Fibertex A/S

Application of Formtex Controlled Permeability Formwork in the Arabian Gulf

Documentation Report

December 2002

COWI
ALMOAYED
GULF
كوي
المؤيد
الخليج

COWI كـــوي
ALMOAYED المـؤيـــد
GULF الخليــــج

Fibertex A/S

Application of Formtex Controlled Permeability Formwork in the Arabian Gulf

Documentation Report

December 2002

Report no.	201689-1
Issue no.	01
Date of issue	9 December 2002
Prepared	CDF
Checked	AJC
Approved	CDF

Table of Contents

1 Introduction

On behalf of Fibertex A/S, COWI-Almoayed Gulf WLL has carried out a testing programme to assess the effect on concrete performance that the use of Formtex Controlled Permeability Formliner (CPF) has in the hot and humid climate of the Arabian Gulf.

The concrete was produced and the test panels cast and cured by Haji Hassan Readymix (HHR), Bahrain. Documentation for fresh and hardened concrete properties was also provided by HHR.

Coring and testing of the cores were carried out by Al-Hoty Analytical Services (AHAS), Bahrain.

This report includes description of concrete and panel production and documentation in sections 2, 3.1, 4.1 and 4.2.

The tests carried out by AHAS are described in sections 3.2 and 4.3.

Section 5 comprises conclusions relating to the effects of using CPF in the Arabian Gulf.

2 Production of Test Panels

2.1 Concrete mixes

2.1.1 Mix designs

Four concrete mix designs were selected as typical examples for high quality concrete construction in the Arabian Gulf. They included:

	Panel 1	Panel 2	Panel 3	Panel 4
OPC cement	-	-	Yes	Yes
SRPC cement	Yes	Yes	-	-
PFA flyash	-	30 %	-	-
MS microsilica	-	-	5 %	5 %
Max. nom. aggregate size	20 mm	20 mm	20 mm	20 mm
Target water/cement ratio	0.38	0.38	0.45	0.55

The target water/cement ratio is calculated as follows:

w/c = free water content / (cement + flyash + microsilica).

An activity factor of 1 has been applied for flyash and microsilica (silica fume) as this is common practice in most countries in the Arabian Gulf.

The mix designs were prepared by HHR, partly from their selection of standard concrete mix designs.

2.1.2 Laboratory trial mixes

A 35 litre laboratory trial mix was produced outdoors for each mix design on 25-26 July 2001. The fresh concrete temperature was 33° C. The following properties were concluded:

	Trial mix 1	Trial mix 2	Trial mix 3	Trial mix 4
w/c-ratio	0.38	0.34	0.45	0.55
Temperature, ° C	33	33	33	33
Fresh concrete density, kg/m^3	2,490	2,472	2,426	2,434
Air content, %	0.7	0.7	2.2	2.2
Slump, mm Immediately 30 min 60 min 90 min	 215 110 60 40	 220 50 - -	 165 90 55 -	 180 90 60 -
Bleeding (bucket procedure), total, kg/m^2	1.7	1.7	0.3	1.4
100 mm cube compressive strength, MPa 3 days 7 days 28 days	 34.7 43.5 54.4	 30.0 39.3 46.2	 31.1 40.7 53.1	 25.0 34.8 40.3

More details about the trial mixes e.g. the bleeding rate are included in Appendix A.

In the laboratory trials the bleeding test in ASTM C 232 (bucket procedure) was applied. CPF was not used in the laboratory trials.

The results of the four trial mixes did not result in changes in mix designs or mixing and test procedures.

2.1.3 Full scale concrete mixes

The concrete was mixed in HHR's production plant No.2, which is a 3 m^3 computer controlled, forced action mixer. 2 m^3 concrete was mixed for each panel.

In order to simulate normal summer concreting conditions, crushed ice was added to the mixes as substitution for some of the mixing water.

