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EXPERIMENTS ON WATERPROOFING CONCRETE TO INHIBIT AAR

BY

G E Blight

University of the Witwatersrand, Johannesburg,
P O WITS 2050, South Africa

ABSTRACT

Laboratory experiments were undertaken to test the effectiveness of four surface treatments for waterproofing concrete. These were two coatings and two pore liner penetrants (a silicone and a silane). The results showed that none of the treatments waterproof concrete. Subsequent field trials showed that in the South African climate it is not necessary to surface treat sound concrete. Also, that if the surface is cracked, water can enter through the cracks even if the surface has been treated.

INTRODUCTION

It has long been known qualitatively that AAR in concrete can proceed only if water is present to sustain it. Vivian[1] showed 40 years ago that the amount of expansion that occurs in mortars depends on the amount of removable water in the mortar. Vivian's original results are shown in Figure 1. If the removable water is less than about 4 per cent by dry mass, no expansion due to AAR occurs. Once the removable water exceeds 4 per cent the expansion becomes directly proportional to the excess of removable water over 4 per cent (the available water).

Vivian defined removable water as the water lost after prolonged storage over calcium chloride (a relative humidity of 32 per cent). The available water is that part of the total water that is loosely held in capillaries in the mortar. Note from Figure 1 that the available water may be contained within the concrete ab initio (sealed specimens) or be allowed to penetrate the mortar from outside (unsealed specimens) after some drying has occurred. Assuming that Vivian's results on mortar are applicable to concrete, it is clear that if the available water in concrete can be kept to zero, expansion by AAR will be minimized or even eliminated.

The above statement does not define available water with any precision. What is needed is a criterion in terms of a measurable moisture tension-related variable. Possible variables would be the relative humidity (RH) or the pore water suction (p").

The evidence[2,3,4,5], shows that if the relative humidity in the atmosphere surrounding a concrete structure can be maintained at below 95 per cent, AAR will be inhibited. However, the relative humidity of the surroundings is usually not the same as the relative humidity in the pores of the concrete where the AAR occurs.

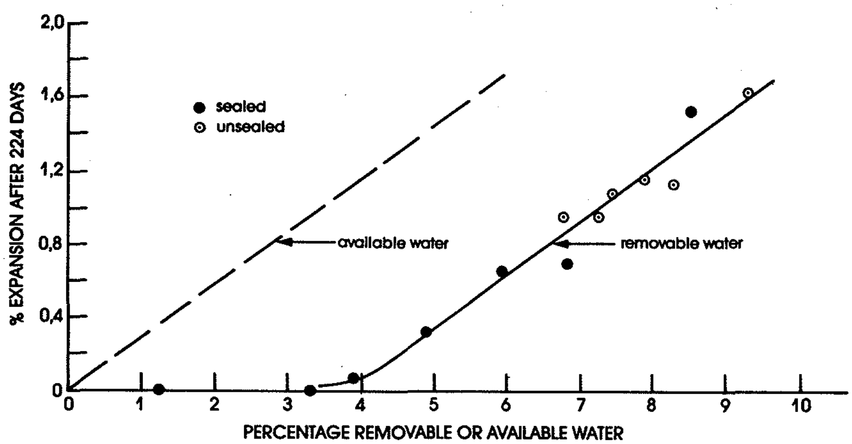

Figure 1: Vivian's observed relationship between removable water and expansion

Relative humidity in a material like concrete can be related to the pore water suction p" by the Kelvin equation[eg. 6,7]:

$$p'' = 311 \log_{10}(RH) \text{ in MPa}$$

where RH is expressed as a fraction of unity, eg. 0.95.

Even at a RH of 0.95, the suction is nearly 7MPa. This moisture stress exerts an equal isotropic compressive stress on the concrete. Even if the suction is not completely effective, the concrete must, at RH = 0.95, be subjected to an isotropic compressive stress of several MPa.

The only recorded measurements of the swelling pressure exerted by AAR are due to McGowan and Vivian[7]. Their measurements indicated swelling pressures of no more than 500kPa. Clearly, concrete can only expand if the swelling pressure exceeds the moisture stress. As the moisture stress is so large at RH = 0.95 and below, it appears unlikely that the cut-off RH could be less than 0.95 per cent in the pores of the concrete.

One obvious way of inhibiting AAR is to dry the interior of the concrete out to below the cut-off RH and then maintain it in that condition by means of a waterproofing layer or coating.

