

Durability of Hydrophobic Treatment of Concrete

J. de Vries¹, R.B. Polder² and H. Borsje²

¹Ministry of Transport, Civil Engineering Division, Utrecht, and

²TNO Building and Construction Research, Delft, The Netherlands

Abstract

The subject of this study was the performance of hydrophobic treatment to protect concrete against chloride penetration from de-icing salts. Hydrophobic treatment makes a concrete surface absorb less water and less chloride. Several types of tests were carried out to study the performance of hydrophobised concrete. Salt ponding/drying tests showed that the penetration of chloride can be reduced by about 80% due to hydrophobic treatment. The water repellent effect remained constant over three years outdoor exposure. Corrosion which had already started before application of the hydrophobic agent was not influenced by hydrophobic treatment. No effect of hydrophobic treatment was measured on carbonation. Long term absorption tests with drinking and salt water showed significant less absorption by hydrophobic concrete.

Keywords: hydrophobic treatment, chloride, concrete, corrosion, durability.

1 Introduction

1.1 General

In 1994, the Civil Engineering Division of the Dutch Ministry of Transport decided to apply hydrophobic treatment to all new concrete bridge decks as an additional protective measure against penetration of de-icing salts. A typical cross section of a bridge deck is given in fig. 1. This measure was thought useful because of the increasing use of very porous asphalt. This type of asphalt reduces the noise caused by the contact between the road and the tyres. It also improves road safety by preventing aquaplaning and reducing spray during heavy rainfall, as well as improving visibility of road markings and traffic signs.

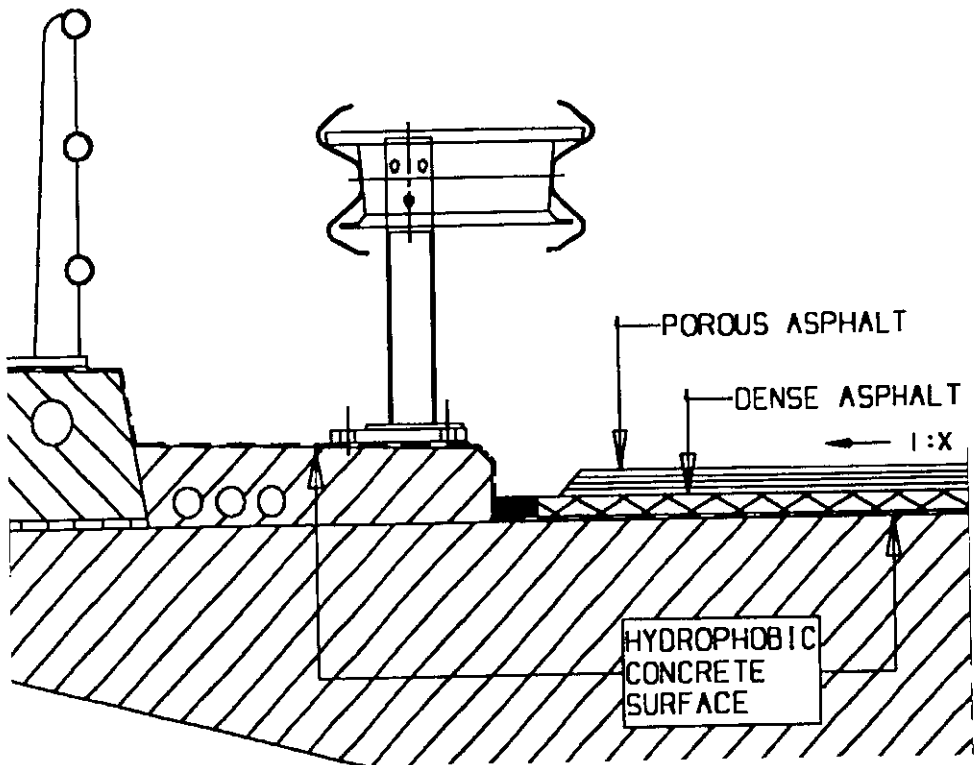


Figure 1: Typical detail cross section of a viaduct with porous asphalt

Due to the very open structure of porous asphalt it requires more de-icing salt and it allows easier chloride penetration, increasing the risk of reinforcement corrosion.

