Improvement of Concrete Surface by Controlled Permeability Formwork – Increase of Cracking Resistance

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Summary

Some aspects of performance of reinforced-concrete members formed against permeable formwork are considered on the basis of laboratory tests. The series of beams made from different concrete were tested up to failure. The particular measures concerned the increase in cracking resistance of RC beams when the effective kind of controlled permeability formowork was applied. The series of two sizes of beams were tested, with rectangular and T-shape cross-section.

Keywords: concrete ; controlled permeability formwork ; cracks ; cracking resistance ; durability of concrete ; properties of concrete surface ; reinforced-concrete members.

1. Introduction

In concrete structure exposed to external aggressive influences the quality of the surface skin is a crucial factor for durability of that structure. To extend the service life of concrete structure, the resistance of the surface to physical actions, as well as to penetration by aggressive chemical agents should be increased. The important way to obtain this resistance, apart from quality of mix proportions, efficient curing and compacting procedures, is proper forming of concrete surface. Conventional formwork, like impregnated plywood or steel, is impermeable to water and air. As a result of entrapped air and water at the formwork many blowholes and other structural faults on the formed surface of concrete usually occur [1]. The use of permeable formwork is relatively simple and an effective method for solution the problem.

Controlled permeability formwork (CPF) was originally developed in Japan [2]. Since the late 1980s many tests have been done to clarify the real effects of such a formwork. Although a number of CPF systems are commercially available now, all of them fulfil three basic functions:

- a filter that allows passing of water and air out from the concrete mixture but retains cement,
- a drainage that transfers the water and air removed from concrete to outside the formwork,
- a curing system that maintains some water ready to be taken back by hardening concrete.

When concrete is cast against CPF there is a significant change in surface appearance. The visible effects on surfaces comparing conventionally formed concrete are the following:

- elimination of blowholes and other faults,
- darker colour,
- textured dull finish.

The use of CPF for forming vertical or inclined concrete surfaces is particularly beneficial. While the main reason for eliminating blowholes is aesthetic, there are many construction cases where achieving a smooth, fault-free concrete surface is more critical. Such surfaces are also more suitable to cover with protection coatings or paintings.

Nowadays, in Europe there are two kinds of CPF in use, both based on a non-woven polypropylene fibre fabric. The CPF system named *Zemdrain* is a propylene fabric spun bonded, while the second one with commercial name *Formtex* has thermally bonded fibres on one side of the fabric.

Many tests concerning properties of concrete with reference to durability were done for both kinds of CPF systems [3], [4]. All those investigations were based on specimens taken from simple members, usually in the form of core specimens. The general aim of the tests presented in this paper was to clarify how the improved mechanical properties of formed concrete surfaces may influence the behaviour of members subjected to bending and shear, regarding mainly cracking appearance.

The CPF system used in the tests was based on the thermal-bonded polypropylene fabric *Formtex*, developed and marketed by *Fibertex*, Denmark.

2. Test Members

For the first time the cracking of RC members formed against permeable and impermeable formwork has been tested and compared. The experiments on members subjected to bending and shear were the basis for this comparison. Two kinds of beams were tested in typical four-point test:

- simple prismatic beams (BP) with rectangular cross-section *H*/*B* = 0.30/0.20m, 2.60m long, with main reinforcement varying according to different concrete strength (*Fig. 1a*),
- T-beams (BT) with rib cross-section *H*/*B* = 0.30/0.12m, the flange width 0.30m and depth 0.05m, 4.40m long (*Fig. 1b*).

a) b)

