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THE BEHAVIOUR OF COATINGS ON CONCRETE SUPPORTS IN RELATION WITH DIFFERENT FORMS OF WATER ATTACK

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Abstract
Coatings are designed to protect concrete against environmental attacks. Water is one of the aggressive parameters able to deteriorate the concrete structure. The aim of this paper is to present the effects of water during operations of application of the coating on the support and on the pull-off test conditions; effects of semi-permanent humidity by absorption from the uncoated face, total immersion or diffusion of water from the back face of the support are analysed. This is sometimes more aggressive than direct attack and may make the coating protection inefficient.
Keywords: Interface, coating, concrete, water, capillarity, water vapour transmission, adhesion.

1 Objectives of the tests

The objectives of the research are to analyse the effect of non-permanent water attack on coating systems used for protection of concrete supports. Four types of aggression modes will be presented here :

- adhesion of coatings on water saturated supports by capillary absorption from the uncoated face; we studied also the influence of the degree of saturation of the support and the use of hydrofugation layer;
- adhesion of coatings on water saturated supports by total immersion into water; degree of saturation of the support and hydrofugation are also analysed;
- adhesion of coatings on water saturated supports by capillary absorption from the uncoated face, submitted to freeze-thaw cycles;
- adhesion of coatings on supports where water vapour transport is coming from the back face of the support.

The pull-off tests have been realised in dry, moist and saturated situations.

2 Description of coatings and repairing systems

2.1 Supports

Concrete sandblasted supports have been prepared at different degrees of saturation obtained in the following conditions :

- dry support (S) : hygrothermic equilibrium at 23 ± 2°C and 50 ± 5 % R.H.;
- moist support (h) : after 7 days of total immersion into water, the support is stored for 24 h at 5°C and 90 ± 5 % R.H. before application in these conditions. It corresponds to a degree of saturation of 95 % [4];
- back moisture (H) : the support is submitted to water capillary absorption from the back face immersed into water on 1 cm high at 23 ± 2°C during 72 h before application;
- hydrofugation (I) : 7 days after hydrofugation, the support is submitted to water capillary absorption from the back face immersed into water on 1 cm high at 23 ± 2°C during 72 h before application.

2.2 Application and storage

The coating systems are applied according to the prescriptions of the manufacturer. The interval between the different layers is 24 h and the samples are stored for 7 days at application conditions and for 7 days at 23 ± 2°C and 50 ± 5 % R.H. before pull-off test.

2.3 Description of the coating systems

Table 1 describes the different coating systems used and tested for the protection of concrete.

Table 1. Ten coating systems for protection of concrete

System nr	Nature of the resinous layer			Application ratio (g/m²)		
	impregnation	base layer	finishing layer	impregnation	base layer	finishing layer
1	methacrylic (O)	methacrylic (O)	methacrylic (O)	100 - 300	200	200
2	acrylic (A) (+ pigments)	acrylic (A)	acrylic (A)	250	400	400
3	PVAc (O)	methacrylic (A)	methacrylic (A)	200	250	200
4	PUR mono-component	PUR mono-component	-	175	530	-
5	methacrylic (O)	acrylic (A)	-	100	400	-
6	methacrylic (O)	acrylic (A)	acrylic (A)	200	800	400
7	PUR 2 components	PUR 2 components	PUR 2 components	200	300	125
8	vinylic (O)	vinylic (A)	vinylic (A)	200	350	350
9	vinylic (O) (+ pigments)	vinylic (O) (+ pigments)	vinylic (O) (+ pigments)	200	200	200
10	-	methacrylic (O)	methacrylic (O)	-	200	200

(A) = aqueous solution (O) = organic solvent

3 Capillary absorption from uncoated face

3.1 Description and results of the tests

Cores of 5 cm diameter are taken from the specimens prepared as described in chapter 2 and immersed on 1 cm high into water, by the uncoated face in order to promote capillary absorption. The samples are 5 cm high and the adherence is measured directly after the exit from water.