After mixing the concrete was loaded in an agitating truck mixer and taken to the laboratory for testing.

After testing the concrete was taken to the site.

2.2 Test Panels

2.2.1 Formwork

The form for the test panels was made of impregnated (marine) plywood and steel with a height of 3 m, width of 1.1 m and thickness of 0.24 m.

Formtex was placed on one side of the form for each of the four castings in accordance with installation instructions from Fibertex. The Formtex was stretched in vertical direction and subsequently stapled to the form sides in horizontal direction. Formtex was protruding at the bottom through a gap between form side and bottom to permit water to drain out.

All panels were oriented with the wall sides facing east-west; for panel Nos. 1 and 3 the Formtex was facing west and for panel Nos. 2 and 4 facing east.

The panels were reinforced with 10 mm diameter deformed bars per 200 mm in both directions on both sides.

Lifting hooks were arranged at the top for stripping.

2.2.2 Water retention capacity of Formtex

The water retention in two samples, 400 mm x 400 mm, of Formtex after draining was determined at COWI's Concrete Laboratory, Lyngby, Denmark, in accordance with a procedure described in Appendix E.

2.2.3 Concrete casting and curing

The concrete casting was carried out 23 August - 1 September 2001 during which the ambient temperature varied from max. 40^o C during the day to 30^o C during the night. The climatic conditions are characterised as hot and humid.

The site was located within the Haji Hassan premises at Salmabad, approximately 500 m from the batching plant.

The concrete was placed using a concrete pump. The concrete was placed in about 5 layers and compacted with a 48 mm poker vibrator.

The formwork was removed after one day. The panels were cured for 7 days with wet hessian and polythene sheets. During 3 subsequent days the hessian and polythene sheets were kept in place, but without any watering. After a total of 10 days the panels were exposed to the environment.

Concrete cores were taken out through the full thickness of the panels in accordance with a coring plan, Appendix B, on 29 September 2001. A few cores were taken out later on 28 February 2002. The cores were generally taken out from the lower 1 m of the panels with the exception of the additional cores for the DIN water penetration which were taken out halfway up Panel 1.

3 Test Procedures

3.1 Concrete Testing

The concrete testing was carried out by Haji Hassan Readymix concrete laboratory.

3.1.1 Testing of fresh concrete

The testing which was carried out for the four full scale castings included:

Slump	BS 1881-102:1983
Temperature	Recorded to the nearest ^{o} C
Density	BS 1881-107:1983
Air content	BS 1881-106:1983
Bleeding (bucket procedure)	ASTM C-232
Bleeding (draining from Formtex)	Water was collected and weighed in increments until no significant further draining took place

3.1.2 Testing of hardening and hardened concrete

The testing which was carried out for the four full scale castings included:

Temperature monitoring	2-3 thermocouples in each form, up to 40-45 hours after mixing. One thermocouple was placed in the wall centre and the other(s) at the wall surface(s).
Concrete density	2 nos. 100 mm cubes at 7 days and 4 nos. 100 mm cubes at 28 days to BS 1881-114:1983
Compressive strength, 7 days	2 nos. 100 mm cubes to BS 1881-116:1983

Compressive strength, 28 days	4 nos. 100 mm cubes to BS 1881-116:1983

3.2 Core Testing

The cores were taken out and tested by AHAS. The testing for the 4 wall panels included:

