reduced from 12.7 mm to 8.7 mm in wet cured samples and from 11.2 mm to 7.8 mm in dry cured samples.

The better resistance against chloride ingress for concrete cast against CPF liner was documented by measurement of an average chloride migration coefficient of 7.1×10^{-12} m^2/s at 37 maturity days compared to 9.2×10^{-12} m^2/s for concrete cast against plywood formwork and 0.54×10^{-12} m^2/s at 182 maturity days compared to 0.79×10^{-12} m^2/s. This corresponds to a 23% reduction after 37 maturity days and a 32% reduction after 182 days.

CMC-values for the same concrete mix design at 28 maturity days are reported on the Concrete Expert Centre homepage to be more than 27×10^{-12} m^2/s. If comparison was made at this maturity age or at even younger maturity the improvement in CMC-value for concrete cast against CPF liner would probably be even better compared to concrete cast against plywood formwork.

Caution should be taken in predicting service life from the results of the present investigation without knowing more details about the development of time-dependent chloride resistance for the actual concrete mix design.

Yours Sincerely,
Danish Technological Institute

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Appendix 1: Time schedule

Date	**Maturity days**	**Activity**
2016-06-15	0	Casting of two concrete blocks
		Curing of blocks in formwork - start
2016-06-21	8	Curing of blocks in formwork - end
		Demoulding
		Block I - Curing in water - start
		Block II - Curing in air - start
2016-07-12	31	Block I - Curing in water - end
		Block II - Curing in air - end
		Block I & II – Submersion in 2% Cl - start
2016-09-21	107	Block I & II – Submersion in 2% Cl - end
		Block I & II – Core drilling for chloride profiles

Time schedule and activities for the two concrete blocks exposed in 2% Cl solution

Appendix 2: Mix design and concrete properties

Mix Design

Constituent	Unit	Target	Achieved
Low alkali SR cement (CEM I 42,5 N)	kg/m^3	300	298
Pulverized Fly Ash	kg/m^3	100	99
RN 0/4 mm	kg/m^3	632	630
Rønne 4/8 mm	kg/m^3	367	364
Rønne 8/16 mm	kg/m^3	271	271
Rønne 16/22 mm	kg/m^3	540	539
Amex SB 22	kg/m^3	2.00	1.99
Glenium SKY 631	kg/m^3	2.25	3.24
Added water	l/m^3	135.6	135.0
Air	%	5.0	5.2
Effective water	l/m^3	140	139.4
Effective w/c-ratio	-	0.400	0.401

Concrete mix design – target and achieved values

Fresh concrete properties

Slump: 140 mm
Air content: 5.2 %
Density: 2365 kg/m^3

Hardened concrete – compressive strength & density from cast cylinders

Compressive strength - 7 days					Date of testing: 2016-06-22		
Specimen	Diameter [mm]	Height [mm]	Weight [g]	Load [kN]	Failure mode	Density [kg/m³]	Strength [MPa]
1	100.0	200.0	3736.9	262.0	OK	2380	33.4
2	100.0	200.0	3727.3	252.0	OK	2370	32.1
3	100.0	200.0	3734.9	270.0	OK	2380	34.4
Mean						2380	33.3
Standard deviation						6	1.1

Compressive strength and density – 7 days

Compressive strength - 28 days					Date of testing: 2016-07-13		
Specimen	Diameter [mm]	Height [mm]	Weight [g]	Load [kN]	Failure mode	Density [kg/m³]	Strength [MPa]
1	100.0	200.0	3729.8	430.0	OK	2370	54.7
2	100.0	200.0	3743.4	451.6	OK	2380	57.5
3	100.0	200.0	3743.2	453.2	OK	2380	57.7
Mean						2380	56.7
Standard deviation						6	1.6

Compressive strength and density – 28 days

Hardened concrete – chloride migration coefficient from concrete cores

Sample		**1A plywood**	**1B bulk**	**1C CPF**
Sample thickness [mm]		49.7	48.3	51.3
Current at 30V [mA]		39.4	45.6	37.5
Voltage [V]		35.0	35.0	35.0
Test duration [h]		24	24	24
Initial	current [mA]	46.3	53.8	44.0
	temperature [ºC]	20.3	20.3	20.3
Final	current [mA]	40.3	52.2	39.9
	temperature [ºC]	22.5	23.0	22.8
Penetration [mm]		22.3	20.8	19.4
		23.7	23.0	16.2
		23.1	24.1	18.4
		21.2	21.6	19.0
		21.8	21.4	18.9
		21.9	22.0	16.8
		19.9	20.0	21.2
Penetration, average [mm]		22.0	21.8	18.6
D_{nssm} [x10^{-12} m^2/s]		**8.7**	**8.4**	**7.5**

Core No. 1 – NT BUILD 492 – tested on 20.07.2016 (37 maturity days)

Sample		**2A plywood**	**2B bulk**	**2C CPF**
Thickness [mm]		50.9	50.1	49.3
Current at 30V [mA]		42.5	45.8	41.7
Voltage [V]		30.0	30.0	30.0
Test duration [h]		24	24	24
Start	current [mA]	42.5	45.8	41.7
	temperature [ºC]	21.8	21.8	21.8
End	current [mA]	37.2	44.6	35.2
	temperature [ºC]	22.1	22.3	22.1
Penetration [mm]		22.0	19.6	16.3
		19.5	19.5	15.2
		18.8	17.1	14.4
		20.2	19.1	14.9
		20.8	21.1	13.9
		20.2	21.3	18.6
		19.9	21.8	20.4
Penetration, average [mm]		20.2	19.9	16.2
D_{nssm} [x10^{-12} m^2/s]		**9.5**	**9.2**	**7.3**