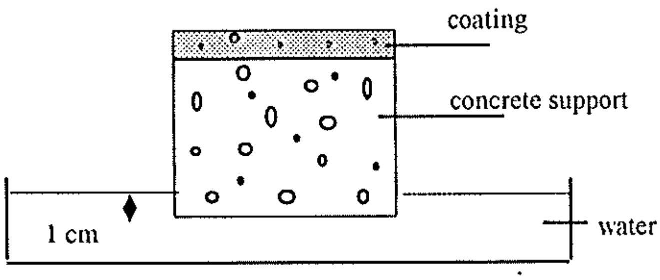

Fig. 1. Test description for capillary absorption by uncoated face

Table 2. Adherence of coatings (N/mm²) and type of rupture* after capillary absorption from uncoated face

System nr	Adherence vs degree of saturation of the support			
	S	h	H	I
1	3.95 c	4.46 c	3.76 c	2.70 c
2	2.02 a	2.50 b	1.25 a	0.90 a
3	4.08 c	3.38 c	2.54 a, c	2.39 a, c
4	3.03 c	4.34 c	4.69 c	3.88 c
5	1.94 a	1.62 a	1.18 a	1.16 a
6	0.56 b	0.92 b	0.66 b	0.29 b
7	4.70 c	3.35 c	3.65 c	3.29 c
8	1.23 a	1.87 b	1.47 b	1.01 a, b
9	2.14 a	3.20 a	1.03 a	1.22 a
10	3.93 c	4.64 c	3.15 c	3.55 c

* a = adhesive rupture
b = cohesive rupture in the coating
c = cohesive rupture in the concrete support

This corresponds to the moist condition test (H).

3.2 Observations

- Coatings on dry support : for all the systems where there is a cohesive rupture in the support, the same behaviour is observed when test is realised on moist coating. Systems 6 and 8 present a cohesive rupture at moist state higher than at dry state (64 % for 6 and 52 % for 8).

- Hydrofugation : the same behaviours than for dry support are observed for hydrofugated support. The systems presenting cohesive ruptures in the support are presenting the same performances while systems showing cohesive ruptures in the coating have lower values (± 50 % for 6). Finally, when the rupture was of adhesive type, the difference between hydrofugation on dry and wet support is high (45 % for 9 and 65 % for 5).

The treatment of the concrete support with these silanes don't permit to avoid alterations of adhesion when water is coming by capillary absorption from the back face.

- When coating is applied on supports submitted to water absorption from back face, we observe more sensitive behaviours, for example for system 3 (the cohesive rupture type becomes adhesive), for system 9 (loss of cohesion) or even for system 2. The adherence falls down for systems 2, 3, 5 and 9.

4 Immersion into water

4.1 Description and results of the tests

Core samples are immersed into water during 3 days; the adherence is measured directly after exit from water.

Table 3. Adherence of coatings (N/mm^2) and type of rupture after immersion into water

System nr	Adherence vs degree of saturation of the support			
	S	h	H	I
1	2.72 a	2.60 a	2.73 a, b	2.48 c
2	0.48 a	0.85 a	0.26 a	0.82 a
3	1.54 a	0.96 a	0.47 a	2.09 a
4	4.76 c	1.99 a	3.52 c	3.40 c
5	0.53 a	0.26 a	0.27 a	0.75 a
6	0.29 a	0.26 b	0.27 b	0.29 b
7	3.91 c	2.01 a	2.31 c	2.40 c
8	1.15 a	0.92 a	0.75 a	1.14 a, b
9	0.87 a	1.34 a	0.31 a	0.79 a
10	2.95 a	1.68 a	1.21 a	3.40 c

This corresponds to the saturated condition test (T).