Test	Method	Cores	Comments
Specific gravity, absorption and voids	ASTM C-642	2 nos. 100 mm diameter cores from each panel	Each core: 6 nos. 20 mm thick slices, 3 from each panel side were cut. First slice from each side included the formed surface.
Capillary absorption	As per submitted, AHAS-report p 3/3	2 nos. 100 mm diameter cores from each panel	Each core: 6 nos. 20 mm thick slices, 3 from each panel side were cut. First slice from each side included the formed surface. Absorption of specimens T-1 and B-1 included the formed surfaces.
Depth of carbonation	100 % CO_2 for 48 h and 7 days, respectively.	3 nos. 100 mm diameter cores from each panel. Additionally 2 nos. 100 mm cores from each panel.	Each core cut in 2 nos. 120 mm thick specimens.
Accelerated chloride penetration	NT Build 443	3 nos. 100 mm diameter cores from each panel	Each core cut in 2 nos. 120 mm thick specimens. Chloride penetration from the formed surfaces.
Water absorption	BS1881:Part 122:1983	3 nos. 75 mm diameter cores from Panels 1 and 3	From each core cut 2 nos. 75 mm thick specimens, both including the formed surfaces.
Water permeability	DIN 1048: Part 105:1991	3 nos. 250 mm diameter cores from Panel 1	Each core cut in 2 nos. 120 mm thick specimens. Water penetration from the formed surfaces.

4 Results and Discussion

4.1 Water Retention Capacity of Formtex

The water retention capacity after about 300 minutes draining was determined to be 0.46 and 0.53 kg/m^2 in the two Formtex samples, Appendix E. There is no standardised test method for this property, and the test results are influenced by:

- Sample size
- Interval before no dripping occurs
- Orientation of fibres
- Alteration of pressure (test conducted at atmospheric pressure).

The determined water retention capacity of about 0.5 kg/m^2 is only an indication of the amount of water which may be available for ensuring a continuation of the hydration.

4.2 Visual Appearance

All four test panels were cast without significant defects (honey combs). Cracks have not been observed.

The concrete surfaces cast against plywood all have a significant amount of blowholes with 1-3 mm diameter, see Appendix D. The concrete surfaces cast against Formtex exhibited virtually no blowholes.

4.3 Concrete tests

The resulting mix designs calculated on SSD-basis (saturated, surface dry aggregates) are the following:

	Panel 1		Panel 2		Panel 3		Panel 4	
Material	Weight	Volume	Weight	Volume	Weight	Volume	Weight	Volume
	kg/m^3	l/m^3	Kg/m^3	l/m^3	kg/m^3	l/m^3	Kg/m^3	l/m^3
Cement, SRPC	434	138	298	95	-	-	-	-

COWI كـــوي
ALMOAYED المؤيـــد
GULF الخليـــج

	Panel 1		Panel 2		Panel 3		Panel 4	
Material	Weight	Volume	Weight	Volume	Weight	Volume	Weight	Volume
	kg/m^3	l/m^3	Kg/m^3	l/m^3	kg/m^3	l/m^3	Kg/m^3	l/m^3
Cement OPC	-	-	-	-	335	106	287	91
Flyash	-	-	135	61	-	-	-	-
Microsilica	-	-	-	-	18	8	15	7
Water	156	156	145	145	147	147	163	163
Sand, Saudi	690	260	694	262	803	303	812	306
10 mm RAK-aggregate	346	128	329	122	326	121	322	119
20 mm RAK-aggregate	817	303	827	306	798	296	801	297
Plasticiser, Isola BT	2.55	2	2.60	2	3	3	3	3
Air content, %	1.3	13	0.6	6	1.7	17	1.5	15
Total	2,445	1,000	2,432	999	2,430	1,001	2,402	1,001
Water/powder ratio	0.36	-	0.34	-	0.41	-	0.54	-

The results of the testing of fresh, hardening and hardened concrete carried out by HHR are reported in Appendix A and summarised in the table below.