Core No. 2 – NT BUILD 492 – tested on 20.07.2016 (37 maturity days)

Sample		**3A plywood**	**3B bulk**	**3C CPF**
Sample thickness [mm]		49.5	50.1	49.1
Current at 30V [mA]		46.0	44.3	38.5
Voltage [V]		30.0	30.0	30.0
Test duration [h]		24	24	24
Initial	current [mA]	46.0	44.3	38.5
	temperature [ºC]	21.9	21.9	21.9
Final	current [mA]	38.9	39.8	32.5
	temperature [ºC]	21.6	21.9	21.7
Penetration [mm]		17.6	17.8	14.5
		20.0	21.1	15.9
		21.0	19.2	15.2
		19.0	22.8	14.8
		21.6	21.7	13.7
		22.4	29.5	11.5
		21.4	22.1	15.7
Penetration, average [mm]		20.4	22.0	14.5
D_{nssm} [x10^{-12} m^2/s]		**9.3**	**10.2**	**6.4**

Core No. 3 – NT BUILD 492 – tested on 20.07.2016 (37 maturity days)

Sample		**4A plywood**	**5A plywood**	**6A plywood**
Sample thickness [mm]		50.3	49.4	50.6
Current at 30V [mA]		5.3	5.5	4.8
Voltage [V]		60.0	60.0	60.0
Test duration [h]		48	48	48
Initial	current [mA]	10.7	11.1	9.8
	temperature [ºC]	20.1	20.1	20.1
Final	current [mA]	10.2	10.3	9.2
	temperature [ºC]	21.4	21.5	21.4
Penetration [mm]		8.6	4.6	6.7
		8.5	5.2	5.9
		7.4	3.3	6.7
		7.6	7.1	5.8
		7.2	7.8	7.8
		9.2	9.8	8.0
		8.0	9.5	8.3
Penetration, average [mm]		8.1	6.8	7.0
D_{nssm} [x10^{-12} m^2/s]		**0.89**	**0.72**	**0.77**

Plywood samples – NT BUILD 492 – tested on 12.12.2016 (182 maturity days)

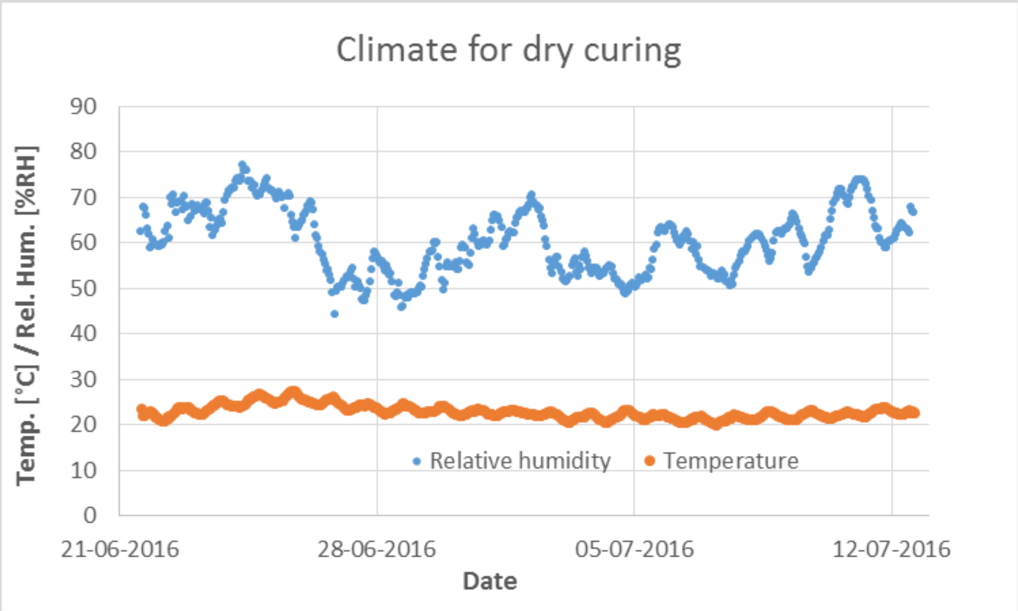
Sample		**4B bulk**	**5B bulk**	**6B bulk**
Sample thickness [mm]		50.9	51.2	49.8
Current at 30V [mA]		5.3	5.9	5.3
Voltage [V]		60.0	60.0	60.0
Test duration [h]		48	48	48
Initial	current [mA]	10.9	12.0	10.8
	temperature [ºC]	20.1	20.1	20.1
Final	current [mA]	11.3	12.7	11.0
	temperature [ºC]	22.2	22.2	21.9
Penetration [mm]		15.1	15.6	17.8
		14.0	9.9	15.6
		16.4	13.5	13.8
		15.9	10.2	12.0
		15.8	7.1	10.4
		13.8	12.6	12.5
		12.4	10.8	13.0
Penetration, average [mm]		14.8	11.4	13.6
D_{nssm} [x10^{-12} m^2/s]		**1.7**	**1.3**	**1.5**

Bulk samples – NT BUILD 492 – tested on 12.12.2016 (182 maturity days)

Sample		**4C CPF**	**5C CPF**	**6C CPF**
Sample thickness [mm]		49.8	49.4	50.7
Current at 30V [mA]		4.8	5.1	4.6
Voltage [V]		60.0	60.0	60.0
Test duration [h]		96	96	96
Initial	current [mA]	9.5	10.3	9.3
	temperature [ºC]	20.1	20.1	20.1
Final	current [mA]	8.4	9.0	8.1
	temperature [ºC]	20.9	21.0	20.9
Penetration [mm]		8.1	9.9	11.9
		9.4	11.1	9.2
		12.1	7.7	10.6
		11.3	8.7	10.6
		9.5	9.0	8.7
		9.5	10.2	11.0
		9.4	6.5	(20.8)*
Penetration, average [mm]		9.9	9.0	10.3
D_{nssm} [x10^{-12} m^2/s]		0.55	0.49	0.58