4.2 Observations

- Coatings on dry support : cohesive rupture type on dry support often becomes adhesive for wet support, except for the two polyurethane based systems. Two methacrylic impregnation systems present adhesive rupture (> 2 N/mm^2) but for vinylic impregnation systems, that falls to 1,15 N/mm^2. Adherence of system 2 falls down for 80 % and the adherence of 6 becomes 50 % lower.

Total immersion into water induces alterations for coatings greater than capillary absorption from uncoated face.

- Hydrofugation : it generally permits to avoid the fall of adherence.
- Application on wet support (near saturation point) induces a loss of adhesion and more adhesive ruptures.
- When coatings are applied on support submitted to water absorption from back face, the loss of performances is greater than for moist state, except for polyurethane based systems and system 1; indeed, in this case, the polymerisation in H state (ambient temperature) is lower disturbed than in moist state (5°C and 90 % R.H.).

5 Water and freeze-thaw cycles

5.1 Description and results of the test

Samples of 40 x 25 x 4 cm are stored at 23 ± 2°C and 50 ± 5 % R.H. for 7 days. They are then immersed into water on 1 cm by the uncoated face for 72 hours (see test principle described in 3.1). The samples are submitted afterwards to 50 cycles :

- 23 h in 1 cm water at 23 2°C;

- 1 h (just after exit from water) of application of calcium chloride ($CaCl_2$ - 500 g/l) at -18°C on coated face (2 cm high).

During the week-end, the samples were maintained in semi-immersion.

The solicitations of the coated concrete are so :

- water absorption from uncoated face, and

- freezing effect on coating, interface and superficial layer of concrete support. This can induce tangential stresses at the interface by difference of thermal dilatation coefficient and thermal gradients. Normal stresses can also appear due to freezing action.

Table 4. Adherence of coatings (N/mm^2) and type of rupture after capillary absorption and freeze-thaw cycles

System nr	Adherence	Type of rupture
1	3.34	c
2	2.85	a
3	1.96	a
4	3.89	c
5	1.66	a
6	0.86	b
7	3.99	c
8	1.26	a
9	3.36	c
10	3.70	c

5.2 Observations

The results are coherent with the conclusions obtained in previous tests :

- systems with adherence greater or near the cohesion of the support when the test is realised in moist state, don't present any perturbation. Their adherence is high again after ageing (systems 1, 4, 7 and 10);
- systems with low adhesion/cohesion values present formation of blisters (systems 2, 6 and 8);
- systems 3, 5 and 9, which showed important alterations of adherence in moist state, present here different behaviours (fall from 4.08 to 1.96 for 3 and 1.94 to 1.66 for 5).

6 Water vapour diffusion

6.1 Description and results of the tests

Support of 40 x 60 cm are fixed on boxes and the coating systems are applied after fixing; one half support has been treated with hydrofugation

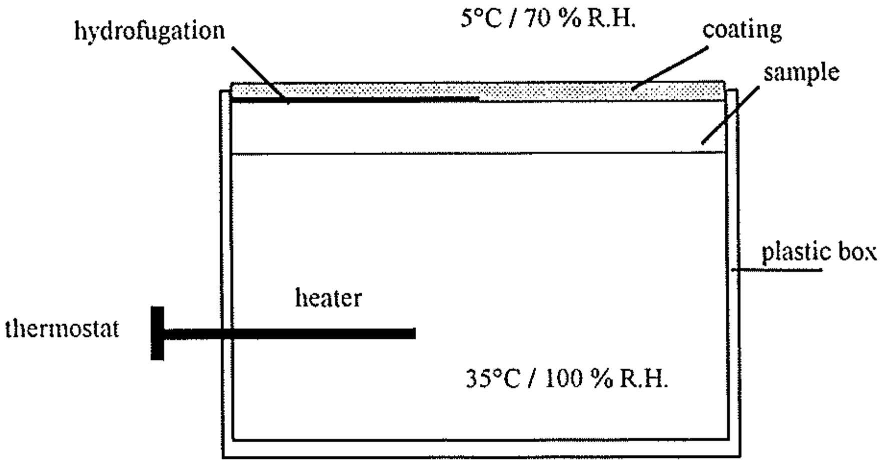

Fig.2. Test device for water vapour diffusion measurements

After 7 days maturation at 23 ± 2°C and 50 ± 5 % R.H., the boxes are placed in a climatic chamber at 10°C and 70 % R.H. for 2 months.

