HYDROPHOBIC TREATMENT OF CONCRETE

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SYNOPSIS

As part of the maintenance policy of the dutch Ministry of Transport, Civil Engineering Division, hydrophobic treatment of concrete was considered as an additional protective measure against penetration of aggressive substances, for instance deicing salts in bridge decks. A set of tests was designed to determine the performance of commercial silicone-based products, using typical 'bridge' concrete (made with OPC or blast furnace slag cement). Nine products were tested; three complied to all requirements. Treated and non-treated concrete specimens were exposed to weekly salt ponding/drying cycles for 12 months. The amount of chloride that had penetrated the hydrophobic concrete was about 20% of that in the controls.

1 INTRODUCTION

Applying a hydrophobic agent makes the concrete surface water-repellent. As a result, the concrete will absorb (far) less water and consequently, less dissolved substances which may be harmful to the concrete or the reinforcement. Hydrophobic treatment is therefore a means of protecting concrete.

The object of the study was to test a series of commercial hydrophobic products and to determine the effects of applying them to concrete. The immediate reason was the question whether concrete underneath an asphalt overlay with a porous wearing course (porous asphalt) could be additionally protected against chloride penetration by applying a hydrophobic agent. This was considered necessary, because in The Netherlands no waterproof membrane is used between the concrete and the asphalt overlay, unlike the widespread practice in other European countries.

2 REASONS FOR HYDROPHOBIC TREATMENT OF CONCRETE

Why give concrete a hydrophobic treatment, you may wonder. After all, good concrete is sufficiently impermeable to be durable itself and to provide protection to the reinforcement. This is actually correct, for in a properly designed and executed concrete structure the quality of the concrete and the

cover is sufficient to achieve the durability desired. However, there are exceptions in which additional protection such as offered by hydrophobic treatment is worthwhile. During execution, imperfections may occur which can have consequences for the durability, such as insufficient cover to the reinforcement or too high concrete permeability due to improper curing.
Further more, concrete may be exposed to very aggressive conditions, for example structures where deicing salts are used frequently.

LITERATURE STUDY

In the Netherlands, the availabe information on hydrophobic treatment concerned only treatment of brickwork masonry and natural stone. A literature survey was carried out [1]. It was found that practically all research or experience reported, concerned plain portland cement concrete, while many Dutch concrete structures are made with blast furnace slag cement (BFSC), containing about 70% slag. Realising the possible limitations, the study led to several conclusions;

- Hydrophobic treatment can reduce the water absorption of concrete by 70 to 90%, also reducing chloride penetration.
- The best results are obtained when using agents based on silanes and oligomeric siloxanes.
- Applying a hydrophobic agent does not adversely affect the adhesion of coatings or adhesion promoting layers.
- Due to the absence of water absorption, water repellent concrete will reach its equilibrium moisture content quicker than unprotected concrete. There are indications that this slows down ongoing reinforcement corrosion [2].

THEORY

When a porous building material such as concrete comes into contact with (liquid) water, water is sucked into the pores of the material by capillary forces. The capillary forces are determined by: the surface tension of the liquid, the contact angle between the liquid and the pore walls, and the radius of the pores. Narrow pores attract moisture stronger (higher) than wide pores do. A viscous liquid is less (quickly) attracted than a thinly liquid substance. However, in the context of this article, the contact angle (Θ) is the most interesting aspect. A small contact angle indicates molecular attraction between the liquid and the substrate, in this case water and concrete. A liquid drop spreads over a flat surface, the meniscus in a capillary lies above the level of the surrounding liquid and is hollow towards the "dry" side (fig. 1).
In the absence of such attraction between a solid substance and a liquid, a drop remains on the surface in the form of a sphere, the height of rise is negative; i.e. the liquid level in the capillary is below that of the surrounding

liquid and the meniscus is convex on the dry side. We are all familiar with this: Look at mercury on glass or water on greased paper (fig.2)