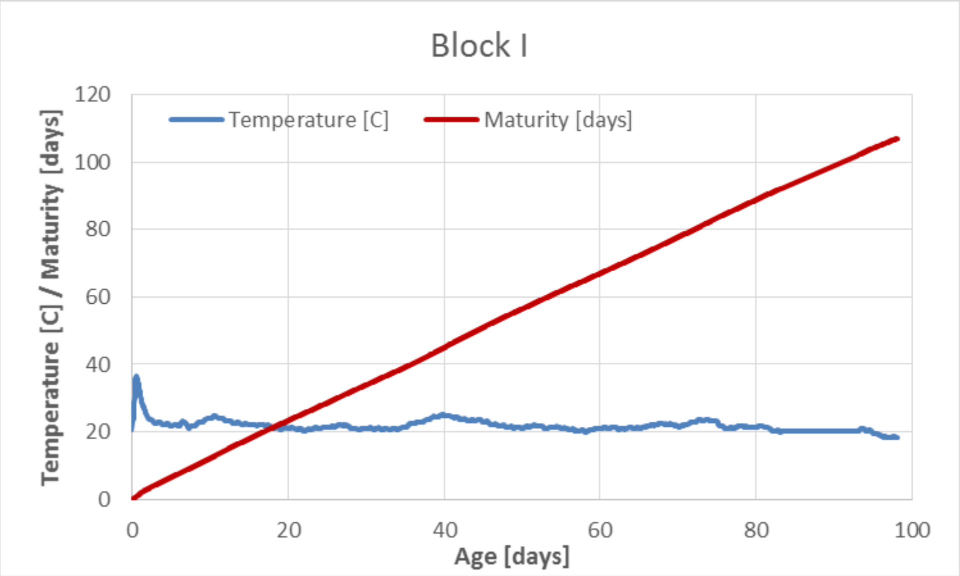
Plywood samples – NT BUILD 492 – tested on 12.12.2016 (182 maturity days)
**) Outlier - not included due to defect.*