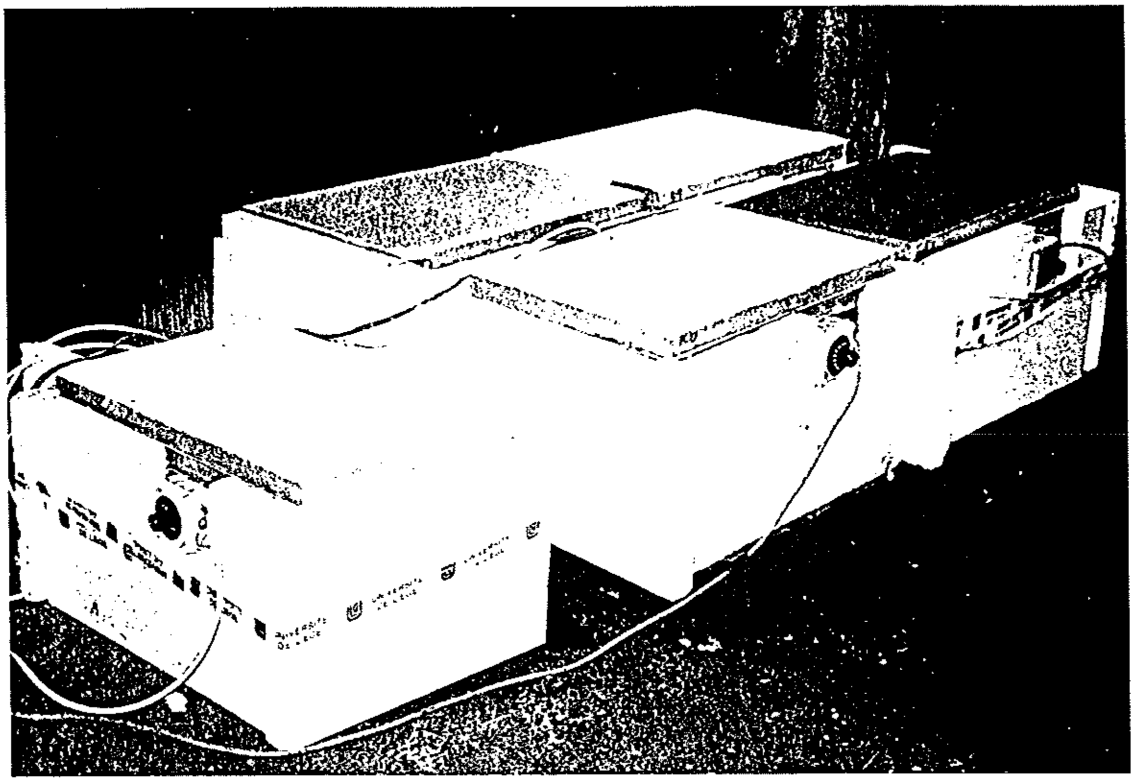

Photo 1. Illustration of test device for water vapour diffusion measurements

Table 5. Adherence (N/mm²) after water vapour diffusion test (2 months)

System nr	Without hydrofugation	With hydrofugation
1	3.11	2.61
2	1.11	1.35
3	1.55	2.26
4	3.42	3.19
5	1.29	1.71
6	0.44	0.61
7	3.44	3.59
8	2.27	2.09
9	2.91	2.35
10	3.40	3.34

6.2 Observations

Systems presenting cohesive rupture type before ageing have an excellent behaviour after the test, except for system 3. Adherence for system 2 falls down for 55 % of its initial value while systems 6 and 8, characterised by cohesive ruptures in the coating, present a loss of cohesion of 20 %.