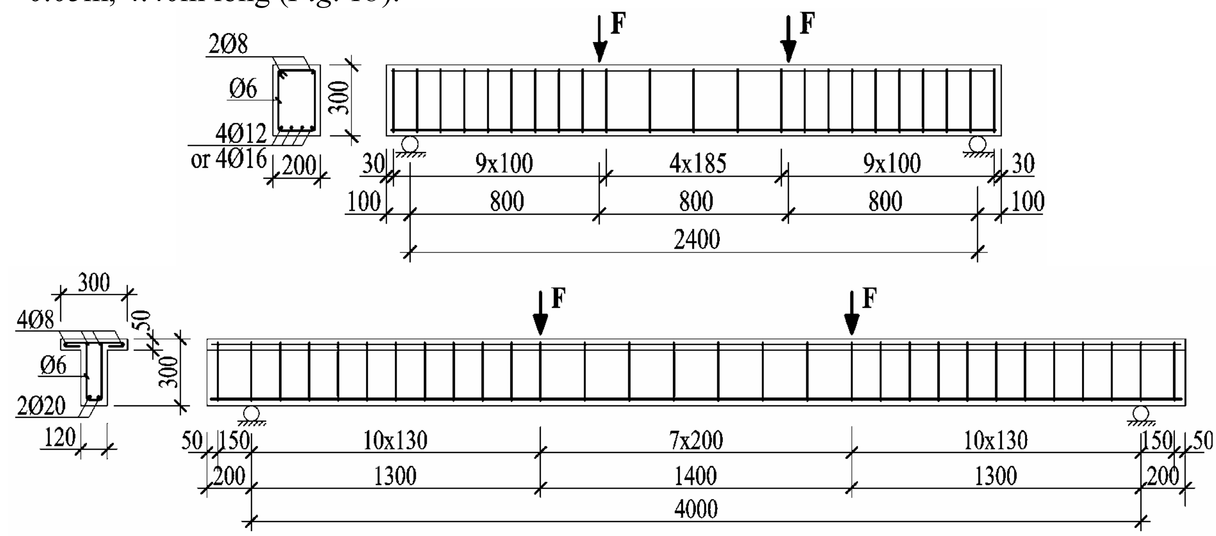

Fig. 1 Dimensions and reinforcement of beams in tests (in mm): a) prismatic beams, b) T-beams

Seven series of two prismatic elements were prepared. In each series the beams were formed with and without CPF. Another two series of T-beams were tested too. Exactly the same concrete mixture and reinforcement was used for both elements in series.

Several mix proportions were used, with various *w*/*c* ratios and various kind of coarse aggregates. The properties of materials in particular series of beams are presented in *Table 1*. The reinforcement of the beams was provided in such a way that flexural and shear failure was likely to occur.

Table 1 Description of materials in series of beams (BP – prismatic beams, BT – T-beams)

Series number & symbol	Kind of coarse aggregate	Properties of concrete			Main reinforcement f_{yk} = 410MPa
		Compressive cylindrical mean strength f_{cm} (MPa)	Tensile splitting mean strength f_{ctm} (MPa)	Modulus of elasticity E_{cm} (GPa)	
1-BPb	basalt	39.6	3.4	35.6	4∅12
2-BPb	basalt	55.8	4.5	41.9	4∅16
3-BPb	basalt	100.9	7.2	51.9	4∅16
4-BPg	granite	37.3	3.3	27.3	4∅12
5-BPg	granite	38.9	3.1	28.8	4∅16
6-BPq	quartzite	31.8	3.5	25.2	4∅12
7-BPq	quartzite	32.4	2.4	33.6	4∅16
8-BTq	quartzite	31.8	3.5	25.2	4∅20
9-BTq	quartzite	32.4	2.4	33.6	4∅20

Different concretes were introduced to check the effectiveness of CPF in cases of various mix proportions and consistence. Concrete recipes used in tests are presented in *Table 2*.

Table 2 General data for concrete recipes used in series of beams

Series number - symbol of beam	Consistence Vebe (s)	Mix proportions (kg/m³)					w/c
		Cement kind; amount	Sand	Coarse aggregate	Water	Admixtures SP, SF; amount	
1-BPb	11	CEM I 32.5R; 300	653	1524	149	-	0.50
2-BPb	12	CEM I 32.5R; 500	571	1330	180	-	0.36
3-BPb	12	CEM I 42.5R; 455	615	1435	113	SP; 9, SF; 45	0.25
4-BPg	9	CEM I 32.5R; 300	600	1400	149	-	0.50
5-BPg	9	CEM I 32.5R; 300	600	1400	149	-	0.50
6-BPq	7	CEM II 32.5; 420	645	1099	197	-	0.47
7-BPq	5	CEM II 32.5; 375	662	1127	175	SP; 3	0.60
8-BTq	7	CEM II 32.5; 420	645	1099	197	-	0.47
9-BTq	5	CEM II 32.5; 375	662	1127	175	SP; 3	0.60

3. Test instrumentation

In typical four-point test (*Fig. 1*) the force F was applied in steps of 5kN. After each increment of loading the following data were recorded:

- deflections of beams, by means of inductive gauges, exact to 0.01mm (automatic record),
- concrete strains, by means of electro-resistance gauges (automatic record),
- cracking load, F_{cr}, and ultimate load, F_u,
- after cracking – width and extent of cracks, particularly in the level of main reinforcement,
- camera-record of crack development.

The cracks were watched and measured with microscopic glass exact to 0.005 mm. Such accuracy was possible because the surfaces were covered with brittle white painting.

