2nd International Conference on
Concrete under severe Conditions, Tromso (Norway), June 21-24, 1998

ANALYSIS OF THE RESISTANCE TO WATER OF THE INTERFACE BETWEEN CONCRETE AND REPAIRING SYSTEMS : EXPERIMENTAL APPROACH

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Abstract
The behaviour of the interface between repairing mortars and the concrete support will act on the properties of the bond; the water migrates from both sides of the structure and will corrode steel bar reinforcement. This paper analyses the effects of the nature of the mortar, the steel reinforcement protection system and the type of surface preparation.
Keywords : Interface, repair, concrete, resistance to water, adhesion.

1 Introduction

Water is the first cause of the alteration of the adhesion between concrete and repairing mortars : it may be present at the interface and act by mechanical processes (freezing), chemical reactions (hydrolysis) or physical action (modification of interfacial forces).

It is of the prime importance to be able to understand the mechanisms of degradation in order to be able to choice the best repairing systems and steel reinforcement protection.

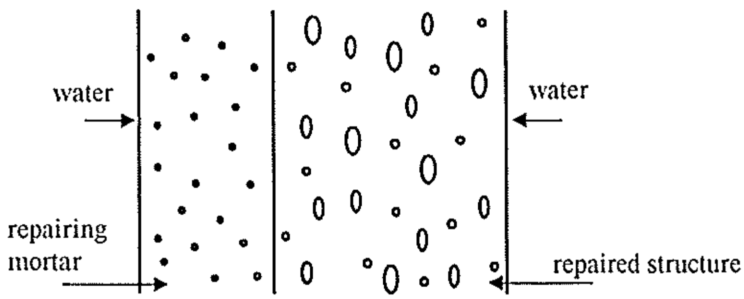

Fig. 1. Water intrusion in concrete, repair system and interface

A lot of parameters affect the behaviour of the interfacial zone [1] [2] : in our case, diffusion and permeability coefficient or water vapour transmission factor let us explain these mechanisms of degradation. The information's given hereafter are an illustration of the effects of water at the interface between repairing mortars and a repaired structure where steel bar reinforcement is embedded at the interfacial zone.

2 Description of the phenomenon's at the interface

The interface is submitted to a double solicitation due to water :

- first, there may be water or aqueous solutions transfers, due to migration and infiltration along this interface, or diffusion and capillar absorption from the zones just near the one that has to be repaired. The resistance to these attacks will depend directly to the quality of the interface : preparation of the surface, adherence, porosity, ...
- secondly, we may observe a solicitation due to the presence of the reinforcement. Due to corrosion, this steel reinforcement expands, inducing ruptures in the concrete support, in the repairing mortar or at the interface. The corrosion will depend on the possibilities of infiltration of water or other solutions at the interface, but also on the steel protection, the alkalinity of the repairing mortar and its impermeability.

The next parameters will be studied : the repairing mortar type (Polymer Cement Concrete or Polymer Concrete); the type of protection system against corrosion; the type of surface preparation.

3 Description of the tests and products

3.1 Type of samples

The specimens are 4 x 4 x 16 cm samples composed with concrete support and repairing mortar. The steel reinforcement bar is between the two layers. The support and the repairing mortars volumes are 2 x 4 x 16 cm. The steel reinforcement of 8 mm diameter is at the interface and immersed in the two layers. It is 12,5 cm long.

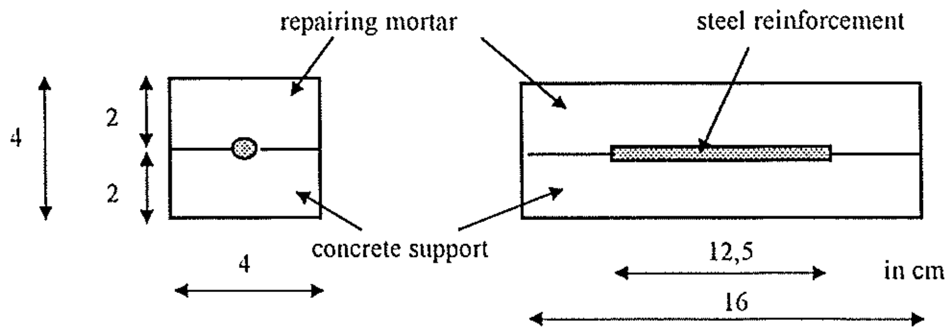

Fig. 2. Type H sample

It can represent the situation where we have a repairing system applied on a concrete support after sandblasting or hydrojetting surface preparation.

This repairing system is of course not the best situation but the aim of the test is the analysis of the behaviour of the mortars or the coatings as protection systems against the corrosion of steel.