Hydrofugation of the support generally limits the loss of adhesion or cohesion of coatings (35 % in place of 55 % for system 2) and induces a lightly higher value of cohesion for systems 6 and 8.

7 Conclusions

Table 6 presents a summary of the results of the tests realised on ten systems and twelve ageing situations :

first letter :	test conditions	S = dry coating
		H = moist coating
		T = immersed coating
second letter :	application conditions	S = dry support
		h = moist support
		H = moist support due to capillary absorption
		I = support with hydrofugation

The tests in dry conditions were previously realised during the research program [8].

Table 6. Adherence (N/mm²) for the 120 combinations of systems and supports

System nr	SS	Sh	SH	SI	HS	Hh	HH	HI	TS	Th	TH	TI
1	4.5	4.06	3.28	3.53	3.95	4.46	3.76	2.7	2.72	2.60	2.73	2.48
2	1.94	1.3	0.92	1.73	2.02	2.50	1.25	0.90	0.48	0.85	0.26	0.82
3	4.13	4.12	2.99	4.18	4.08	3.38	2.54	2.39	1.54	0.96	0.47	2.09
4	3.71	3.26	3.68	3.96	3.03	4.34	4.69	3.88	4.76	1.99	3.52	3.4
5	2.55	0.81	0.96	2.21	1.94	1.62	1.18	1.16	0.53	0.26	0.27	0.75
6	0.5	0.31	0.26	0.71	0.56	0.92	0.66	0.29	0.29	0.26	0.27	0.29
7	4.22	3.46	3.12	3.74	4.7	3.35	3.65	3.29	3.91	2.01	2.31	2.4
8	2.5	1.91	1.02	1.58	1.23	1.87	1.47	1.01	1.15	0.92	0.75	1.14
9	1.83	3.13	0.59	1.48	2.14	3.20	1.03	1.22	0.87	1.34	0.31	0.79
10	5.03	3.48	2.95	4.08	3.93	4.64	3.15	3.55	2.95	1.68	1.21	3.40

Some general comments can be made on the results presented in table 6.

- Coatings laid down on dry support : the most brittle link of the system is the interface between base layer and concrete support. This interface is generally reinforced by the resistance of the impregnation; when the test is realised on samples humidified by capillary absorption, same conclusions can be made. However, when adherence is measured in immersion conditions, we observe some falling down of the adherence, that can be due for example to blistering.
- Coatings laid down on moist supports (95 % saturation) : the positive contribution of the resistance of the impregnation seems to be again effective for tests in dry and moist conditions. However, a decrease of the cohesion of the support can be observed, due to the lower penetration of the impregnation into the support.
- Coatings laid down on saturated support : same conclusions than for moist supports can be made, with a more important decrease of the properties and contribution of the impregnation to the adherence of the interface.

- Coatings laid down on supports with hydrofugation : hydrofugation generally induce a better behaviour of the interface for dry supports tested in dry or moist conditions. It seems to act as protection against water or vapour penetration. For the water vapour diffusion tests, coatings, laid down on hydrofugated supports present a better behaviour than for normal dry supports. However, adherence measured on moist or immersed samples shows the same decrease than the one observed for coatings laid down on dry supports.

This could lead to a classification of the test and application conditions, classified as a function of a decreasing adherence value.