FIG. 1 Interaction between water and non-hydrophobic concrete surface

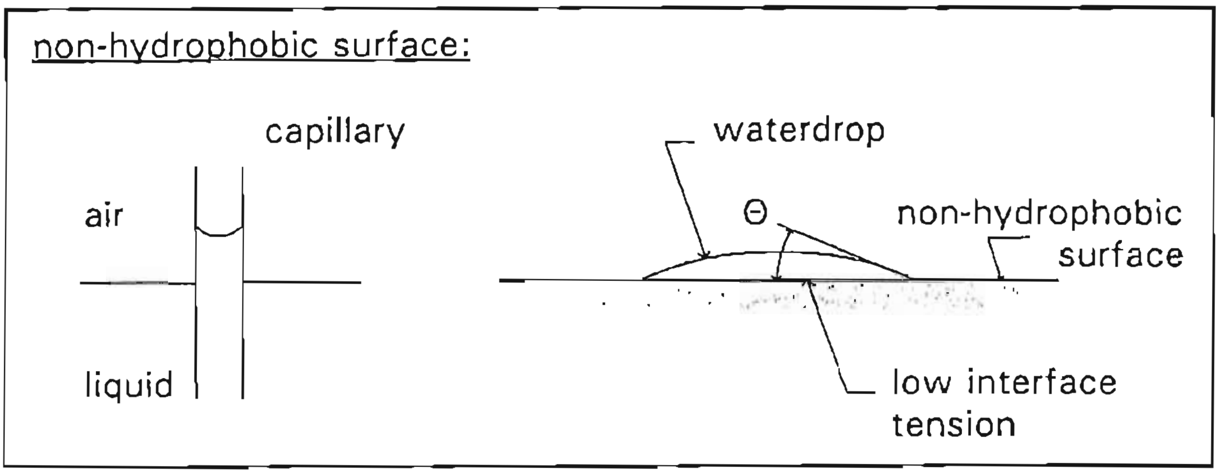
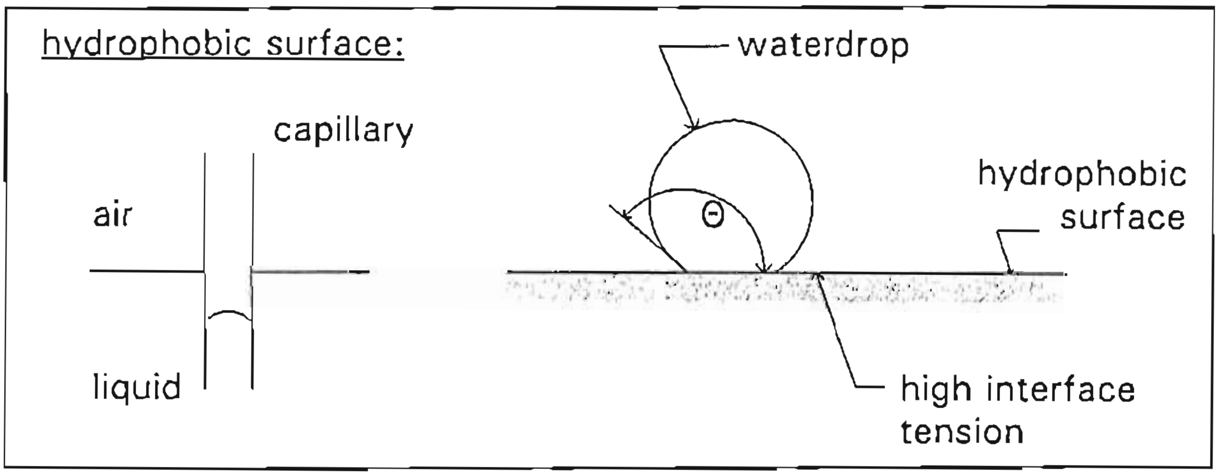
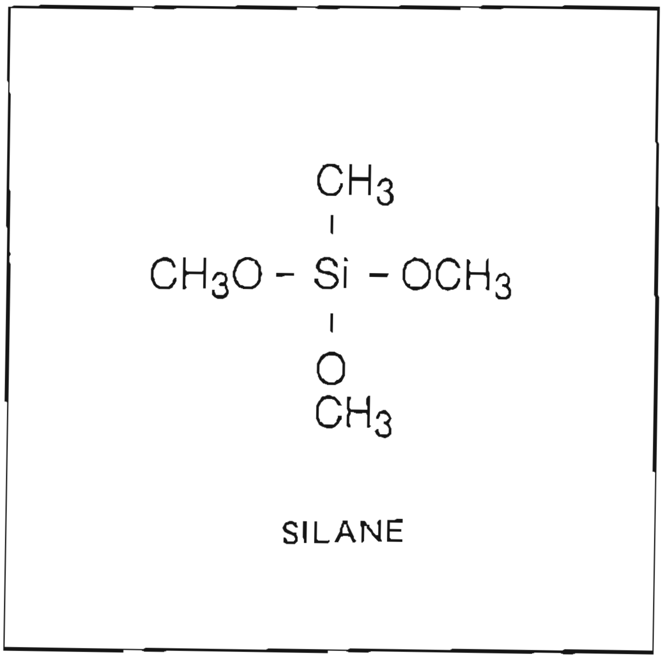