	Panel 1	Panel 2	Panel 3	Panel 4
Water/powder ratio	0.36	0.34	0.41	0.54
Fresh concrete temperature, ^{o} C	32	28	28	31
Fresh concrete density, kg/m^3	2,498	2,498	2,459	2,459
Air content, %	1.3	0.6	1.7	1.5
Slump, mm Immediately 30 min	 80 40	 180 -	 80 60	 110 -
Bleeding (bucket procedure), total, kg/m^2	n.d.	1.1	0.1	0.7

	Panel 1	Panel 2	Panel 3	Panel 4
Bleeding (draining from Formtex), total, kg/m^2	1.0	0.8	0.8	0.6
Max. temperature during hardening, ^{o} C Age at max. temperature, hours	69.2 20	54.9 23	65.6 22	58.8 24
Hardened concrete density, kg/m^3 7 days, 2 cubes 28 days, 4 cubes	 2,497 2,491	 2,474 2,477	 2,457 2,472	 2,463 2,460
Cube compressive strength, MPa 7 days, 2 cubes 28 days, 4 cubes	 46.0 51.9	 39.9 52.2	 46.9 56.8	 35.8 49.1

More details about the trial mixes e.g. the bleeding rates and temperature development are included in Appendix A.

Determination of bleeding (draining from Formtex) is made difficult by the sun radiation on some of the form surfaces during the bleeding period. Although attempts were made to minimise evaporation, this exposure could have created a risk of evaporation of some of the drained water. The risk is expected to have been larger for Panels 2 and 4 where the Formtex was facing east; all panels were cast in the morning. The total bleeding from Panels 2 and 4 could have been slightly higher than the measured values.

The results of the four full scale castings are - with normal variations - complying with the expectations.

4.4 Core Tests

All cores were taken out by AHAS and brought to their laboratory for storage, preparation and testing.

4.4.1 Specific gravity, absorption and voids (ASTM C-642)

This part of ASTM C-642 is primarily carried out in order to check the quality of the concrete in the four panels. The tests are carried out using specimens with a thickness of about 40 mm. With an expected effect of the CPF of about 5 mm from the formed surface, only 5 mm/40 mm = 10-15 % of the total volume of the specimens with one surface cast against CPF should be affected.

In AHAS' report the following identification of the specimens has been used:

P-1 0-40 mm from the plywood surface
P-2 40-80 mm from the plywood surface
P-3 80-120 mm from the plywood surface
F-1 0-40 mm from the CPF surface

F-2 40-80 mm from the CPF surface
F-3 80-120 mm from the CPF surface.

The following data have been extracted from the report:

Panel	Specimen	Absorption after immersion, %	Absorption after immersion and boiling, %	Bulk specific gravity (dry)	Bulk specific gravity after immersion	Bulk specific gravity after immersion and boiling	Apparent specific gravity	Volume of permeable pore space voids, %
1	P-1	4.56	4.87	2.31	2.42	2.42	2.60	11.3
	F-1	3.48	3.85	2.34	2.45	2.46	2.60	9.8
2	P-1	4.51	4.95	2.32	2.42	2.43	2.61	11.0
	F-1	4.37	4.90	2.29	2.39	2.40	2.57	11.2
3	P-1	4.96	5.32	2.30	2.41	2.42	2.61	12.2
	F-1	4.61	5.02	2.30	2.40	2.41	2.60	12.3
4	P-1	4.91	5.42	2.30	2.41	2.42	2.63	12.4
	F-1	4.18	4.61	2.31	2.41	2.42	2.58	10.7
Average	All P-1	4.74	5.14	2.31	2.42	2.42	2.61	11.7
	All F-1	4.16	4.60	2.31	2.41	2.42	2.59	11.0
Ratio	All F-1/ All P-1	88 %	89 %	100 %	100 %	100 %	99 %	94 %

The average values are calculated as the average of the two specimens from the two cores from one panel. The ratio is calculated as the average test result for the CPF-specimen relative to the plywood specimen.

The absorption is reduced significant, on an average by 11-12 %, whereas the specific gravities are not affected. The permeable pore space has on an average been reduced by 6 %.

These quality improvements are high, especially by taking into consideration that only 10-15 % of the volume of the CPF-specimens is expected to be affected. The effect in the 5 mm surface layer is certainly significantly higher.

