EFFECTS OF SUNSHINE/RAIN CYCLES ON THE BEHAVIOUR OF REPAIRING SYSTEMS

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Abstract
The synergetic effect of sunshine radiations and rain is analysed on different repairing systems based on PC, PCC and CC mortars. The behaviour of the composite structure is described by visual observations and adherence measurements.
The effect of temperature gradients and variations seems to be more effective for PC mortars than for PCC and CC repairing systems. The surface preparation factor is also considered by the comparison between sandblasted and polished concrete supports.

1. Introduction

Some ageing factors have a synergetic effect on the properties of materials : a good behaviour may be completely destroyed if a supplementary ageing happens. The aim of the tests described hereafter is to analyse this synergy between sunshine and rain on the durability of adherence between concrete and repairing systems. We developed here unclassical test methods in order to simulate as well as possible on site conditions; complementary tests were implemented with QUV and Xenon arc lamps, which let us the opportunity to compare tests devices and test conditions [7].
We already presented some results about the effects of water itself, which is probably the first cause of alteration of adhesion between concrete and repairing systems [1] [2] [3] : water present at the interface may act by mechanical processes (freezing), chemical reactions (hydrolysis) or physical action (modification of interfacial forces).

In this case, we must take into account the effect of water on the surface of the repairing system and eventually the modification of physical characteristics of water by sun radiations, with a synergetic effect of cold/warm cycles.

2. Effects of water and sunshine radiations

2.1. Effects of water

As already said in Introduction, water may act at different levels : before, during or after the application of the repair system; by permeation, capillary succion or diffusion mechanisms depending on the saturation level of the concrete support and the nature of the new layer.

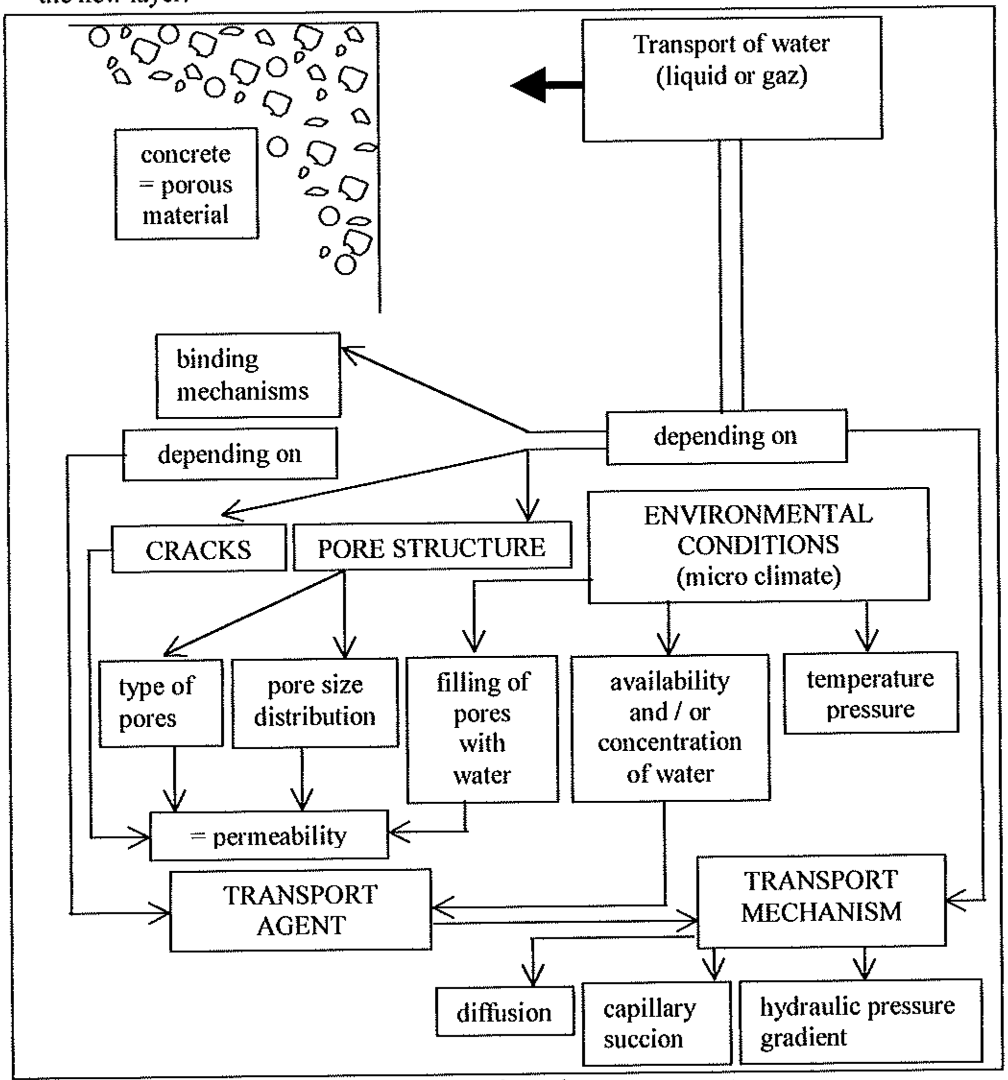

Figure 1: Transport mechanisms of water through concrete structure

We shall here consider its action as variation of temperature factor, inducing temperature gradients in the hole thickness of the composite material concrete support/repairing system. Due to differences of the dilatation coefficient α of the layers, shearing stresses may appear [4] [5] if release is not sufficient.