The climate in South Africa is relatively dry. The highest RH recorded has been 0.96, while the average maximum is only 0.75. Hence a concrete structure should dry out to below RH = 0.95 provided a) it is protected from rain; b) water cannot accumulate in or on it via faulty drainage; and c) the concrete is not situated in an artificially high humidity environment.

The above considerations have led to the following investigations:

.1 a laboratory investigation of various types of waterproofing and;

.2 an extension of this investigation to structures in the field.

TYPES OF WATERPROOFERS USED IN INVESTIGATION

Two major studies[8,9] list five types of waterproofers for concrete:

.1 Pore liner penetrants, usually operating as water repellants.
.2 Pore blocker penetrants that seal surface pores.
.3 Sealers that form an impervious surface skin on the concrete
.4 Coatings that form a thicker impervious surface skin.
.5 Renderings which are thick coatings, usually applied by trowel.

The four waterproofers tested in this work were two coatings and two pore liner penetrants, described as:
Coating 1: a cementitious slurry.
Coating 2: an aqueous dispersion of synthetic resins.
Penetrant 1: silicones in hydrocarbon solution.
Penetrant 2: alkyl alkoxy silane.

LABORATORY TESTS

100x100x200 mm concrete prisms were treated with each of the four waterproofers. The treated prisms were then subjected to two moisture regimes. Three prisms for each of the four treatments were submitted to each regime. The efficacy of the treatment was judged by weighing the prisms to assess progressive gain or loss of moisture.

Regime A tested the waterproofing of the coatings. Coatings were applied to oven dried specimens. After curing, the prisms were weighed and placed on racks where they were subjected to a wet atmosphere in a fog room. The results showed that none of the coatings were waterproof. The best performance was that of Penetrant 2 (silane), but it was clear that the moisture content of the other three sets of specimens was heading towards an equilibrium water content (probably close to saturation), when the tests were terminated after 110 days. The results of this set of tests is shown in Figure 2.

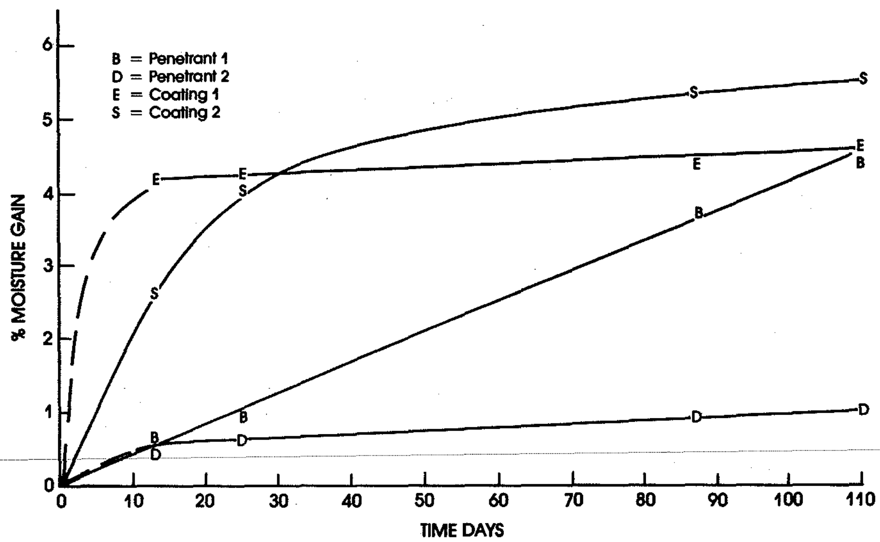

Figure 2: Absorption of water by dried coated concrete subjected to mist spray

Regime B tested the ability for moisture to be lost through the coating from concrete that is already wet, when the concrete is exposed to a low RH environment. The uncoated specimens were soaked in water for 7 days, allowed to surface dry for one day and were then coated. The specimens were stored over calcium chloride to give an ambient atmosphere RH = 0.32. The prisms were periodically weighed.

The results showed that the water repellent penetrants, and Coating 1 proved most effective in allowing water to pass out of the concrete. All specimens lost moisture more slowly than they gained it.

The next series simulated the South African climate in the laboratory. The coated specimens originally subjected to Regime B were stored in the fog room for 7 days. A cyclic drying-wetting regime simulating a climate of short wet periods followed by much longer drying periods was then started. The specimens were stored in a drying atmosphere at RH = 0.32 for 7 days, then at RH = 1.0 for 6 hours, then at RH = 0.32, and so on.

The results of this treatment are shown in Figure 3. After an initial uptake of moisture, all, including the untreated controls, dried out progressively and approached the initial moisture content.