4.4.2 Capillary absorption

2 cores were taken from each of the four panels. 3 nos. 20 mm thick slices were cut starting from the formed surfaces of each core.

Capillary absorption was carried out by submerging the bottom 1 mm of the specimens in water. The formed surfaces were submerged.

The specimen weight was determined after 10 min, 30 min, 1 h, 2 h, 3 h, 4 h, 5 h, 6 h, 24 h, 48 h, 72 h and 96 h. During the testing small fractions of the slices from core 2-C1-1 and 3-C1-1 broke off so that the test results had to be discarded. New cores were taken and the absorption test repeated with those.

The test results are summarised by calculating the average absorption of the four slices without a formed surface from the two cores from the same panel:

Panel	Specimen	Q_{cap}	$t_{cap}^{0.5}$	k	m
		Kg/m^2	$s^{0.5}$	$kg/(m^2 \times s^{0.5})$	s/m^2
1	P-1	1.85	149	0.0124	56×10^6
	Internal	1.69	122	0.0139	37×10^6
	F-1	0.90	185	0.0049	86×10^6
	F-1, % of P-1 & Int.	52		36	169
2	P-1	1.71	180	0.0096	81×10^6
	Internal	1.71	180	0.0096	81×10^6
	F-1	0.58	180	0.0032	81×10^6
	F-1, % of P-1 & Int.	34		33	100
3	P-1	2.07	137	0.0151	47×10^6
	Internal	1.99	122	0.0163	37×10^6
	F-1	1.36	167	0.0081	70×10^6
	F-1, % of P-1 & Int.	68		50	179
4	P-1	1.90	116	0.0164	34×10^6
	Internal	1.93	103	0.0187	27×10^6
	F-1	1.65	125	0.0132	39×10^6
	F-1, % of P-1 & Int.	85		72	137

Panel	Specimen	Q_{cap}	$t_{cap}^{0.5}$	k	m
		Kg/m^2	s$^{0.5}$	kg/(m^2 x s$^{0.5}$)	s/m^2
Aver-age	F-1, % of P-1 & Int.	60		48	146

The capillary absorption number, Q_{cap}, has been reduced by 15-66 % (average reduction 40 %) by using Formtex, the capillary porosity number, k, has been reduced by 28-67 % (average reduction 52 %), and the resistance number, m, has been increased by 0-79 % (average increase 46 %) - all indicating that the surface layer next to the Formtex is significantly less permeable than normal high quality concrete mixes.

4.4.3 Depth of carbonation

The first set of specimens consisting of 3 cores from each panel, each cut in two 120 mm long halves, were sealed with epoxy on all cut surfaces and the formed surfaces subsequently exposed to 100 % CO_2 for 48 hours.

The specimens were split and the depth of carbonation determined. This testing did not show any measurable carbonation. Therefore, another set of 2 cores from each panel were taken out, and the testing repeated, but with 7 days exposure to 100 % CO_2. The test results are summarised below:

Panel	Specimen	Depth of carbonation, mm
1	C2 P	3
	C2 F	0.5
2	C2 P	2
	C2 F	0.5
3	C2 P	2
	C2 F	0.5
4	C2 P	2.5
	C2 F	0.5
Average	All C2 P	2.5
	All C2 F	0.5

Panel	Specimen	Depth of carbonation, mm
Ratio	All C2 F/All C2 P	20 %

The depth of carbonation has for all panels been reduced dramatically by using CPF, namely by 75-83 % with an average reduction of 80 %. The effect of using CPF is convincing for all four concrete mixes, indicating that the surface layer is significantly less permeable than in the normal high quality concrete mixes.