2.2. Effect of sunshine

Two main actions can be distinguished : a photochemical effect and an energetic effect. Each wavelength of sunshine radiation is characterised by an energy given by the law of Planck :

$$E = h \partial$$

where h = Planck's constant (J.s)
∂ = frequency (1/s).

For low wavelengths (UV radiations), the quantum energy E may be greater than bonding energy of materials (like $C-C$, $C=C$ and $C-H$ bondings).
Moreover, the radiations may be transmitted, reflected or absorbed. In the last case, there is an increase of the superficial temperature of the material due to this energy absorption.
With the combination of photochemical action responsible for dissociation of molecules and energetic action that will provide energy to accelerate reactions of degradation, sunshine effects may be explained.
Other complementary effects may be observed : differential dilatation due to different dilatation coefficients α or disparition of volatil components and modification of the material structure (E-modulus, hardness, release properties, ...).

The aim of the tests we set up is the analyse of the effect of temperature variations affecting repair mortar applied on concrete support. These temperature gradients are induced by sunshine/rain cycles.

3. Description of the test program

3.1. Samples

The sandblasted concrete supports are 100 x 50 cm concrete slabs fixed on quay walls along the river Meuse. The exposition is "moistly environment with freeze (2b)", according to the Belgian Standard NBN B15-001 (EN 206) "Concrete Performance, production, placing and compliance criteria".

Photo 1: Situation of sandblasted concrete supports

Samples of 100 x 20 cm (concrete + repair mortar) were extracted from the slabs after one year exposure in site conditions.

The polished concrete support are made of a classical concrete support (limestone aggregates, quartz sand, cement CEM II B-M 32,5, W/C = 0,5) treated by polishing. Samples of 50 x 20 cm were sawed after 28 days maturation in laboratory conditions (20 ± 2°C and 90 ± 5 % relative humidity).

The rather high length of the test samples (100 cm for sandblasted concrete, 50 cm for polished concrete) allows a better evaluation of temperature gradient effects on the durability of adherence.

3.2. Materials
The three main types of mortars – PC, PCC and CC – were tested and evaluated.

Table 1: Description of the repair mortars

Reference	Mortar type	Binder material	Surfacing mortar	Binding layer	Protection layer
1	PCC	PVAc + cement	-	-	-
3	CC	cement	-	-	-
4	PC	epoxy	-	✔	✔
5	PCC	PVAc + cement	-	✔	-
6	CC	cement	✔	-	-
7	PC	epoxy	-	✔	-
8	PCC	PBA/PS + cement	✔	-	✔
9	PCC	PBA/PS + cement	✔	-	✔
10	PC	epoxy	-	✔	✔
11	CC	cement	-	✔	-
12 bis	PCC	PMA/PVAc + cement	✔	✔	✔
13	PCC	PVAc + cement	✔	✔	✔

PVAc = polyvinyl acetate
PMA = polymethacrylate
PS = polystyrene
PBA = polybutylacrylate
Ref. 8, 9, 12, 12 bis are copolymer
Ref. 12 bis is a bicomponent while ref. 12 is a monocomponent

4. Description of ageing

Samples are aged by means of 20 cycles, according to the next sequency :

- 7 hours exposure to I.R. radiations by means of lamps. The distance between lamps and mortar is chosen in such a way that the surface temperature is 60°C;
- 1 hour water aspersion. The temperature of water is at ambient temperature (> 5°C);
- 16 hours immersion into water.

5. Test results

Visual observations were realised after the 20 cycles.

Table 2: Visual observations on sandblasted and polished supports

Reference	Observations
Sandblasted concrete	
3	no degradation
4	no degradation
5	no degradation
6	cracking network of the upper layer (photo 4)
7	no degradation
8	no degradation
9	no degradation
10	sticking off of the mortar on one edge and blistering of protection layer
11	superficial cracking
12	no degradation
Polished concrete	
1	no degradation
6	no degradation
8	no degradation
12	large crack in the middle of the sample up to the concrete and many little cracks
13	2 cracks

Table 2 gives the results which are the means of 7 tests and are compared to the values before ageing.