Appendix 3: Exposure conditions

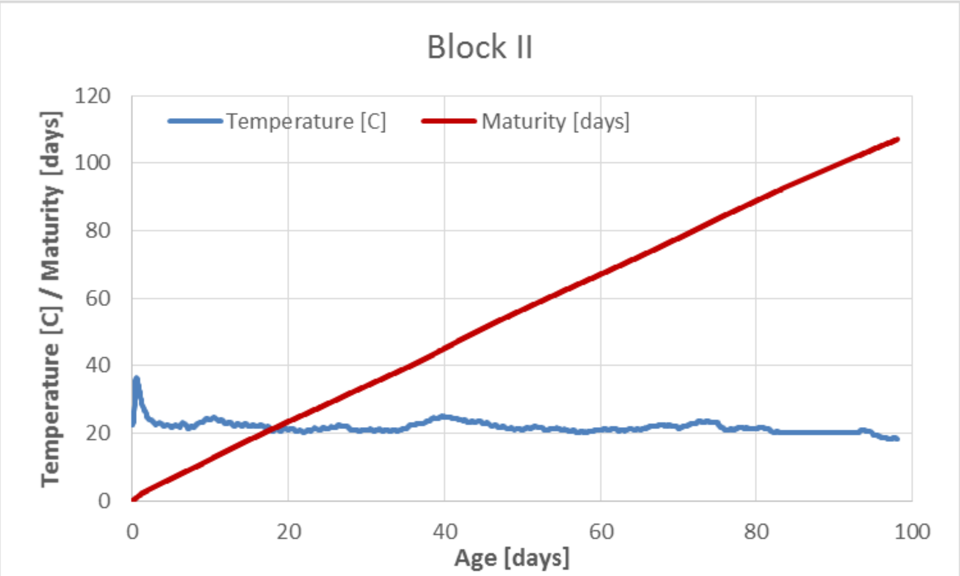


Climate during dry curing of block II. Mean values: 60.3 %RH & 22.9 °C

Appendix 4: Concrete temperature & maturity



Block I – Concrete temperature & maturity

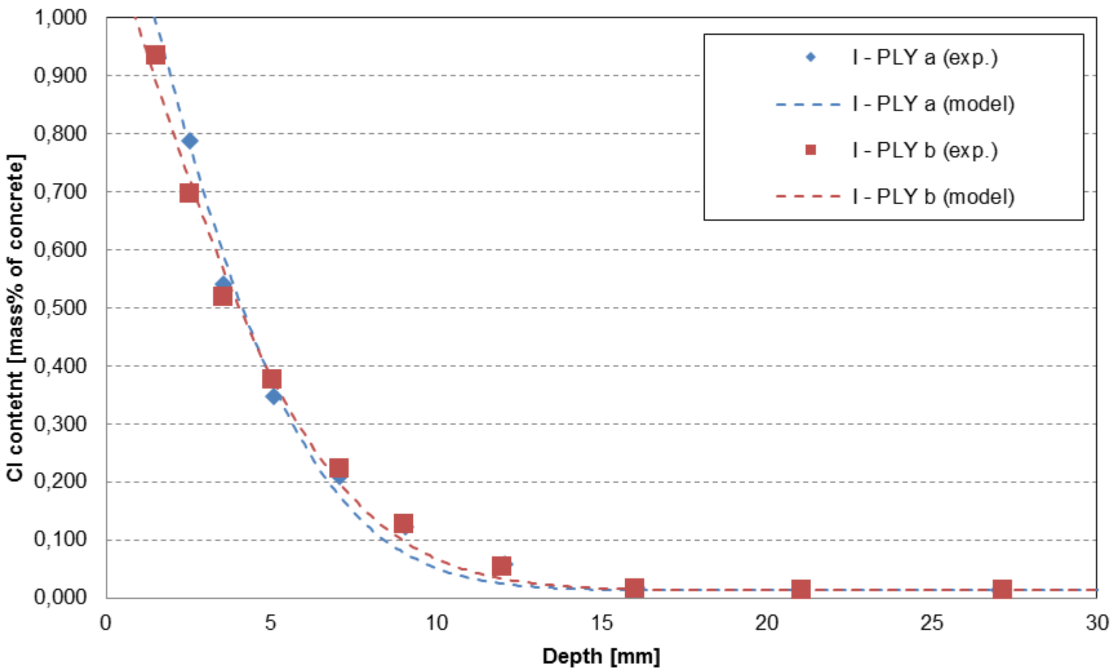


Block II – Concrete temperature & maturity

Appendix 5: Choride profiles after exposure in 2% Cl solution

I - PLY a			I - PLY b		
Depth	Chloride content	Chloride content	Depth	Chloride content	Chloride content
[mm]	[mass% Cl of concrete]	[mass% Cl of binder]	[mm]	[mass% Cl of concrete]	[mass% Cl of binder]
0.5	1.067	6.272	0.5	1.025	6.025
1.5	1.017	5.978	1.5	0.938	5.514
2.5	0.787	4.626	2.5	0.700	4.115
3.5	0.542	3.186	3.5	0.522	3.068
5.1	0.348	2.046	5.0	0.379	2.228
7.1	0.209	1.229	7.0	0.225	1.323
9.1	0.122	0.717	9.0	0.129	0.758
12.1	0.059	0.347	12.0	0.055	0.323
16.1	0.017	0.100	16.0	0.019	0.112
21.0	0.014	0.082	21.0	0.016	0.094
27.1	0.014	0.082	27.1	0.015	0.088
Initial	0.013	0.076	Initial	0.013	0.076

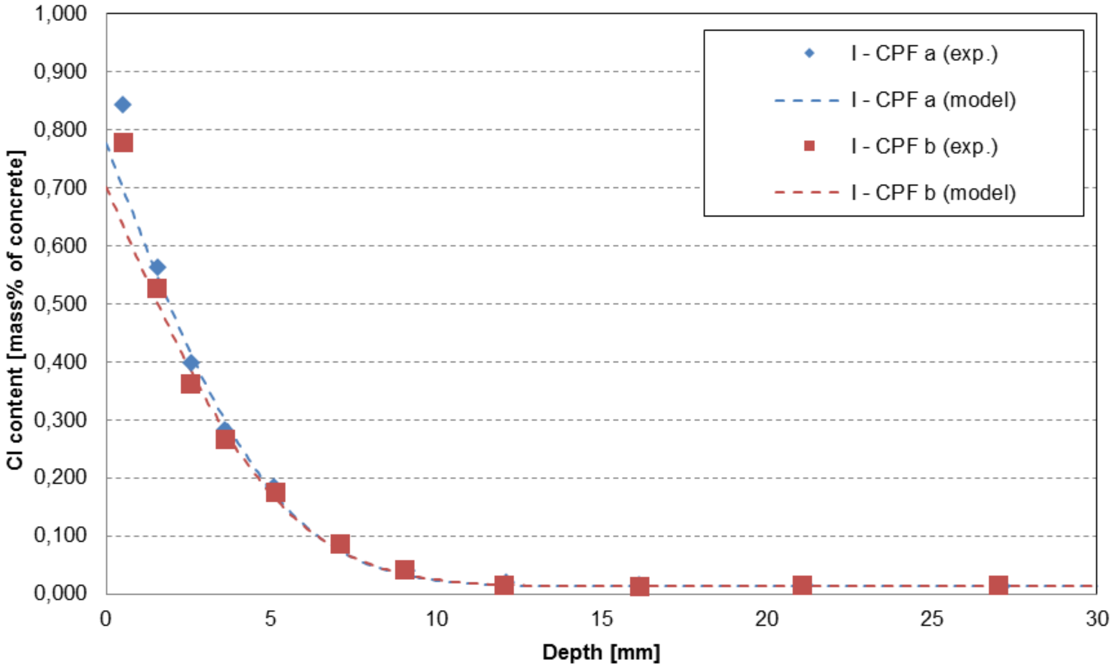
Block I – Plywood formwork – Wet curing – Chloride analyses



Block I – Plywood formwork – Wet curing – Chloride profiles after 71 calendar days exposure in 2% Cl solution (76 maturity days exposure)

I - CPF a			I - CPF b		
Depth	Chloride content	Chloride content	Depth	Chloride content	Chloride content
[mm]	[mass% Cl of concrete]	[mass% Cl of binder]	[mm]	[mass% Cl of concrete]	[mass% Cl of binder]
0.5	0.843	4.955	0.5	0.780	4.585
1.6	0.564	3.315	1.5	0.528	3.104
2.6	0.398	2.339	2.5	0.364	2.140
3.6	0.283	1.663	3.6	0.268	1.575
5.1	0.184	1.082	5.1	0.177	1.040
7.1	0.088	0.517	7.1	0.088	0.517
9.1	0.041	0.241	9.0	0.042	0.247
12.1	0.020	0.118	12.0	0.015	0.088
16.1	0.016	0.094	16.1	0.013	0.076
21.1	0.016	0.094	21.1	0.016	0.094
27.1	0.013	0.076	27.0	0.016	0.094
Initial	0.013	0.076	Initial	0.013	0.076

