APPETENCY AND ADHESION : ANALYSIS OF THE KINETICS OF CONTACT BETWEEN CONCRETE AND REPAIRING MORTARS

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Abstract

The definition of the adhesion itself presents a duality : on the one hand, adhesion is understood to be a process through which two bodies are brought together and attached (bonded) to each other, in such a manner that external force or thermal motion is required to break the bond. The term "adhesion" (or "sticking") is usually applied in this sense in colloid research on coagulation phenomena.

On the other hand, we may examine the process of breaking a bond between bodies that are already in contact; and here, as a quantitative measure of the intensity of adhesion, we can take the force or energy required to separate the two bodies.

We studied this problem in the context of repairing mortars laid down on a concrete support; we focused our research on the behaviour of a cementitious slurry applied on two types of concrete support, characterised by their surface preparation (sandblasted and polished surface). We measured and observed the penetration of this slurry into the concrete support.

Keywords: appetency, adhesion, adherence, repair, kinetics, succion, cement, concrete.

1 Introduction

When a slurry is applied on a concrete support, bonds are developing because there is a potential attraction between the two bodies [2]. A physiological comparison let us say that there is here *partiality*. Partiality (lat. *appetentia*) is like a penchant that let the two bodies to do something they want or like to do.

This word represents the physical, chemical and mechanical properties that will influence the macroscopical manifestation of the *adhesion*, that means *adherence*. From appentency (partiality) to adherence, there is a cause to effect relation : it is because there is a potential reactivity of the bodies that it will be possible to measure adherence by means of a test. Adhesion is the physical or physico-chemical phenomenon happening at the interface that will really produce the bonds.

Here we want to explain the influence of the kinetics of contact of the cement slurry on the concrete support on the creation of the bonds and the quality of adherence. Capillary succion is one of the most important mechanism at the base of the creation and the resistance of the interface [3].

2 Transport mechanisms at the interface

Three major transportation mechanisms are observed into porous media :

- Diffusion, related to the transfer of molecules or ions into the interstitial solution, from area of high concentration to area with lower concentration.
  The phenomenon is directed by Fick's laws :

$$F = - D \frac{dc}{dx}$$

where F is the flow rate (g/m².s)
D is the diffusion coefficient (m²/s)
c is the concentration (g/m³)
x is the distance (m).

The second Fick's law represents the variation of the concentration with the time. This transport mechanism may be present when a cement slurry is laid on a concrete support saturated with water : diffusion of ions could be observed from the interstitial solution of the slurry to the water present into porous skeleton of the concrete and inversely. The analysis of the ionic composition of the slurry is very interesting : it permits to compare its concentration value with the one of water and water into concrete.

Table 1. Ionic composition of city water (Liege, Belgium), interstitial water of concrete and centrifugated solution of a cement slurry (mg/ℓ)

Ions	Cement slurry	City water	Concrete
OH^-	4720	-	2245
Cl^-	1390	55.64	-
Ca	1210	145.73	945.89
Mg	< 0.05	14.24	-
Na	1500	16.49	542.56
K	7360	2.98	7897.8
pH	13.1	7.35	13.1

N.B. the values for concrete interstitial solution are coming from analysis for CPA 69 after 5 hours [5].

We may conclude that there are ions movements at the interface and not always in the same direction because the hardening of cement will modify the concentration of the different ions into water.

- Permeation, concerning the movement of liquids and gazes due to difference of pression. The mechanism is described by Darcy's law :

$$K_w = \frac{V}{t} \cdot \frac{\ell}{A} \cdot \frac{1}{\Delta h}$$

where K_w is the coefficient of water permeability (m/s)
V is the volume of the liquid (m^3)
t is the time (s)
ℓ is the thickness of the penetration section (m)
A is the area of the penetration section (m^2)
Δh is the height of the water column (m).

This phenomenon supposes that there is a pressure gradient between the surface and the deepness of the concrete : this is very imprevious because the only difference could come from the force of application of the slurry or the thickness of the new layer, which is no more than 40 to 50 Pa.