4.4.4 Accelerated chloride penetration (NT Build 443)

3 nos. cores were taken from each of the four panels, each cut in two half cores, sealed on cut surfaces and with the formed surfaces subsequently exposed to chloride containing water for 60 days in accordance with NT Build 443. The test results are summarised below:

Panel	Depth, mm	Total acid soluble chloride content as % by weight of dry concrete	
		Plywood	Formtex
1	0-10	0.437	0.346
	10-20	0.188	0.156
	20-30	0.077	0.087
	30-40	0.066	0.051
	40-50	0.042	0.032
	Initial Cl-content	0.014	0.015
	C_S, %	0.548	0.453
	D_e, m^2/s	121×10^{-12}	87×10^{-12}

Panel	Depth, mm	Total acid soluble chloride content as % by weight of dry concrete	
		Plywood	Formtex
2	0-10	0.338	0.201
	10-20	0.158	0.052
	20-30	0.098	0.037
	30-40	0.054	0.036
	40-50	0.042	0.037
	Initial Cl-content	0.013	0.017
	C_S, %	0.425	0.281
	D_e, m^2/s	117×10^{-12}	58×10^{-12}
3	0-10	0.624	0.256
	10-20	0.262	0.121
	20-30	0.175	0.040
	30-40	0.080	0.041
	40-50	0.064	0.023
	Initial Cl-content	0.015	0.015
	C_S, %	0.710	0.394
	D_e, m^2/s	247×10^{-12}	39×10^{-12}

Panel	Depth, mm	Total acid soluble chloride content as % by weight of dry concrete	
		Plywood	Formtex
4	0-10	0.521	0.200
	10-20	0.227	0.126
	20-30	0.181	0.058
	30-40	0.132	0.049
	40-50	0.055	0.037
	Initial Cl-content	0.013	0.014
	C_S, %	0.624	0.285
	D_e, m^2/s	184×10^{-12}	53×10^{-12}
Average for all four panels	C_S, %	0.577	0.353
	D_e, m^2/s	167×10^{-12}	59×10^{-12}

The chloride penetration has typically been reduced by more than 50 % by using CPF in stead of impermeable formwork.

The effective chloride transport coefficient, D_e, is very high for all four panels and for both form surface types. Values which are about 100 times smaller would have been expected – also when compared to the other properties which have been measured.

For comparative purpose, however, it is obvious that the chloride transport coefficient has been significantly reduced: to about one third when using CPF in stead of impermeable formwork.

4.4.5 Water absorption (BS 1881:Part 122:1983)

3 cores were taken from each of the Panels 1 and 3. Two 75 mm thick specimens were cut from each core including the original concrete surfaces.

The 30 minutes absorption to BS 1881:Part 122:1983 is carried out by submerging the samples completely in water. The test results, therefore, represent the average condition of the specimens and not especially the formed surface layers. The test results obtained by adhering to the specified specimen sizes are:

Panel	Specimen	Water absorption (30 min) as percentage of dry mass
1	1C4 P	1.59
	1C4 F	1.53
3	3C4 P	1.84
	3C4 F	1.87
Average	All C4 P	1.72
	All C4 F	1.70
Ratio	All C4 F/All C4 P	99 %

As expected, the test results did not show any effect of using CPF. Therefore, 5 mm thick slices were cut from the formed surfaces of the specimens with the aim of increasing the fraction of the sample which has been affected by usage of CPF.

The following test results were obtained with these modified specimens:

Panel	Specimen	Water absorption (30 min) as percentage of dry mass on outer 5 mm discs
1	1C4 P	1.84
	1C4 F	1.63
3	3C4 P	1.91
	3C4 F	1.75
Average	All C4 P	1.88
	All C4 F	1.69
Ratio	All C4 F/All C4 P	90 %

The beneficial effect of using CPF is clearly demonstrated here, resulting in an average reduction of the 30 minutes absorption of 10 %.

4.4.6 Water permeability (DIN 1048:Part 105:1991)

3 nos. 250 mm diameter concrete cores were taken from Panel 1 and tested for water penetration in accordance with DIN 1048:Part 105:1991.