Hydrophobic treatment was expected to provide a preventive measure with a good performance to cost ratio. The decision was supported by a research programme started in 1992, which consisted of a literature study, development of test methods and requirements for commercial products, research into the performance of hydrophobised concrete and tests focused to application.

The literature study and test results of nine hydrophobic products and various other research results like application variations have been published elsewhere [1, 2, 4]. This paper summarises the most important results and reports further work.

1.2 Hydrophobic agents

Commercial hydrophobic agents for concrete consist of silanes and/or siloxanes. Silanes contain 100% active substance or they are dissolved in alcohol or hydrocarbons (with 10 to 40% active substance). Siloxanes are dissolved in alcohol or hydrocarbon solvents (about 10 to 20% active substance). Silanes and mixtures are also available as water-borne systems, so-called "micro-emulsion" (with 10 to 20% active substance). For environmental reasons, the government in the Netherlands does not allow the use of the agents containing hydrocarbons.

Test methods and requirements were developed. The main requirements [3] to the hydrophobised concrete surface are:

- water absorption less than 20% of control concrete (not hydrophobised);
- penetration depth at least 2 mm;
- water evaporation through hydrophobic concrete > 60% of control;
- resistant to the heat of hot asphalt, 160°C. Water absorption after heating less than 30% of control;
- alkali resistance, by means of water absorption < 20% of control when applied to strongly alkaline portland cement-sand mortar.

Three, out of nine, commercially available products met these requirements:

- product A, 99% silane (no solvent)
- product B, 100% silane (no solvent)
- product E, 20% silane dispersed in water.

Further research was carried out with these products.

2 Standard test set up for hydrophobic agents

The composition of the concrete used for the tests was specified precisely [3]: 340 kg/m³ cement, water-cement ratio 0.50 and aggregate with $D_{\max} = 32$ mm and precisely controlled grading. Two cement types were used: portland cement (OPC, CEM I) and blast furnace slag cement (BFSC, CEM III/B), which are normally used in The Netherlands. All concrete specimens were cured by 3 days covering with plastic foil and then placed in air at 20°C and 65% RH.

Application of the hydrophobic agent was done by dipping the specimens at a minimum age of 4 weeks in the agent for 5 seconds with one surface only. This was repeated after 10 minutes. The treated specimens were cured for at least 4 weeks at 20°C and 65% RH. Both formwork and finished concrete surfaces were tested [3].

3 Chloride penetration

With two hydrophobic agents (products B and E) salt ponding tests were carried out. After 52 weekly cycles the chloride content was less than 0.5% by mass of cement at a depth of approx. 20 mm in hydrophobised concrete; in non-treated portland cement concrete this was about 2.8% [1, 2, 4] This means that the hydrophobic treatment has reduced the chloride penetration by a factor of 5 to 6. The chloride content of the outermost layer is reduced by at least a factor 3. This corresponds roughly to the reduction of the (pure) water absorption. It may be concluded that hydrophobic treatment of concrete, made with either portland cement or blast furnace slag cement, strongly slows down the penetration of chloride under salt application-drying cycles.

4 Durability of the water repellent effect

In order to study the durability of the water repellent effect, two series of $100 \times 100 \text{ mm}^2$ concrete specimens were hydrophobised and exposed outside. Twenty four specimens were exposed for 21 months (series Y, formwork and finished surfaces). Twenty four more specimens (series X, in triplicate, only finished surfaces) were exposed for a total of 35 months. Both series included controls. Specimens were made with OPC and BFSC (standard concrete compositions, see 2). Three hydrophobic products (codes A, B, E) were applied on one side and the other five sides were coated with a dense epoxy coating. The specimens were exposed with the treated sides upward, on the roof of a building at TNO in The Netherlands, with free access of wind, rain and sunshine. Several times the specimens were taken inside, allowed to equilibrate in 20°C and 65% RH and tested for water absorption, whereafter the outside exposure was continued.