Table 7. Classification of adherence vs condition of application and test

Class	Situation
Class 1	SS, Sh, SH, SI, HI, TI
Class 2	HS, TS
Class 3	Hh, Th
Class 4	HH, TH

8 Acknowledgement

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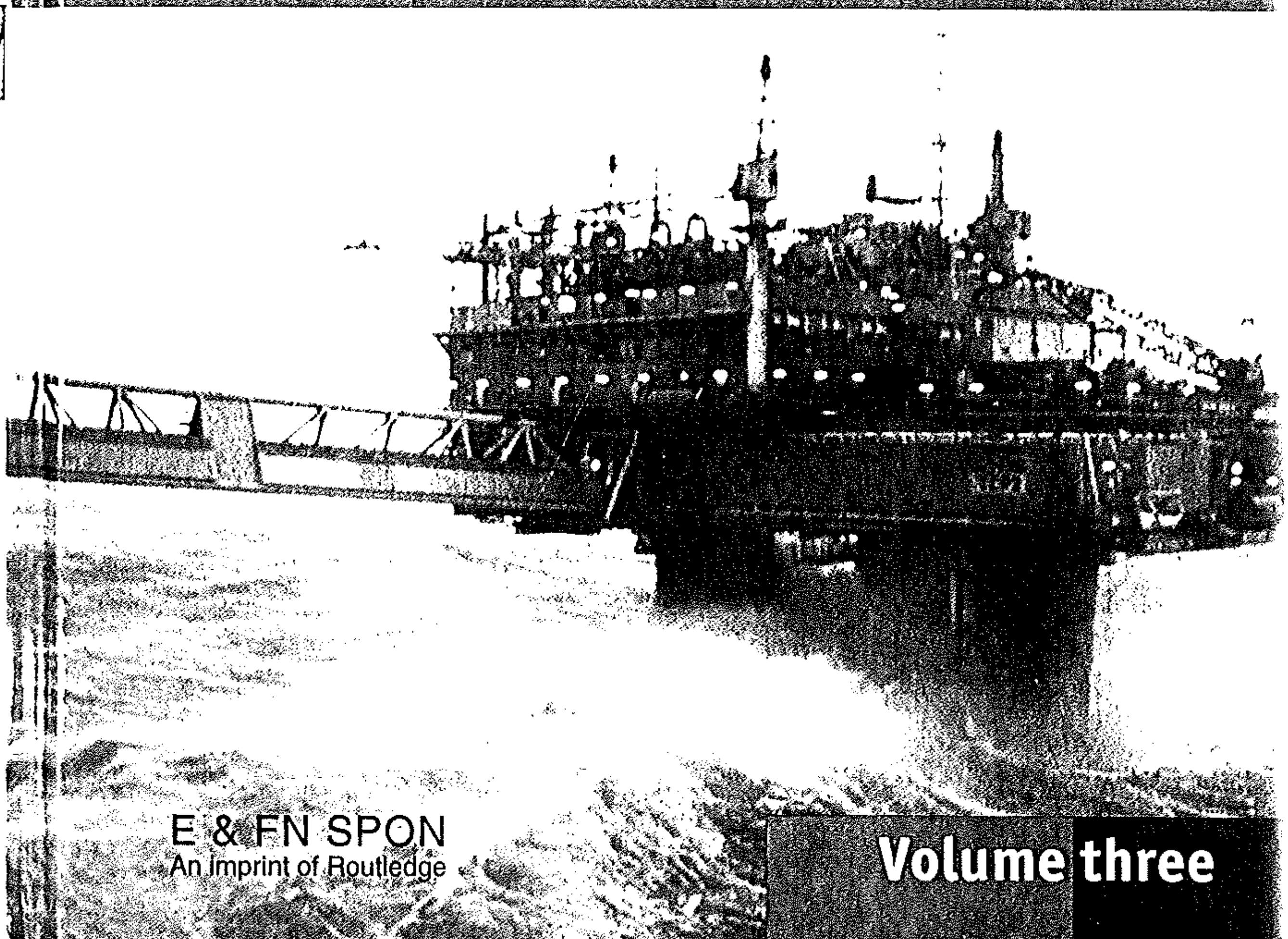
CONCRETE UNDER SEVERE CONDITIONS 2

Environment and Loading



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Volume three