General view of prismatic beam (series BP) on the testing stand shows *Fig. 2a*, while the T-beam (series BT) is presented in *Fig. 2b*.

a) **b)**

Fig. 2 Beams of series BP (a) and BT (b) equipped to tests

4. Test results

Test results and direct observations showed the noticeable increase in cracking resistance of beams formed against CPF compared with similar beams cast against ordinary impermeable forms. In average, it was assessed as about 20% but in particular pairs of beams the results differed. Similar differences were obtained in deflections and in the summarized width of cracks along the beams. The main results are presented in *Table 3*.

Group of selected diagrams for one series of prismatic beams made from concrete with basalt aggregate (series 2-BPb) is presented in *Fig. 3*. In this case the first cracks were observed in beams formed against CPF at the load of 2*F* = 60kN, while in beams formed against impermeable formwork at the load of 2*F* = 50kN. Similar comparison of diagrams for beams made from ordinary concrete made from granite aggregate (series 4-BP) is presented in *Fig. 4*.

Table 3 Basic test results for 7 series of beams BP and 2 series of beams BT

Series number – symbol of beam	Cracking load $2F_{cr}$ (MPa)	Ultimate load $2F_u$ (MPa)	Max strain in compressed concrete $\varepsilon_{c,max}$ (‰)	Deflection a_{70} at load $2F$=70 kN (mm)	Σw_{70} – sum of cracks width at load $2F$=70 kN (mm)
1-BPb	40	134	2.67	4.13	0.51
1-mBPb	50	135	2.79	2.92	0.28
2-BPb	50	210	1.66	2.66	0.29
2-mBPb	60	212	2.99	1.71	0.12
3-BPb	60	222	3.32	1.76	0.12
3-mBPb	70	225	3.56	1.27	0.03
4-BPg	30	135	3.33	3.61	0.66
4-mBPg	40	135	3.24	2.46	0.42
5-BPg	40	210	2.02	2.22	0.25
5-mBPg	50	212	2.71	1.56	0.14
6-BPq	32	129	3.69	4.01	0.90
6-mBPq	34	137	3.74	3.54	0.63
7-BPq	50	210	3.17	2.49	0.29
7-mBPq	50	211	2.63	2.32	0.17
8-BTq	10	90	1.89	15.54	2.01
8-mBTq	15	91	1.72	14.56	1.72
9-BTq	15	89	1.68	16.07	2.21
9-mBTq	20	90	1.65	14.83	2.01

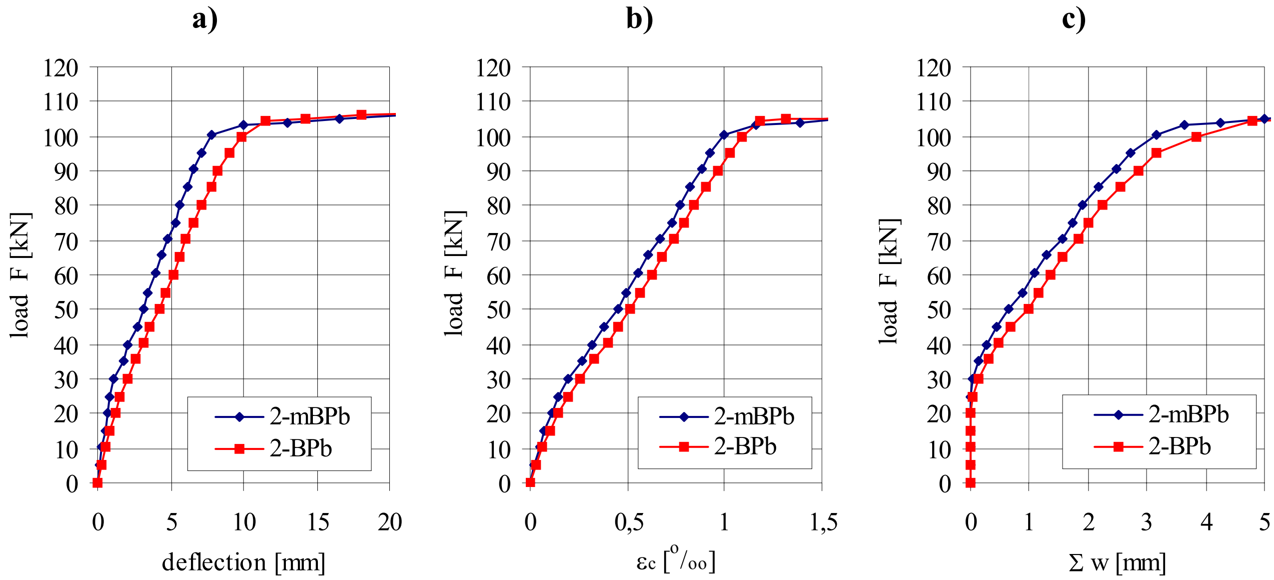

Fig. 3 Diagrams for beams formed from concrete B60 (f_{cm}=55.8 MPa) with and without CPF: a) load vs. deflection, b) load vs. compressive strain, c) sum of cracks width along the beam at reinforcement level

In all series of beams, despite differences in concrete properties, the tendency of increased cracking resistance in members formed against CPF is visible.