The results (fig. 2) showed that the water absorption of the controls decreased with time. Direct comparison of hydrophobised samples to controls was no longer considered useful. Instead, the water absorption coefficient (WAC) over 24 hours was evaluated. This is the slope of water absorption against the square root of time. The WAC of OPC controls showed a strong reduction, whilst that of BFSC controls showed only a small reduction. The WAC was found to be low and fairly constant for all hydrophobised specimens.

It is concluded that the water repellence of concrete treated with each of the three products had not significantly deteriorated during 35 months exposure to outdoor climate. In non-treated OPC concrete, the water absorption of the control concrete decreased quite strongly over time, so the relative effect of hydrophobic treatment decreased. Clearly this is not due to degradation of the hydrophobic effect. The reduction of the water absorption of untreated OPC concrete is probably due to carbonation of the surface layer, which makes it denser. After three years, the absorption of treated OPC concrete is still 50% of control concrete. For non-treated BFSC concrete, the water absorption of control specimens decreased only slightly. BFSC concrete does not show densification upon carbonation, so the water absorption decreases only due to further hydration of the cement, mainly slag particles. Hydrophobised BFSC concrete retained its much lower water absorption as compared to non-treated concrete.

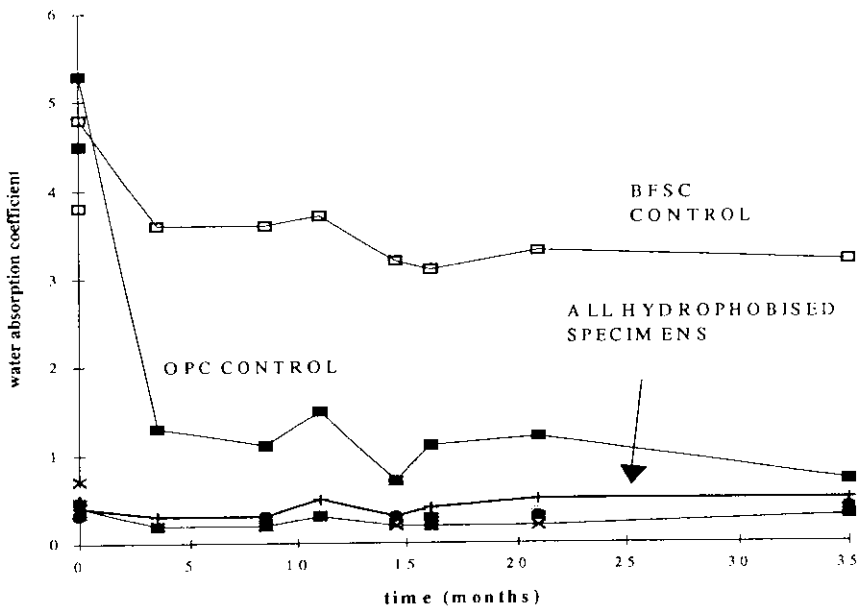


Figure 2: Water absorbtion coefficient of specimens exposed outside

Overall the conclusion is that hydrophobised concrete has retained its water repellence after three years and the expectation is that the water repellence will be durable for many more years.

5 Effect on corrosion

5.1 Test set-up

The effect of hydrophobic treatment on ongoing corrosion caused by chloride penetration was investigated using macrocell specimens [2]. These specimens were beams of $300 \times 150 \times 150 \text{ mm}^3$ with two reinforcing bars at 25 mm depth from the upper surface and two bars at 110 mm depth. The specimens were exposed to cyclic salt solution ponding on the upper surface for 24 hours followed by drying in air of 20°C and 50% RH. During the major part of the ponding period the salt solution contained 10% NaCl and the cycle comprised 1 day salt application and 13 days drying. The upper bars were expected to start corroding, which should be indicated by a

measurable macrocell current between one upper bar and the two lower bars. In addition steel potentials were measured using a reference electrode placed on the upper surface. Six specimens were made with OPC and six with BFSC, all having a standard concrete composition (see section 2).