There were two possible conclusions relating to concrete structures exposed to the South African climate:

.1 Either it is not necessary to waterproof exposed concrete because it will dry out completely between the brief wet spells it experiences; or

.2 the waterproofing need not be 100 per cent effective. Provided most of the precipitation is excluded, the concrete will subsequently dry out.

To examine these tentative conclusions, it was decided to test some reinforced concrete structures in the field.

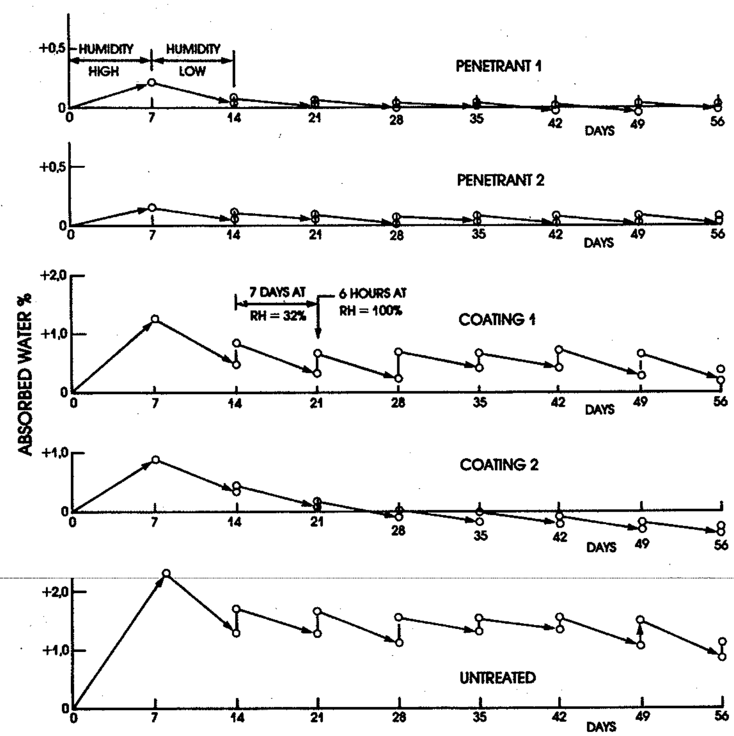

Figure 3: Progressive drying of treated and untreated concrete specimens in alternating low and high humidity environments
(Low = RH 32% High = RH 100%)

FIELD EXPERIMENTS INVOLVING WETTING FOLLOWED BY DRYING

A group of columns supporting an overhead structure was selected for the field trials. The columns were washed down with high pressure water jets and were then coated with the four waterproofers. The column shafts are completely protected from impinging rain by the overhead structures they support. This situation was chosen deliberately so that the moisture condition of the column surfaces could be controlled artificially. The effect of wetting and drying was assessed by inserting thermocouple psychrometer probes to a depth of 100mm into holes drilled into the columns.

A psychrometer probe[10] consists of a thermocouple sealed into a cavity in the concrete. The air surrounding the probe comes to thermal and moisture equilibrium with the air in the cavity. A current is passed through the thermocouple which cools by the Peltier effect until the temperature falls below the dew point of the moisture in the surrounding air. Moisture then condenses on the thermocouple junction. The cooling current is interrupted and the condensed moisture starts to evaporate at the dew point temperature. The thermocouple is used to measure this temperature and hence the relative humidity in the cavity and the related pore water suction (p") in the concrete can be determined via the Kelvin equation.

The measuring range of the psychrometer is from RH = 100 to about RH = 0.96. Below RH = 0.96 it is not possible to condense water out of the atmosphere by cooling the air. The range does not quite cover the RH interval of 0.95 to 1.00, but the actual range of interest is probably less than this.

Figure 4 shows the results of two sets of measurements on the untreated control column and the column treated with Penetrant 1 (silicone). Not all of the columns are in the same physical condition. Some are completely sound, but