Another observation was connected with the behaviour of beams after cracking and close to failure. The development of many cracks with relatively small width was recorded in beams made in CPF (Fig. 5 and 6) – the crack pattern was more regular than in beams made in impermeable formwork. It was also more symmetrical on both sides of beams.

Although the bearing capacity of both beams in a series was almost the same, the deflection of beams made in CPF was significantly smaller up to the level of load very close to failure (see Fig. 3a and Fig. 4a). Such results in deflection are in full consistence with results of the summarised total width of cracks measured along the beams (see Fig. 3c and Fig. 4c).

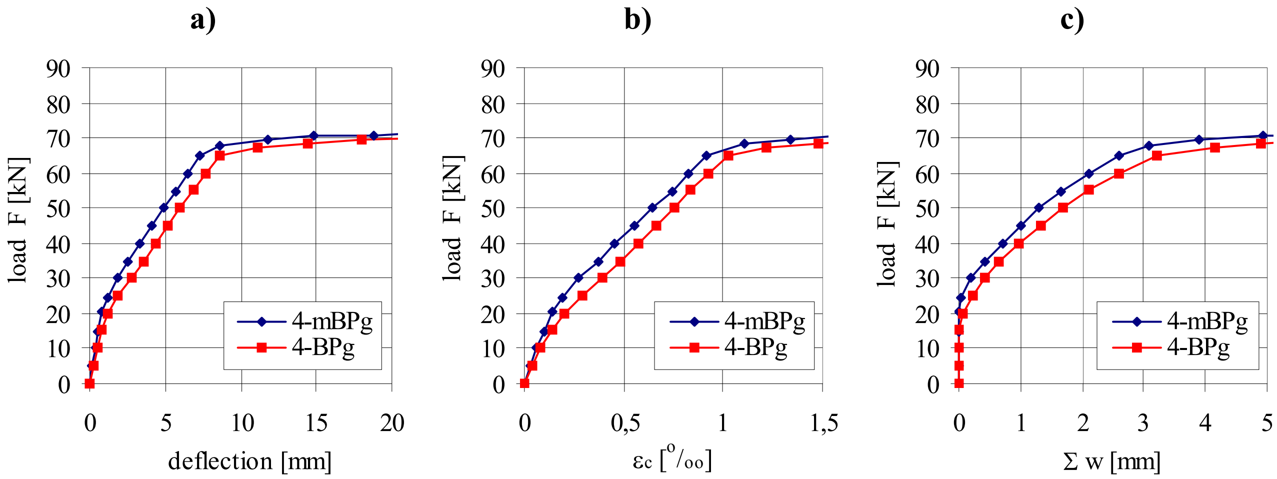

Fig. 4 Comparison of diagrams for beams made from ordinary concrete B30 (f_{cm}=37.3 MPa), with and without CPF: a) load vs. deflection, b) load vs. compressive strain, c) sum of cracks width along the beam at reinforcement level