5.2 Corrosion initiation

After about one year no corrosion had been initiated; this was demonstrated by negligible macrocell currents and passive steel potentials (see table 1, at 44 weeks). Apparently, the chloride had not reached the steel yet in such a concentration that corrosion was activated. In week 59 after starting salt application, chloride penetration was stimulated by polarising the steel positively for one week, applying 1 A/m^2 (steel surface), with an activated titanium mesh as a counter electrode, placed in the ponding solution. After this treatment, macrocell currents became significant and steel potentials became quite negative, suggesting initiation of corrosion had taken place (62 weeks).

In week 70, three specimens of each cement type were treated with a hydrophobic agent (20% silane in water, product E) and all were transferred to a climate room with air of 20°C and 80% RH. This climate was thought to represent the outside conditions more realistically than 50% RH. After that, the ponding cycles were continued for about one year. During this period, steel potentials and macrocell currents in all OPC specimens were quite stable at levels which indicated active corrosion (table 1, 120 weeks). In the BFSC specimens, steel potentials gradually became more positive and macrocell currents decreased to negligible values, suggesting repassivation, probably because of the relatively low chloride content at the depth of the rebar (see 5.3). The corrosion rate results from macrocell measurements were confirmed by polarisation resistance measurements.

5.3 Results

After a total period of about two years, four specimens were destructively investigated. The chloride penetration profiles of hydrophobised and control specimens were very similar. Apparently the profiles were mainly established in the first 70 weeks, before the hydrophobic treatment. The chloride content at the depth of the rebars in the two investigated OPC spec-

Notes: H = hydrophobised in week 70; N = non-hydrophobised

Table 1: Corrosion potentials and macrocell corrosion currents of the upper bars
 (@ =average values of three specimens, # = average of two specimens)

	Steel potential (mV Ag/AgCl)			Macrocell current density (mA/cm ²)		
Time (weeks)	44	62	120	120	210	220
Cement Type, treatment	@	@	@	@	#	#
OPC H	-40	-310	-240	0,8	0,67	0,65
OPC N	-40	-270	-240	0,9	0,55	0,77
BFSC H	-90	-350	-100	-0,01	0,015	0,03
BFSC N	-100	-310	-110	-0,01	0,02	0,04
Note	1	2	3	3	4	3

1 representative for first year of salt ponding/drying

2 shortly after forced chloride penetration

3 during exposure in 20°C/80% RH

4 during outside exposure (temperatures -2 to +8°C)

imens was about 1% (by mass of cement), which had caused and sustained active corrosion. In the two investigated BFSC specimens, the chloride content at the bar depth was between 0.2 and 0.6%, which apparently was insufficient to sustain active corrosion.

The remaining eight specimens were exposed outside (unsheltered) for two years at TNO in The Netherlands. In the winter of 1996/1997, with temperatures between 0 and 10°C, galvanic currents and polarisation resistances were measured. Subsequently the specimens were placed in a climate room with air of 20°C and 80% RH and measurements were carried on. It was found that the corrosion situation had not changed over two years. The corrosion rate in cold exposure was somewhat lower than previously (table 1, 210 weeks). After placing at 20°C, the corrosion rates were similar as before the outside exposure (table 1, 220 weeks). Steel potentials and electrical resistance of the concrete followed corresponding trends.