- Capillary succion, related to the transport of liquids into porous solids, due to interfacial tension between liquid and solid. The phenomenon is described by a combination of Poiseuille's law and Laplace's law :

$$\ell_p^2 = \frac{r_o \cdot \gamma_{LV} \cdot \cos\theta}{2\eta} \cdot t$$

where r_o is the radius of the pore (m)
γ_{LV} is the superficial tension of the liquid (mN/m)
θ is the contact angle
η is the viscosity of the liquid (mPa.s)
t is the time (s).

This is an important and fundamental mechanism acting on the quality of the interface between the slurry and the concrete support.
It will indeed regulate the transfer of water from the slurry to the support, especially when it is dry : this will modify the hardening process of the cement and the development of adhesion at the interface. The test described in chapter 4 will try to analyse the phenomenon.

3 Description of the materials

We used prefabricated slabs of concrete made of :

- 2/8 limestone aggregate,
- 0/2 and 0/5 sand,
- CEM II B 32,5 cement and water (W/C = 0.5).

Some tests have been realised on rock itself in order to point out the influence of the cement paste. Two types of surface treatments were applied on the concrete support : the first one was a sandblasting with Corindon 1/1.4 and the second was a polishing of the surface with output of fine particles after treatment. It corresponds to a linear rugosity factor R_a respectively of 1.13 and 1.02.

Table 2. Physical and mechanical characteristics of the sandblasted and polished concrete, and limestone rock

Test	Sandblasted concrete	Polished concrete	Rock
Water absorption (% in mass)	5.49	5.38	0.27
Water absorption under vacuum (% in mass)	8.99	8.59	0.28
Total porosity (% in volume)	19.96	19.07	0.78
Specific surface (m²/g)	1.81	1.87	0.54
Porous volume (cm³/g)	0.046	0.046	0.0058
Mean radius (nm)	165	136	12

The slurry applied on the concrete support is a mix of water and cement CEM I 42,5 with W/C = 0.4 We measured the viscosity, the superficial tension and the contact angles with the supports in order to quantify and to modelize the capillary succion of this slurry into the concrete support [1].

4 Description and results of the capillar tests

The most commonly used test to analyse water transfer at the interface is the water capillar succion test [3]. It is described in a lot of standards (NBN B 14-201, DIN 52617,…) that differ often by the time when a measurement is realized. The results given hereafter (Fig. 1) present the capillar succion on concrete and rock by means of the impregnation ratio (S_t) : this is related to the evolution with time of the water capillar absorption (E_c) and the absorption under vacuum (E_t) :

$$S_t = \frac{E_c}{E_t} \, x\, 100$$

This coefficient is defined by standard NBN B 15-201 (1976).