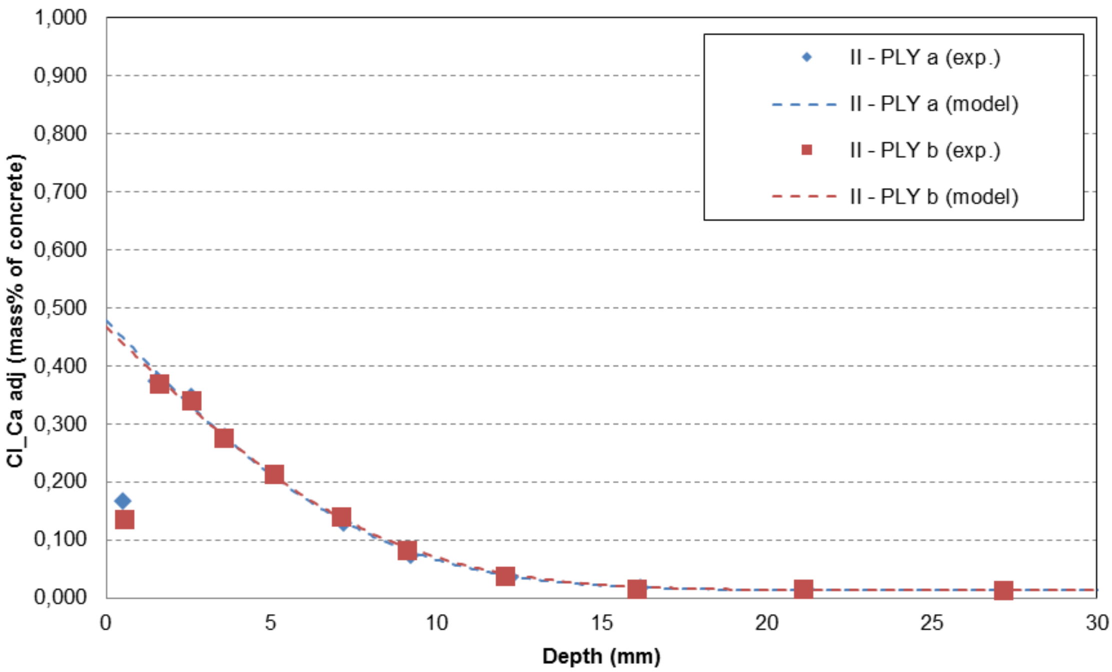
Block I – CPF formwork – Wet curing – Chloride profiles



Block I – CPF formwork – Wet curing – Chloride profiles after 71 calendar days exposure in 2% Cl solution (76 maturity days exposure)

II - PLY a			II - PLY b		
Depth	Chloride content	Chloride content	Depth	Chloride content	Chloride content
[mm]	[mass% Cl of concrete]	[mass% Cl of binder]	[mm]	[mass% Cl of concrete]	[mass% Cl of binder]
0.5	0.168	0.988	0.5	0.136	0.799
1.5	0.375	2.204	1.6	0.369	2.169
2.6	0.347	2.040	2.6	0.341	2.004
3.6	0.279	1.640	3.6	0.276	1.622
5.1	0.212	1.246	5.1	0.214	1.258
7.2	0.129	0.758	7.1	0.140	0.823
9.2	0.074	0.435	9.1	0.083	0.488
12.2	0.036	0.212	12.1	0.037	0.217
16.2	0.018	0.106	16.1	0.016	0.094
21.2	0.016	0.094	21.1	0.015	0.088
27.1	0.013	0.076	27.1	0.013	0.076
Initial	0.013	0.076	Initial	0.013	0.076

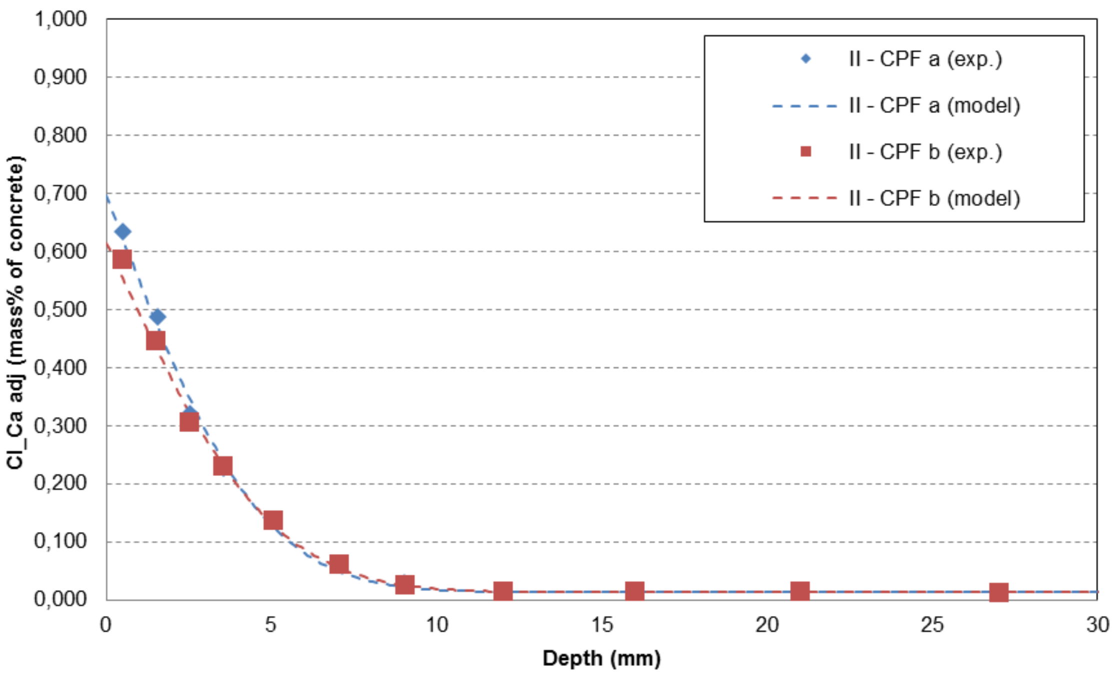
Block II – Plywood formwork – Dry curing – Chloride analyses