3.2 Concrete support

The support is a standardised mortar according to EN 196 : sand; cement, water.
The cement used for the mix was Portland cement with 11 % C_3A. It is minimum 28 days old. The preparation of surface was of two types :
- sandblasting of the support and the reinforcement;
- brushing with metallic brush of the support and reinforcement.

3.3 Repairing systems and steel protection

We used systematically impregnation layers for PC mortars and slurries for PCC mortars in order to promote adherence. The protection of steel reinforcement was realised with :
a) nothing;
b) isolation primer (epoxy resin);
c) anodic primer (organic coating with inhibitor pigments);
d) alkaline primer (mineral coating with inhibitor pigments).
All the products in this research were used in accordance with specifications of manufacturers. Table 1 gives the information's on the systems tested.

Table 1. Description of the systems tested

System nr	Mortar type	Reinforcement protection	Bonding layer	Remarks
A	PC	epoxy resin	epoxy resin	same material for protection and bonding layer
B	PC	epoxy resin	epoxy resin	idem
C	PC (low density)	epoxy resin	epoxy resin	idem
D	PC	lead silichromate	epoxy resin	24 h between protection and bonding layers
E	PCC	epoxy resin	cementitious slurry	24 h interval
F	PCC	epoxy resin	cementitious slurry	2 protection layers; 24 h between protection and bonding layers
G1	PCC	epoxy resin	diluted mortar with polymeric emulsion	2 protection layers (2 x 300 ml/m²); 24 h interval
G2	PCC	cement modified with polymers	diluted mortar with polymeric emulsion	2 protection layers (2 x 500 ml/m²); 3 h interval
G3	PCC	monocomponent resin without solvent	diluted mortar with polymeric emulsion	2 protection layers (2 x 100 ml/m²)
H	PCC	cement modified with polymers		2 protection layers; 24 h between protection and bonding layers
I	PCC	epoxy resin	Portland cement with polymeric emulsion	2 protection layers + sand; 24 h interval

4 Ageing cycles

Five types of ageing were organised in order to test the durability of the repairing systems and steel protection :

Ageing 1 : demineralised water
The samples are vertically posed (4 x 4 cm) and half-immersed in water during one week; they are reversed and posed in the same conditions the next week. The water is removed each week and the cycles are repeated respectively for 6, 12 and 24 months.
This alterned immersion promotes phenomenon's of capillar absorption and evaporation.

Ageing 2 : artificial seewater
The composition of the artificial seewater is given in table 2; the cycles sequency is the same than for ageing 1.

Table 2. Composition of artificial seewater

Product	Concentration (g/l)
NaCl	30
$CaSO_4$	1,5
$MgSO_4$	6
$MgCl_2$	5

Ageing 3 : natural ageing in industrial environment (Vilvoorde, Belgium)
The samples are posed on their face 4 x 4 cm.

Ageing 4 : natural ageing in rural environment (Hofstade)
The samples are posed on their face 4 x 4 cm.

Ageing : Kesternich cycles
The 80 Kesternich cycles are realised in accordance with ISO 3231 : *Paints and varnishes – Determination of resistance to humid atmospheres containing sulphur dioxide* (1974).

Only the results of ageing 3 and 4 are presented here.

5 Results of the tests

The quality of the repairing mortar was evaluated by means of visual observations and pull-off tests. Table 3 gives the results of the tests; the observation of the type of rupture is given by the percentage of rupture at the interface. The results are the mean of minimum 3 tests and are realised only the samples type H (reinforcement in the plane of the interface).

Table 3. Adherence of repairing systems

System type	Surface preparation (1)	Ageing type (2)	Ageing time (months)	Adherence (N/mm²)	Percentage of rupture at interface or in the mortar
A	S	3	12	3,81	33
A	S	3	24	3,95	38
A	S	4	24	4,21	0
A	B	3	12	3,62	40
A	B	3	24	3,51	25
A	B	4	24	4,01	13
B	S	3	6	4,32	25
B	S	3	12	4,39	55
B	S	3	24	4,88	60
B	S	4	24	4,09	27
C	S	3	24	2,54	37
D	S	3	24	5,18	0
E	S	3	24	3,02	100
F	S	3	24	3,08	13
F	D	4	12	3,83	30
G1	S	4	12	2	100
G2	S	3	12	2,10	100
G3	S	3	12	0,58	100
H	S	3	24	4,22	100
I	S	3	12	1,22	100

(1) S = sandblasting B = brushing
(2) 3 = natural industrial environment 4 = natural rural environment

The results of the visual information's are long to be presented here. However, some general considerations can be given :

- there is no problem (no separation, corrosion,...) for systems A, D, E and H;
- for the other systems, the degradation is almost always a separation of the two layers initiated at one or the two edges of the sample. It concerns almost exclusively sample type H (where the reinforcement is in the plane of the interface);
- for the samples type C, the degradation is observed from 12 months ageing;
- for samples type F, the industrial ageing seems to be more aggressive than natural rural ageing.