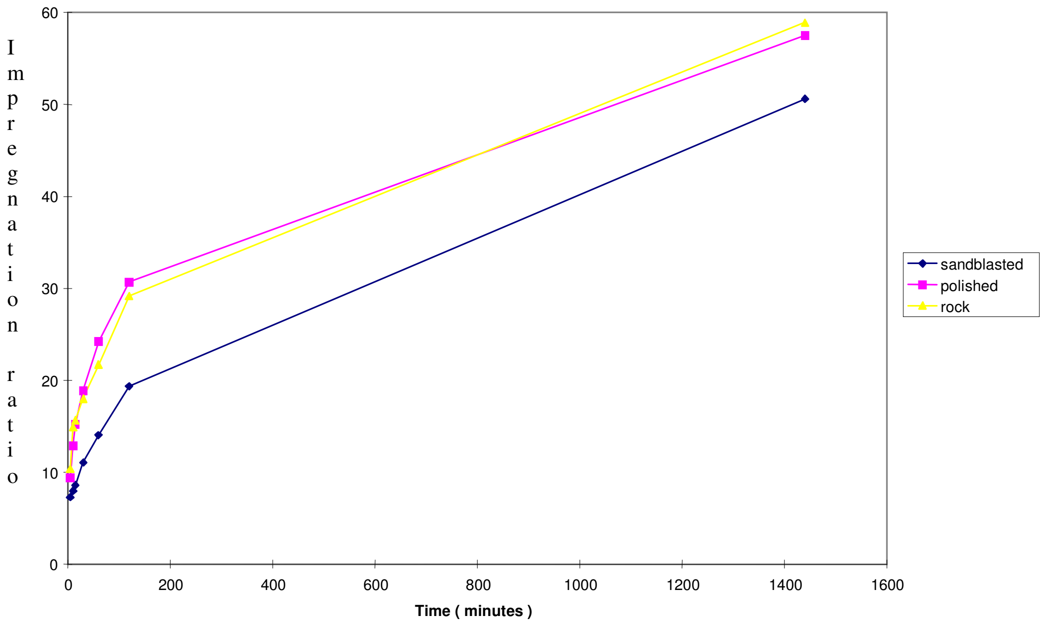

Fig. 1. Impregnation ratio for sandblasted and polished concrete surface and rock - variation in mass

The disadvantage of this test is the impossibility of realising measurement just after the contact between concrete and slurry. It is the reason why we developed a new test that register continuously the variation of mass of the sample immerged into water (Fig. 2).

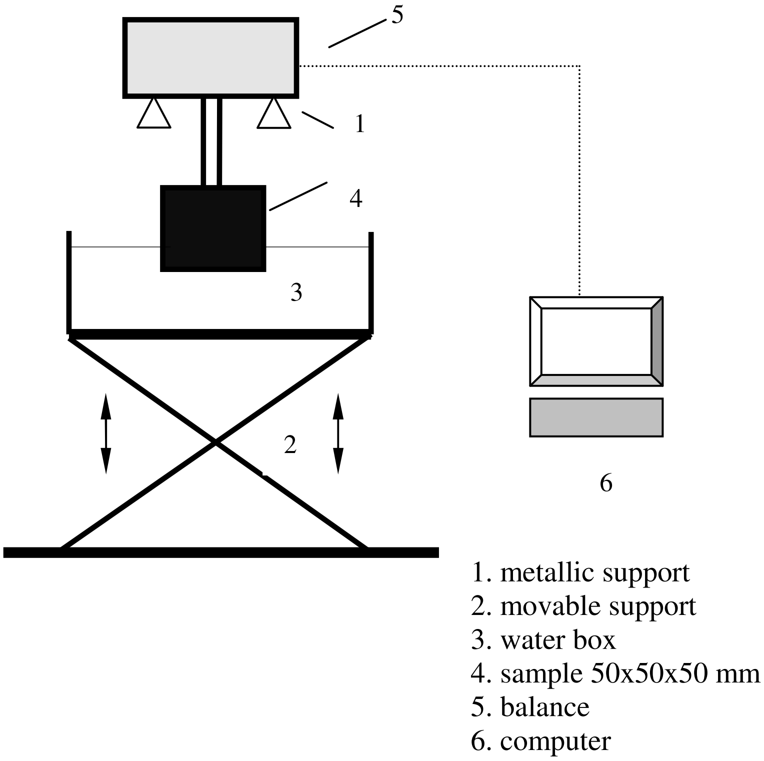

Fig. 2. Measurement of water absorption by capillar succion

We registered the capillary succion during more than 40 minutes and the figure 3 gives the evolution between 0 and 2400 seconds.