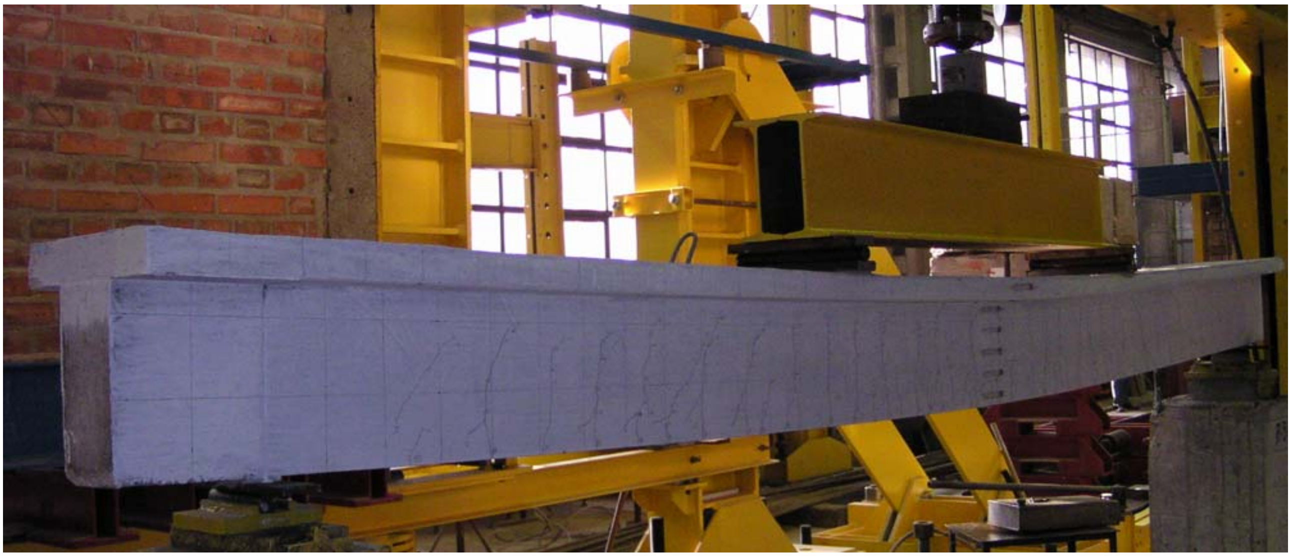

Fig. 5 Beam 8-mBT after test – regular cracks on the surface of concrete formed against CPF

5. Conclusions

The results of tests were considered interesting from at least two points of view. The stiffness of beams formed in CPF is noticeably greater and this is beneficial from a mechanical point of view. The later the cracks appearance and the smaller the width of cracks, the higher durability of concrete members.

The effect of forming concrete against CPF resulting in increased cracking resistance was recorded in all series of beams, nevertheless this influence was a greater in members made from concrete with a higher *w/c* ratio. The influence of compacting concrete quality, particularly vibrating intensity, was recorded too. Many factors should be taken into account for future investigations in this area but, in general, this way of improving durability seems to offer potential.

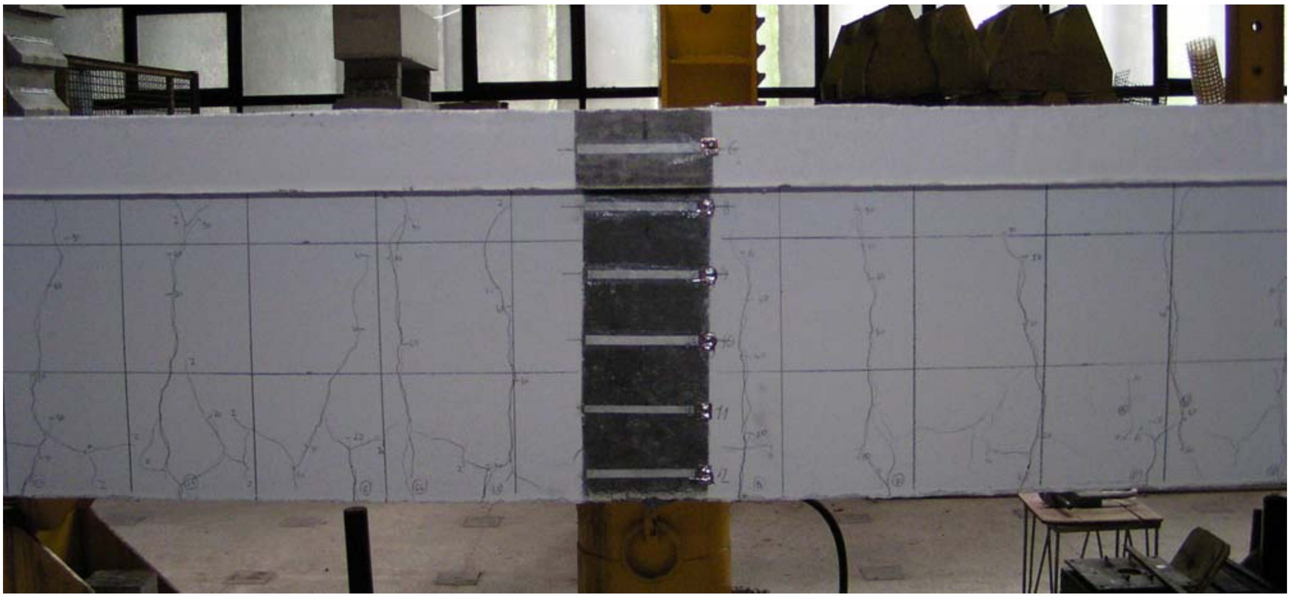

Fig. 6 Middle part of beam 8-mBT – many regular cracks of small width on the surface of concrete formed against CPF were observed almost up to failure

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