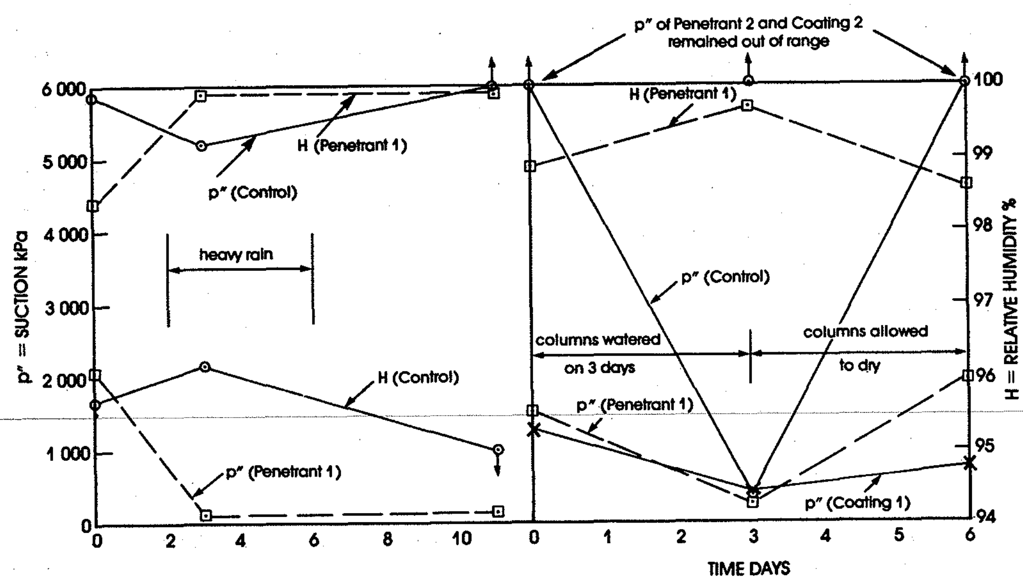

Figure 4: In situ psychrometer measurements in twocolumns supporting overhead structure.

others show signs of AAR attack, in the form of cracks in the columns, or in the mushroom slabs they support, or both. As it happened, the control column is completely sound whereas the silicone-treated column has a badly cracked mushroom slab, although the column itself has only minor cracks in it.

The left hand section of Figure 4 shows results of preliminary measurements on the two columns to establish the range of p" or RH to be expected. p" in the control column was very high (more than 5000kPa) and the measurements eventually went out of range. p" in the silicone-treated column, however, was unexpectedly low (2000kPa) and after a spell of heavy rain, reduced even further. A few days later streaks of white AAR gel appeared through cracks in the column and ran down the surface. This showed that water was entering the column via the structure it supports and causing further AAR.

In a second series of tests conducted during very hot dry weather, initial p" readings were taken and the columns were then watered by hose over a period of six hours on three consecutive days to represent as severe a condition of wetting as is ever likely to occur on an outside structure.

The wetting caused p" in the control column to fall from beyond the range of the psychrometer to only 350kPa (Figure 4). After 3 days of drying, the p" was again out of range.

p" in the silicone treated column started at 1500kPa, fell to 250kPa after 3 days watering and then rose again to 1900kPa after 3 days of drying. This indicated that water was entering the concrete through pre-existing cracks, even though the surface had been treated. There was no rain during the test and the water could not have been entering through the superstructure. However, atmospheric drying removed the water relatively quickly.

These tests confirmed the conclusions drawn earlier:

.1 If there is no internal source of water from, for example a blocked internal drainage pipe, etc, sound concrete will quickly dry out after being surface wetted. It probably does not need to be waterproofed.
.2 If there is an internal source of water it is pointless to waterproof the concrete.

The column treated with Coating 1 is also cracked by AAR. p" in the column started at 1200kPa, but fell to 300kPa after the period of watering. Three days later p" had increased but was still at a relatively low 800kPa. These results confirm that water can enter a concrete member through surface cracks, even if the surface has been treated. The rate at which the structure dries again depends on the type of treatment.

The column treated with Coating 2 is in sound condition. That treated by Penetrant 2 is cracked, but the psychrometer probe was inserted in an area of sound concrete. p" recorded in these two columns started out of measuring range and remained out of range even after the watering.

GENERAL CONCLUSIONS

.1 None of the surface treatments tested proved able to waterproof concrete.
.2 Conversely, once the concrete was wet the surface treatments were sufficiently permeable to allow it to dry out again.
.3 When surface treated concrete that is wet internally is subjected to short periods of wetting followed by longer periods of drying, it is possible progressively to dry out concrete. This is directly applicable

in climates where brief wet spells are followed by longer dry spells.

.4 Provided the concrete is sound, exposed reinforced concrete structures in South Africa quickly dry out after surface wetting, and do not need to be waterproofed.

.5 If there is an internal source of water in the concrete, waterproofing the exterior of a structure is obviously ineffective.

.6 Even if the surface of cracked concrete is surface treated, water can still enter through the cracks.

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