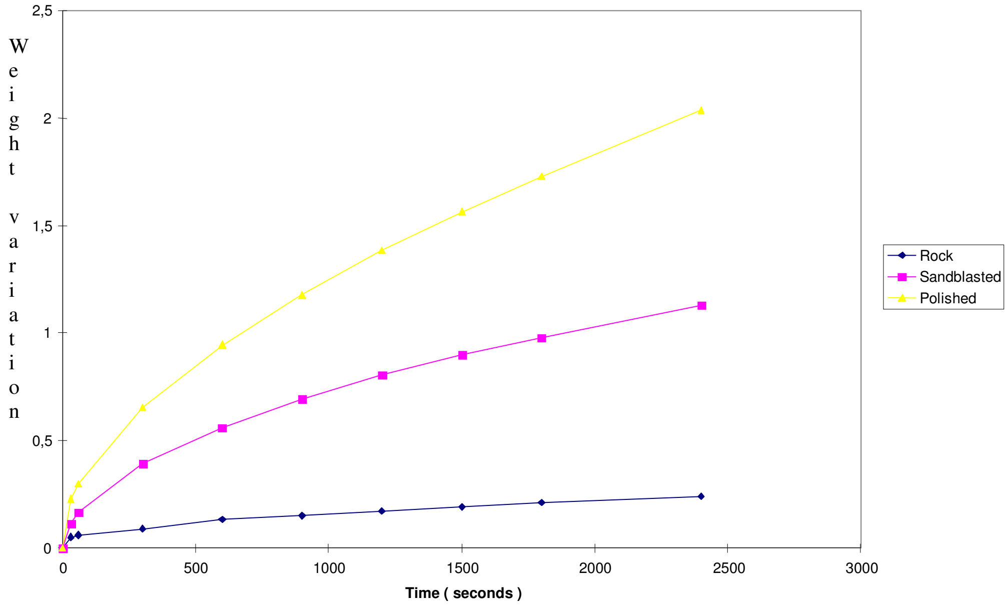

Fig. 3. Water capillar absorption between 0 and 2400 seconds on rock and sandblasted and polished surfaces – variation in mass.

We observed here a different behaviour of sandblasted and polished surfaces : the speed of absorption and the quantity of water are higher for polished one than for sandblasted one. This phenomenon is observed directly after the contact between water and concrete and may be due to :

- the shape of the entrance of the pores and capillaries;
- the granulometric distribution of the capillaries at the surface;
- the presence of a pollutant,…

It is clearly before the 20 or 30 first seconds that the rate of impregnation is the higher what is, at a theoretical point of view, something understandable : the larger capillaries are first fulfilled with water, giving a high absorption weight and after that, the thin capillaries absorb water on great height but low volume.

Table 3. Speed of the rate of impregnation of the sandblasted and polished surfaces, and rocks

Type of support	Speed of impregnation (% / $\sqrt{t}$)
Sandblasted	0.1935
Polished	0.5518
Rock	1.1218

5 Microscopic analysis

We present here some results of S.E.M. analysis related to the interfaces between aggregates and cement paste with the slurry. These observations were realised from the analysis of the faces of failure after a pull-off test.
The distinction between the zones of contact aggregate/slurry and cement paste/slurry, particularly when the slurry was applied on a dry support, are clearly visible on photograph 2.
We note a higher roughness of the interface cement paste/slurry and a difference of structure; the aggregates appear more dark and seem to be only lightly covered by a thin layer, while the zone in contact with cement paste is covered by residual cement slurry (photograph 1).

Photograph 1. Failure face of saturated polished concrete support

These observations are available as well as for polished than for sandblasted surfaces. The most effective difference between the two is coming from the air bubbles present in the surface roughness of the sandblasted support (photograph 2).
An EDX analysis attests that the thin layer present on the aggregates is in most of the cases characterised by a high concentration of $Ca(OH)_2$.

Photograph 2. Failure face of cement slurry applied on polished saturated concrete support

The effect of the saturation of the support was more clearly point out by means of fluorescent microscope analysis on thin layer. A zone of 50 – 100 µm with a higher porosity is visible at the interface, as well as between the slurry and the cement paste than between rock and cement paste : it is not clear up to now that this behaviour depends on the saturation ratio but a first analysis let us to conclude that it is more useful for dry support.

6 Conclusions

All the observations presented hereabove let us to make a comparison with the interfacial zone between aggregates and cement paste into concrete. We may indeed consider that we are in the same conditions : on one hand it is the contact between aggregate and slurry and on the other hand it is the interface between old cement paste and slurry.

The analysis of the failure faces shows clearly that, in the first case, the rupture happened in the interfacial zone which means between the $Ca(OH)_2$ crystals as it was already described by Metha [11], Maso [12] and a lot of other authors [8] [9] [10].

In the second conditions, the rupture happens inside the slurry (new cement paste) where hardening is of course no so developed.

Repair technics, where no organic components are used, are not so different, at the point of view of the physico-chemical interactions, from concrete technics.

We shall be able to evaluate the adhesion forces available between rock and slurry and cement paste and slurry, in order to predict adherence.

Finally, adhesion and cohesion are two words for the same effect.

7 References

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