Block II – Plywood formwork – Dry curing – Chloride profiles after 71 calendar days exposure in 2% Cl solution (76 maturity days exposure)

II - CPF a			II - CPF b		
Depth	Chloride content	Chloride content	Depth	Chloride content	Chloride content
[mm]	[mass% Cl of concrete]	[mass% Cl of binder]	[mm]	[mass% Cl of concrete]	[mass% Cl of binder]
0.5	0.635	3.733	0.5	0.587	3.450
1.5	0.488	2.868	1.5	0.448	2.633
2.5	0.321	1.887	2.5	0.308	1.810
3.6	0.228	1.340	3.5	0.231	1.358
5.1	0.137	0.805	5.0	0.138	0.811
7.1	0.062	0.364	7.0	0.062	0.364
9.0	0.029	0.170	9.0	0.027	0.159
12.0	0.015	0.088	12.0	0.015	0.088
16.0	0.013	0.076	16.0	0.015	0.088
21.0	0.016	0.094	21.0	0.015	0.088
27.0	0.014	0.082	27.0	0.014	0.082
Initial	0.013	0.076	Initial	0.013	0.076

Block II – CPF formwork – Dry curing – Chloride analyses



Block II – CPF formwork – Dry curing – Chloride profiles after 71 calendar days exposure in 2% Cl solution (76 maturity days exposure)

Calculated chloride penetration parameters from curve-fitting of chloride profiles acc. to principles in NT BUILD 443:

Sample	$C_{s,co}$	$C_{s,bi}$	$C_{i,co}$	D_e	$K_{0.05}$	
	mass% of CO	mass% of BI	mass% of CO	10^{-12} m²/s	10^{-6} m/s^{½}	mm/year^{½}
I - PLY a	1.335	7.849	0.013	1.7	4.1	23
I - PLY b	1.160	6.821	0.013	2.1	4.4	24

Block I – Plywood formwork – Wet curing – Chloride penetration parameters after 71 calendar days exposure in 2% Cl solution (76 maturity days exposure)

Sample	$C_{s,co}$	$C_{s,bi}$	$C_{i,co}$	D_e	$K_{0.05}$	
	mass% of CO	mass% of BI	mass% of CO	10^{-12} m²/s	10^{-6} m/s^{½}	mm/year^{½}
I - CPF a	0.776	4.561	0.013	1.3	3.2	18
I - CPF b	0.702	4.125	0.013	1.4	3.3	18

Block I – CPF formwork – Wet curing – Chloride penetration parameters after 71 calendar days exposure in 2% Cl solution (76 maturity days exposure)

Sample	$C_{s,co}$	$C_{s,bi}$	$C_{i,co}$	D_e	$K_{0.05}$	
	mass% of CO	mass% of BI	mass% of CO	10^{-12} m²/s	10^{-6} m/s^{½}	mm/year^{½}
II - PLY a	0.478	2.812	0.013	3.2	4.5	25
II - PLY b	0.467	2.745	0.013	3.5	4.6	26

Block II – Plywood formwork – Dry curing – Chloride penetration parameters after 71 calendar days exposure in 2% Cl solution (76 maturity days exposure)

Sample	$C_{s,co}$	$C_{s,bi}$	$C_{i,co}$	D_e	$K_{0.05}$	
	mass% of CO	mass% of BI	mass% of CO	10^{-12} m²/s	10^{-6} m/s^{½}	mm/year^{½}
II - CPF a	0.697	4.098	0.013	1.1	2.8	16
II - CPF b	0.615	3.616	0.013	1.2	2.9	16

Block II – CPF formwork – Dry curing – Chloride penetration parameters after 71 calendar days exposure in 2% Cl solution (76 maturity days exposure)

$C_{s,co}$	Boundary condition at the exposed surface in weight% of concrete
$C_{s,bi}$	Boundary condition at the exposed surface in weight% of binder
$C_{i,co}$	Initial chloride concentration in weight% of concrete
D_e	Effective chloride transport coefficient
$K_{0.05}$	Penetration parameter
C_r	A reference concentration of C_r = 0.05% is applied in the calculation of $K_{0.05}$

Appendix 6: Photos

Photo 1: The mixing station is equipped with a 375/250 liter counter-current mixer, five aggregate silos and four powder silos from Haarup A/S, and process control software from Skako A/S.

Photo 2: The formwork for the two concrete blocks has plywood on one side and CPF liner on the other side (seen through plexiglass in photo). The two blocks were cast from the same batch and separated by a plywood plate in the middle of the mould.