The photo's hereafter present some types of degradation's.

Photo 1. System C - sandblasted - ageing 4 - 24 months :
sticking off the two extremities of the sample

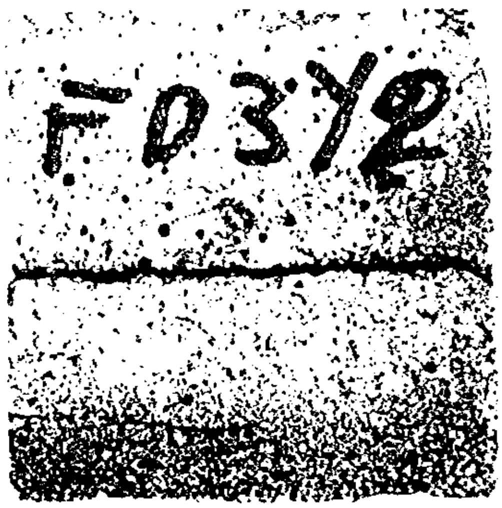

Photo 2. System F - brushed - ageing 3 - 12 months :
sticking off from one extremity of the sample

6 Analysis of the results

One Polymer Concrete and two Polymer Cement Concretes are presenting a good behaviour for durability. The next conclusions can be given.

6.1 Sandblasting

- For one PC mortar, 3 reinforcement protection systems were used (A, D and H). We observed no degradation for the two types of natural ageing and for the three types - isolator, anodic or alkaline - of primers. The adherence is always greater than 3,5 N/mm².
- For the 2 other PC mortars, we observed beginning of sticking off after 12 months exposure in industrial atmosphere. One of the two presents also degradation in rural ageing after 12 months.
- For one of the PCC mortars, 3 reinforcement protection systems were experimented. For the anodic type, we observed a total separation of the two layers after 24 months exposure in industrial area. For the alkaline primer, some beginning of sticking off was observed on some samples after one year in industrial or rural atmosphere. The samples exposed during 24 months didn't present any degradation. For the anodic primer, same conclusions can be given.
- For the three other PC mortars, two of them didn't present any degradation (H and E). However, the third one showed some sticking off after 12 months of rural or industrial exposure.

6.2 Brushing

The best mortar of each category (PC and PCC) was applied on brushed support. The PC mortar didn't present any degradation while PCC mortar was completely disconnected from the support after 24 months of industrial exposure.

6.3 Adherence

The mortars presenting low adherence values (G and I) present also sticking off for the ageing concerned. Among the mortars giving good adherence values (> 3 N/mm²), the degradation percentage is generally low, except for mortars B and C (PC) and mortar F (PCC) applied on brushed surface.
A good initial adherence is so a necessary - but not sufficient - condition to assure the durability of the repairing system.

6.4 Initiation of the sticking off

The separation or sticking off is due to the corrosion of the steel reinforcement. This corrosion is, for all the cases, initiated from the immersed edge in the repairing mortar, when this part is protected by a primer. In the case of alkaline primers, the corrosion is generalised.
In the case of primers based epoxy resins, the corrosion begins at the junction line with the support.

6.5 Adherence of the reinforcement protection

In the case of a cohesive rupture in the support, the steel reinforcement is generally protected when the rupture is of adhesive type in the mortar or at the interface, we observe also a rupture at the interface between the steel bar and the support, except for samples : E, G1, I : ruptures between primer based epoxy resin and the mortar; G2 : rupture between alkaline primer and the mortar; G3 : rupture in the primer based resin.

7 Conclusions

When high quality mortars (non porous materials) are used, steel corrosion generally begins at the interface between the two layers. This corrosion is essentially due to a loss of alkalinity at the interface and may propagate if the adhesion is not sufficient.
The preparation of surface seems to be essential because we observed that alkalinity was better preserved in case of sandblasting than for metallic brushing.
The repairing on the face 40 x 40 mm is not so hard that the one realised on the plane 40 x 160 mm, due to a difference of contact surface. It is always necessary to clear the steel bar to avoid the creation of the interface along its axis.
The three epoxy mortars present different behaviours : one is perfect while the other was degraded during natural ageing : the fissuration was probably due to internal tensions in relation with thermal shocks.
The four PCC are presenting the same dispersion in their behaviour. The best epoxy mortar is minder sensible to the quality of surface preparation than the PCC's : the wetting properties of epoxy resin are higher than water.