The test results were:

Panel	Specimen	Depth of water penetration, mm
1	1C6 1-2 P	24
	1C6 1-1 F	18
	1C6 2-2 P	24
	1C6 2-1 F	20
	1C6 3-2 P	24
	1C6 3-1 F	15
Average	All 1C6 P	24
	All 1C6 F	18
Ratio	All 1C6 F/All 1C6 P	75 %

The water penetration is unexpectedly high for a concrete mix with such a low water/cement ratio and with a permeable pore space of 9.8-11.3 %. A penetration of about 5 mm would have been expected. An explanation to the magnitude of the water penetration has not been found.

However, the effect of using CPF is significant, giving a reduction of the water penetration of 25 % compared to the penetration into a concrete surface cast against a normal impermeable form.

5 Conclusion

Four 3 m high, 1.10 m wide and 0.24 m thick concrete walls panels were cast using normal plywood formwork on one side and Formtex, controlled permeability formwork liner, on the other side. Four different concrete mixes were used, all with 20 mm maximum, nominal aggregate size, representing high performance to normal performance concrete types in the Arabian Gulf. Different combinations of SRPC, OPC, flyash and microsilica were used.

The concrete properties were documented through testing of the fresh, hardening and hardened concrete.

The actual water/powder ratios (powder = sum of cement, flyash and microsilica) for the four mixes were 0.34, 0.36, 0.41 and 0.54, and the 28 days cube compressive strength ranged from 49 MPa to 57 MPa.

The draining of water from the freshly cast concrete through Formtex ranged from 0.6 to 1.0 kg/m^2.

The main test results when comparing test specimens including the formed surfaces cast towards plywood and Formtex, respectively, were:

- The absorption (ASTM C-642) after immersion and after immersion and boiling, respectively, determined on 40 mm thick core slices was on an average for the four wall panels reduced by 12 % (range 3 % to 24 %) and 11 % (range 1 % to 21 %), respectively.

- The volume of permeable pore space (ASTM C-642) determined on 40 mm thick core slices was not reduced for the wall panels with w/c-ratios of 0.34 and 0.41, but was reduced by about 13 % for the other two wall panels with w/c-ratios of 0.36 and 0.54.

- The capillary absorption number, Q_{cap}, was on an average reduced by 40 %. The reduction ranged from 15 % to 66 %.

  The capillary porosity number, k, was on an average reduced by 52 %. The reduction ranged from 28 % to 67 %.

  The resistance number, m, was on an average increased by 46 %. The increase ranged from 0 % to 79 %.

- The depth of carbonation after 7 days exposure to 100 % CO_2 was on an average reduced by 80 %. The reduction ranged from 75 % to 83 %.

- The chloride penetration (NT Build 443) after 60 days exposure to chloride containing water was on an average reduced by 47 %. The reduction ranged from 14 % to 61 %.

- The effective chloride transport coefficient, D_e, was on an average reduced by 65 %. The reduction ranged from 33 % to 84 %.

- The 30 minutes water absorption (BS 1881-122:1983) using 5 mm thick core slices was reduced by 12 % and 8 % for the wall panels with w/c-ratio of 0.36 and 0.41, respectively.

- The water penetration (DIN 1048:Part 105:1991) was reduced by 25 % for the wall panel with w/c-ratio of 0.36.

For the whole range of concrete mixes tested in this investigation programme, the beneficial effect of Formtex is clearly demonstrated for all tested properties. In all cases the effect appears to be caused by a densified, less permeable surface layer created by draining of surplus water through the Formtex.

The densified, less permeable surface layer will significantly reduce the rate of ingress of gases and liquids from the environment through the critically important concrete cover layer. The significantly reduced penetrability will prolong the time before critical amounts of gases and liquids will be able to pass through the concrete cover and therefore result in a significantly longer satisfactory service life before any deterioration can start.