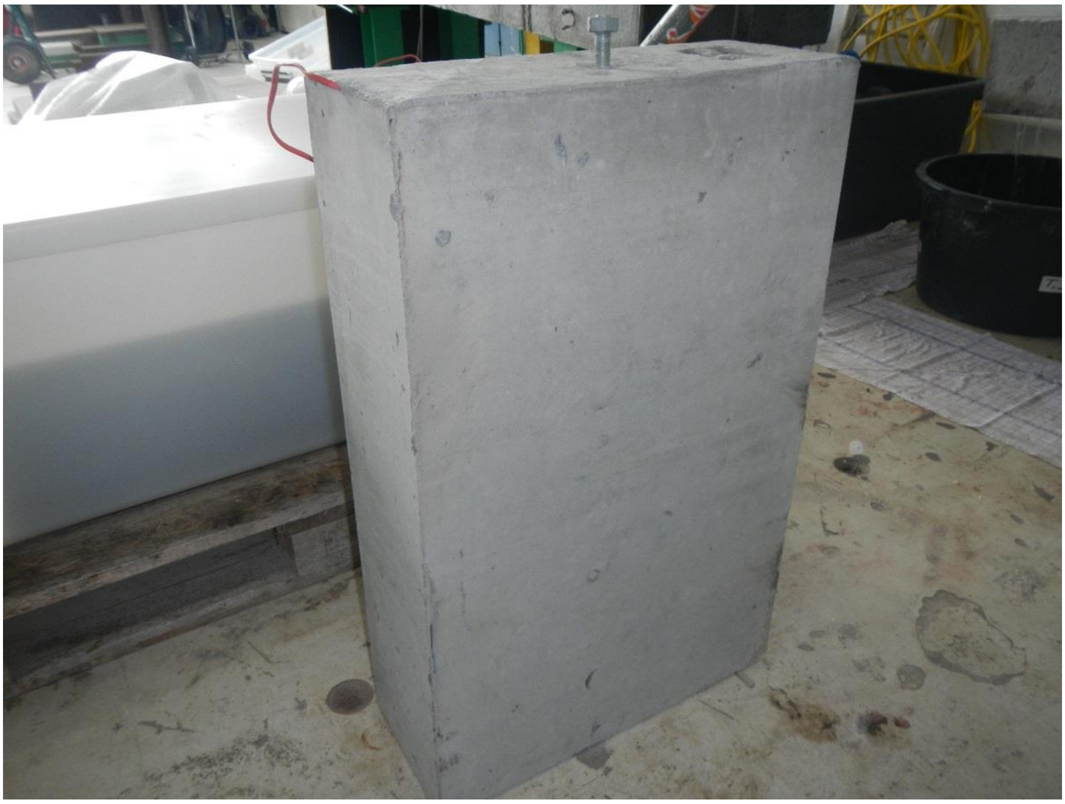


Photo 3: Concrete block with visible side cast against plywood.

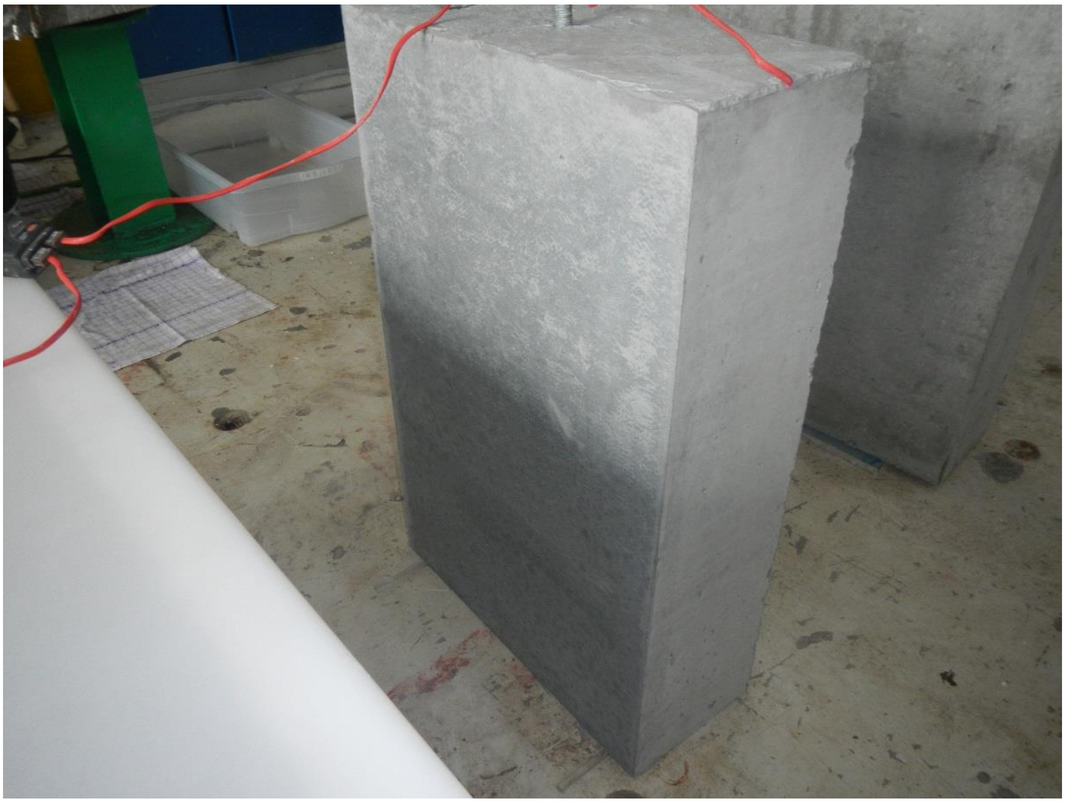


Photo 4: Concrete block with visible side cast against CPF liner.