At the point of view of the ageing, we observed that :

- all the mortars presented good performances in natural ageing;
- the PC's offer a better chemical resistance in sulphuric and natural industrial atmosphere;
- we observed a very good correlation between natural industrial ageing and 240 cycles of 1 day of Kesternich ageing.

But as it is often the case in civil engineering applications, the quality of the work is the first condition influencing durability.

8 Acknowledgements

The results are the part of a larger research program sponsored by the Walloon Ministry for Research and New Technologies, with the help of the Walloon Ministry of Equipment and Transport, Belgium.

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Edited by O.E. Gjørv, K. Sakai and N. Banthia

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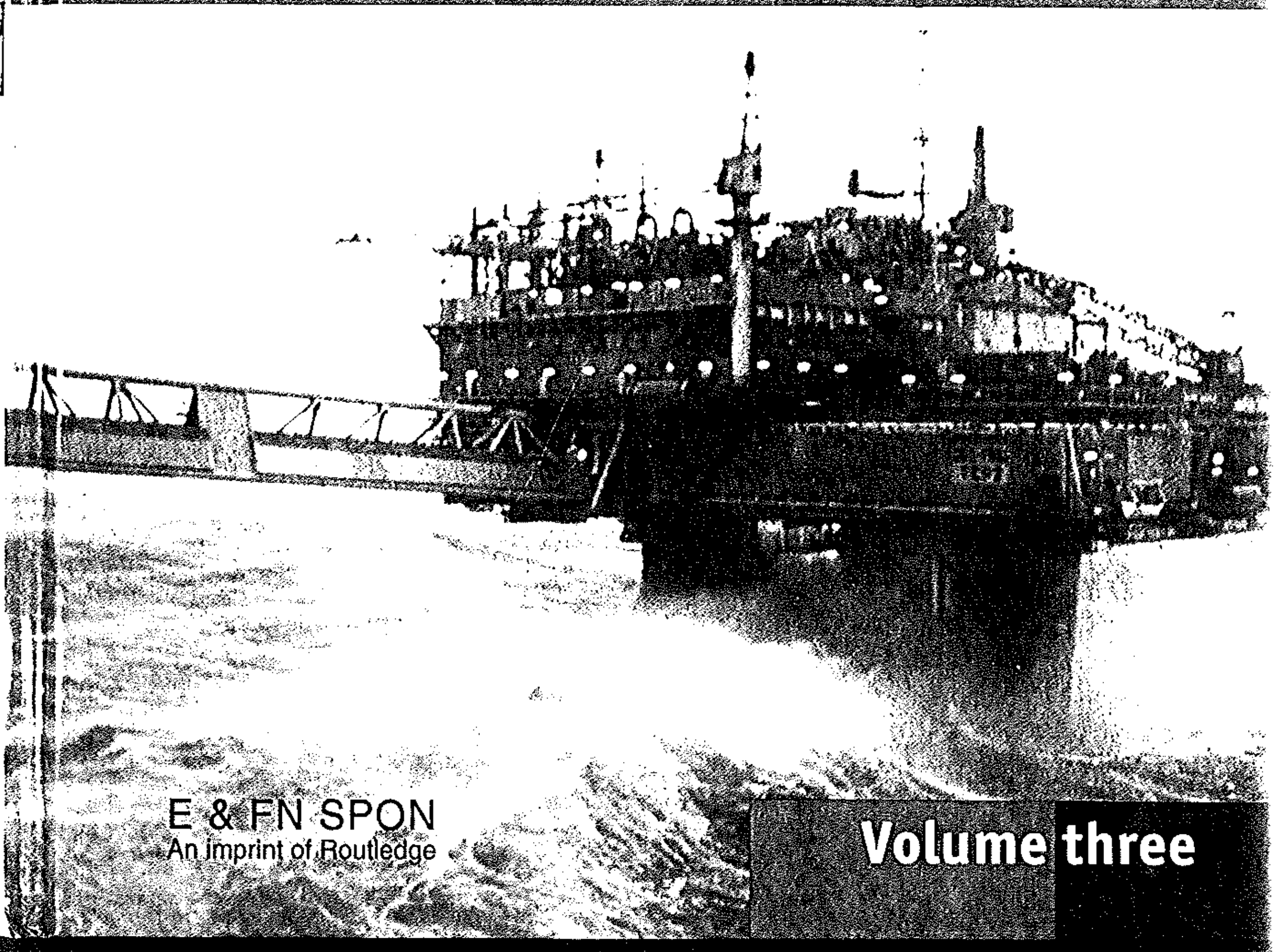

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