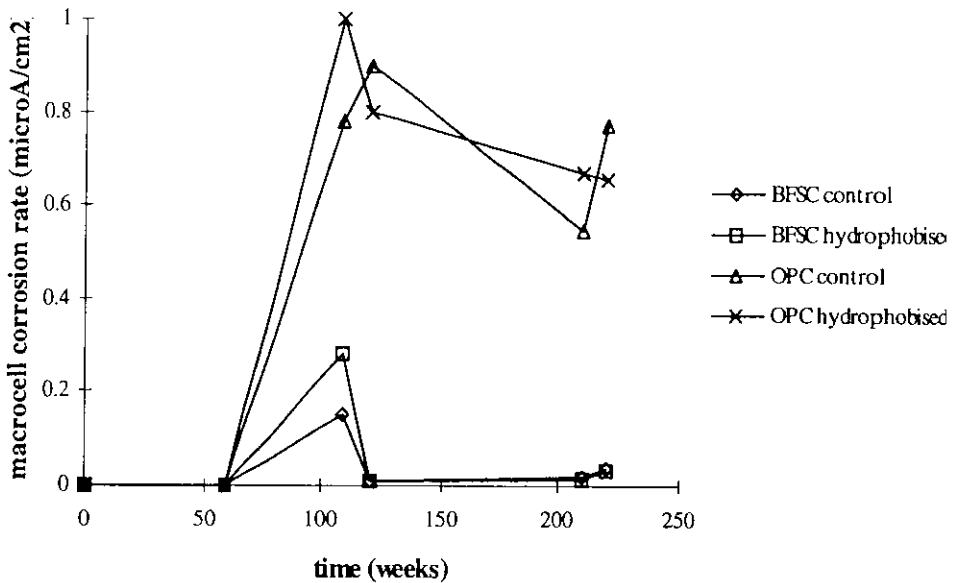


Figure 3: Corrosion rates as a function of time for hydrophobised and control macrocell specimens

The main results are illustrated in fig. 3. There was no significant difference in corrosion rates between hydrophobised and non-hydrophobised specimens. It appeared that the hydrophobic treatment had no effect on corrosion rates.

It was concluded that ongoing corrosion due to a high chloride content is not slowed down significantly by hydrophobic treatment after corrosion initiation.

6 Carbonation

Carbonation depths of the macrocell specimens (see section 5) were measured before and after outdoor exposure. During the salt ponding period the specimens were stored dry (20°C and 50% RH) for 70 weeks and under a higher humidity (20°C and 80% RH) for another 50 weeks. This was fol-

Table 2: Carbonation depths measured using phenolphthalein; -H denotes: hydrophobised, -N: non-hydrophobised (control)

Carbonation depths of the macrocell specimens				
exposure	sheltered	sheltered	unsheltered	unsheltered
	side surfaces	bottom sur-	top surface	top surface
specimen	1997	face 1997	1997	1995
	(mm)	(mm)	(mm)	(mm)
OPC - H	1-4	0-2	1-3	1-2
OPC - N	1-4	0-2	0-2	1-2
BFSC - H	1-15	4-13	3-9	1-5
BFSC - N	0-13	3-12	2-5	1-7

lowed by storage under 20°C and 80% RH without salt ponding up to 200 weeks. This latter period of 80 weeks can be regarded as 'sheltered' conditions: Apart from the salt exposed top side, the other five sides were never wetted. Next, these five sides of the specimens were coated. From this moment the specimens were exposed outside and open to wind and rain, with the non-coated side upward, for another 66 weeks. For this top side, the conditions are clearly unsheltered.

The results of the carbonation measurements can be found in table 2. The measurements on the topside have been done before and after outdoor exposure (1995 resp. 1997), the measurements on the other sides at the end of the test (1997). As expected, these results show that under sheltered conditions (the five sides which were never wetted) carbonation is higher than for unsheltered conditions (top sides). More important in view of this research: it appears that hydrophobic treatment does not have any significant influence on carbonation under the tested conditions.

7 Long term water absorption

All above reported results about water absorption were measured by standard procedure [3], this means 24 hour absorption. Longer absorption times might give results which are more alike practice. For this reason specimens are tested with absorption times up to 28 days.

For this test 2 types of hydrophobic agents were used: B (100% silane) and E (20% silane in water). Concrete was standard, 2 types, see chapter 2.