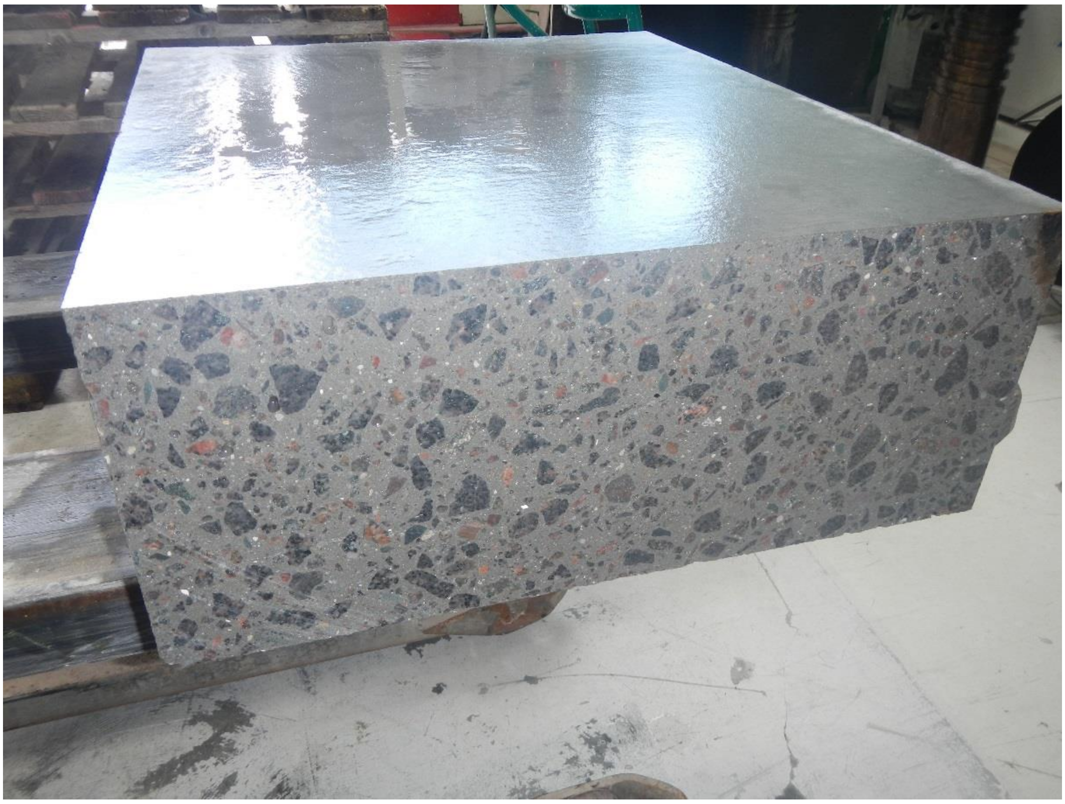


Photo 5: Concrete block after cutting of the bottom part.

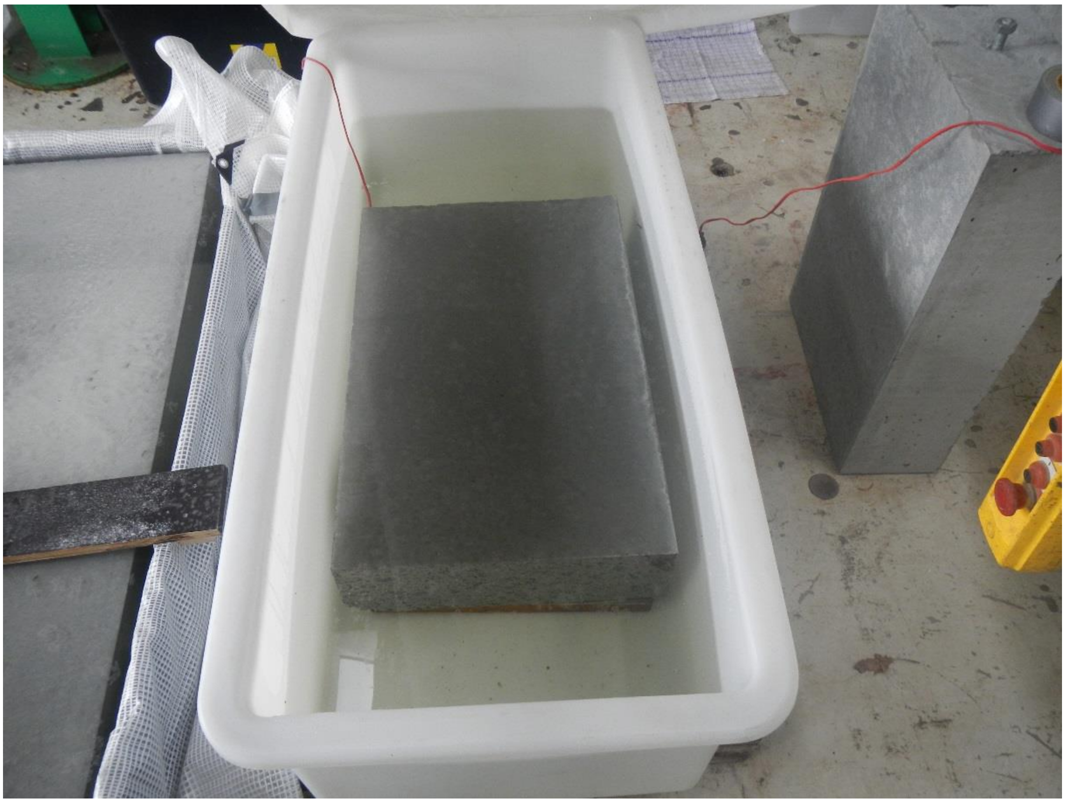


Photo 6: Curing of concrete blocks in wet (middle) and dry (left) conditions.