6 Appendices

Appendix A.	Report from Haji Hassan Readymix
Appendix B	Coring plan
Appendix C	Report from Al-Hoty Analytical Services
Appendix D	Photos
Appendix E	Water retention capacity of Formtex, Report from COWI

Appendix A. Report from Haji Hassan Readymix

Appendix B. Coring plan

Appendix C. Report from Al-Hoty Analytical Services

Appendix D. Photos

Figure 1. Fixing of Formliner on plywood formwork.

Figure 2. Formliner fixed on plywood formwork.

Figure 3. Marine plywood formwork with steel reinforcement.

Figure 4. Form with Formliner assembled and ready for casting.

Figure 5. Sampling of fresh concrete.

Figure 6. Concrete delivery and pumping.

Figure 7. Concrete pumping.

Figure 8. Feeding concrete to the pump.

Figure 9. Placing and compacting the concrete.

Figure 10. Finishing concrete placing and compaction. Notice Thermocouple wires sticking out from the top of the form.

Figure 11. Tray for collection of water drained from Formliner. Draining has started at the right side of the Formliner.

Figure 12. Water has started draining from the form side with Formliner.

Figure 13. Evaporation protection of concrete.

Figure 14. Panel 1 and in the background Panel 2.

Figure 15. Panel 1, plywood face with blowholes and pinholes.

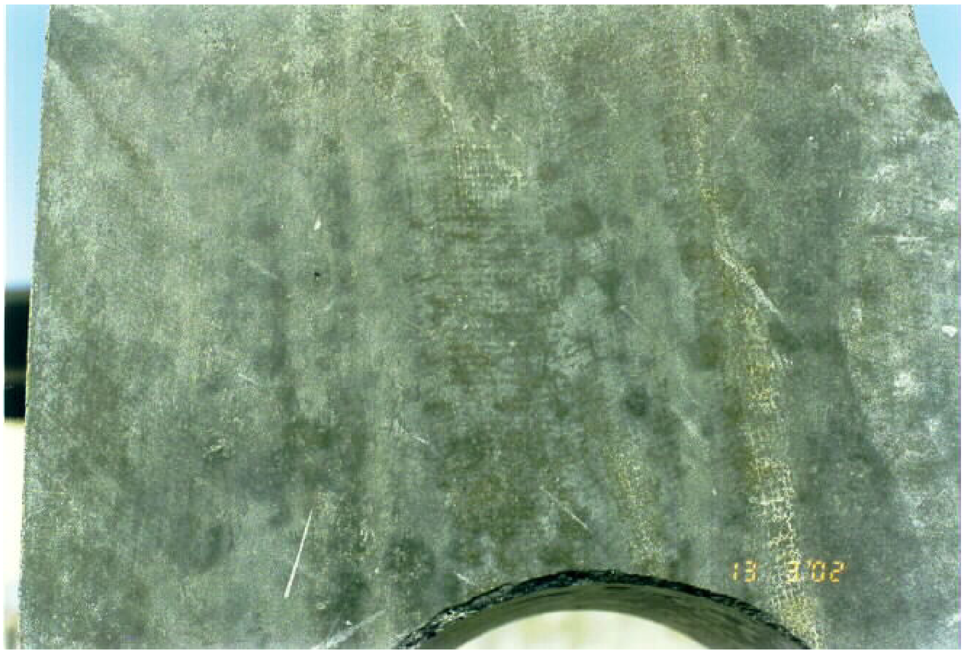

Figure 16. Panel 1, Formliner face without blowholes and pinholes

Figure 17. Panel 2, plywood face.

Figure 18. Panel 2, plywood face.

Figure 19. Panel 2, Formliner face.

Figure 20. Panel 3, plywood face.

Figure 21. Panel 3, plywood face.

Figure 22. Panel 3, Formliner face.

Figure 23. Panel 4, Formliner face.

Figure 24. Panel 4, plywood face.

Figure 25. Panel 4, Formliner face.

Appendix E. Water retention capacity of Formtex

Available at www.formtex.dk