Absorption of tap water and salt water (10% NaOH) was tested. The specimens (coated on 4 sides) were placed with a non-coated side on blocks in a layer of water, to allow the water to absorb into the concrete. Absorption was measured after 1, 2, 3 and 24 hours, 3, 7, 14 and 28 days.

After 24 hours the water absorption was less than 20% to reference (non-treated) concrete, thus according to the requirements of chapter 1.2. The other results are given in figure 4. In all cases the absolute water absorption increases in time for both drinking and salt water. During the whole test period the concrete absorbs less salt water than drinking water. Differences between the performance of the two types of hydrophobic agents are small. From these results it can be concluded that hydrophobic treatment reduces the absorption of drinking and salt water significantly. In view of durability

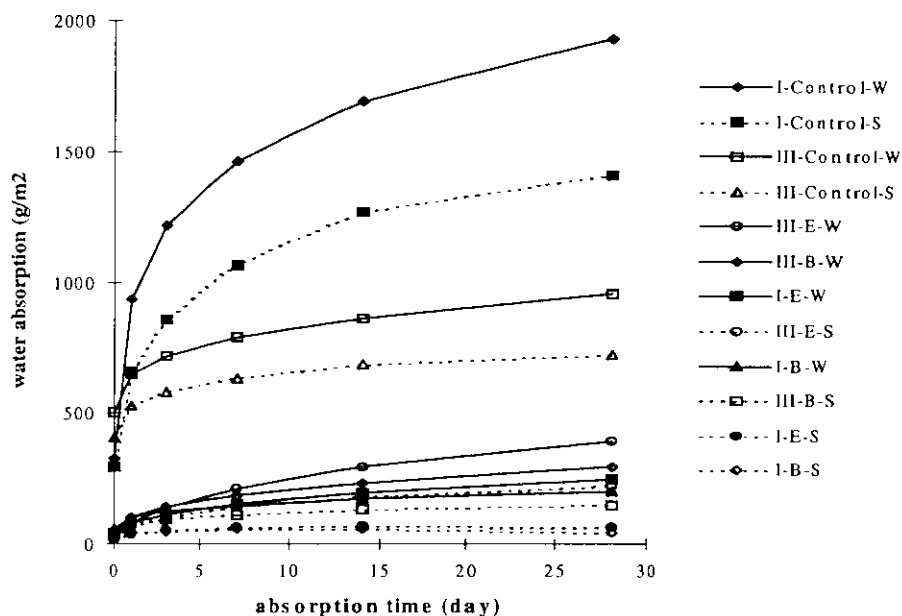


Figure 4: Long term water absorption

Notes: All legends placed in descending order of value at 28 days.

Legend codes: I = CEM I (solid symbols), III = CEM III/B (open symbols); B = hydrophobic B, E = hydrophobic E, Control = non-treated concrete; W = drinking water (solid lines), S = 10% NaCl solution (dashed lines)

of concrete structures it is important to know that the ingress of salt water is less than drinking water. These results indicates that testing the water absorption according to the standard procedure [3] is sufficient.

8 Conclusions

The following conclusions were drawn from this study:

- The recommended tests show that several hydrophobic products have a good performance on concrete such as used in The Netherlands for bridges.
- Water absorption of hydrophobised concrete is reduced to less than 20% of non treated concrete over 24 hours. Long term absorption over 28 days shows similar results.
- Hydrophobic treatment of concrete strongly reduces the penetration of chloride down to 20%.
- During outdoor exposure for up to three years, the hydrophobic effect remained intact; the expected durability of such a treatment is good.
- It appeared that hydrophobic treatment had no effect on corrosion rates of steel that already had initiated corrosion due to a high chloride content before the hydrophobic agent was applied.
- After exposure for several years, carbonation depths were equal for hydrophobised and non-hydrophobised concrete, made with both OPC and slag cement.
- Hydrophobic treatment is a durable protection of concrete.

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