Table 2: Adherence on sandblasted and polished concrete supports before and after 20 cycles ageing

	Adherence (N/mm²)			
Reference	Intact		After 20 cycles	
	mean	characteristic	mean	characteristic
Sandblasted concrete				
3	2,73	1,94	+ 3,46	+ 3,46
4	3,64	3,34	2,78	1,53
5	1,60	1,50	1,88	0,28
6	2,14	1,52	+ 3,56	+ 3,56
7	+ 4,34	+ 4,34	+ 3,87	+ 3,87
8	2,48	2,04	2,19	1,76
9	2,77	2,42	+ 4,02	+ 4,02
10	3,54	1,91	2,18	0
11	1,04	0	0,05	0
12 bis	2,01	1,17	2,34	1,50
Polished concrete				
1	0,54	0,35	1,88	0,74
6	1,05	0,71	2,31	0,97
8	2,77	2,14	3,41	2,70
12	1,45	0,81	0	0
13	2,60	1,89	2,70	0,36

The characteristic adherence takes into account the dispersion of the results and is evaluated by means of :

$$A_c = A_m - 1{,}64\ \sigma$$

where A_c is the characteristic adherence (N/mm²)
A_m is the mean value of the results (N/mm²)
σ is the standard deviation.

The characteristic adherence is the mean value of the results if cohesive rupture is observed. When cohesive failure in the substrate, the results are preceded by "+".

6. Comments on the results

For sandblasted concrete support, next observations can be made :

- PC mortars : only mortar reference 7 presents again, after 20 cycles, cohesive ruptures in the support. Adherence of mortar reference 4 decreases from 3,64 to 2,78 N/mm² with adhesive ruptures between mortar and impregnation layers. Mortar reference 10 stiks off at the edge of the concrete slab.
- CC mortars : mortars references 3 and 6 show an increase of the adherence while mortar reference 11, with a very low initial adherence, no longer adheres. The surfacing mortar of reference 6 shows a cracking network.
- PCC mortars : mortars references 9 and 12 have increased performances while mortar reference 8 shortly decreases. Mortar reference 5 shows an increased performance (higher average) but with higher standard deviation.

For polished concrete surfaces, CC mortar reference 6 and PCC mortars (references 8 and 13) let us to observe an increase of the adherence performances. Mortar reference 12 shows cracking after ageing exposure and a lowering of adherence performances. Mortar reference 13 shows an increased performance (high average) but with higher standard deviation and cracking.

7. Conclusions

The better behaviour of PCC and CC mortars, regarding the one of PC mortars may be explained by different ways :

- The water is not always a disturbant factor when hydraulic binders are used due to the fact that the hydratation of cement is a long way that takes time; that means that during a lot of months, some clinker particules continue to react with water and so to consume water. Moreover, if we observe and analyse the thermodynamic effect of water on superficial tension of liquids and solids at the interface [6], we shall see a large decrease of the values of the work of adhesion between concrete and epoxy or acrylic resin; that means a loss of stability of this interface.
- The effect of the temperature changes due to sunshine/rain cycles has also a harder effect on the dimensional stability of the interface due to different dilatation coefficients of concrete and resins. It is a welknown problem [8].
- The kind of sollicitation (temperature gradients on specimens with high length values), visual inspection and determination of residual adherence at the ends and central areas seems to give an interesting further evaluation to put in relation with the well-known ageing tests on reduced size specimens.

In any case, the best way to design a durable repair system is to be sure that initial adherence attempts a sufficient value, in order to support ageings and disturbances with a minimum of reserve. In this way, the choice of an accurate material in relation with the quality of the support, is of prime importance.

8. Acknowledgements

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9. References

1. Courard L., Degeimbre R., Darimont A., Wiertz J., "Influence of the operative conditions and humidity on adherence of repair mortars".
ICPIC, VIIIth International Congress on Polymers in Concrete, Oostende (1995).
2. Courard L., Degeimbre R., Wiertz J., Van de Put M., "Analysis of the resistance to water of the interface between concrete and repairing systems : experimental approach".
CONSEC '98. 2nd International Conference on Concrete under Severe Conditions, Tromso, Norway (1998).
3. Courard L., Degeimbre R., Wiertz J., "The behaviour of coatings on concrete supports in relation with different forms of water attack".
CONSEC '98. 2nd International Conference on Concrete under Severe Conditions, Tromso, Norway (1998).
4. Günter M. and Hilsdorf H.K., "Stresses due to physical and chemical actions on concrete substrates. Adhesion between Polymers and Concrete : Bonding, Protection, Repair", in Proceedings of an International RILEM Symposium, Paris, (1986), pp. 8-21.
5. Fernandes Canovas M., "Behaviour of epoxy mortar coatings under changes of temperature", Instituto Eduardo Torroja de la Construccion y del Cemento, pp. 275-95.
6. Courard L., "Contribution à l'analyse des paramètres influençant la création de l'interface entre un béton et un système de réparation. Appétence et adhérence : cause et effet d'une liaison". Thèse présentée en vue de l'obtention du grade de Docteur en sciences appliquées. Université de Liège, Faculté des Sciences Appliquées (24 avril 1998).
7. Walloon Ministry for Research, Convention 1684 (1992). "Elaboration des couches d'adhérence entre produits de réparation et leurs supports destinés à la réparation des ouvrages en béton".
8. Naniwa R. and all., "Analysis of differential movement at interfaces between concrete, polymer, cement mortar and ceramic tile". ICPIC, VIIIth International Congress on Polymers in Concrete, Oostende (1995).