FIG. 2 Interaction between water on hydrofobic concrete surface



The weakening of the molecular attraction between water and concrete is precisely what a hydrophobic treatment is aimed at; the concrete becomes water repellent. This can be achieved by impregnating the concrete with water hydrophobic agents, such as silicones. Silicones form a group of related compounds, in which the silanes and siloxanes are the most important ones for concrete. Silanes are small molecules having one silicon atom (fig. 3). Siloxanes are short chains of a few silicon atoms (fig. 4). Both contain alkoxy groups linked to the silicium atoms, so they contain silicon-oxygen bonds, like the silicates in the concrete.

FIG. 3 Molecular structure of silane

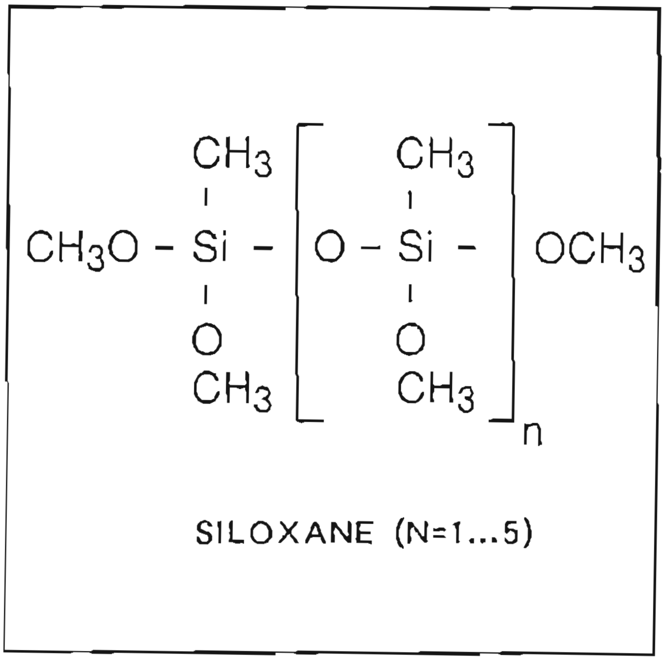


$$\mathrm{CH_3O-\overset{\displaystyle CH_3}{\underset{\displaystyle OCH_3}{Si}}-OCH_3}$$

SILANE

These bonds react with the concrete and then stick to it. In addition, silanes and siloxanes contain organic alkyl groups (CH_3-) which have a fatty character. After reaction of the molecule with the concrete, those alkyl groups protrude from the pore-wall surface into the pores. (fig. 5). This gives the concrete surface a fatty character. As a result, water molecules will be repelled and will no longer be able to wet the surface: the contact angle is greater than 90°, water remains lying on the surface as drops, and it is no longer absorbed by capillary suction (fig.2).

FIG. 4 Molecular structure of siloxane



$$\mathrm{CH_3O-\overset{\displaystyle CH_3}{\underset{\displaystyle OCH_3}{Si}}-\left[O-\overset{\displaystyle CH_3}{\underset{\displaystyle OCH_3}{Si}}-\right]_n OCH_3}$$

SILOXANE (N=1...5)

Silanes are dissolved (approx. 40% active substance) in alcohol or are applied to the concrete as 100% active substance. Once applied, the silane must polymerise, but at the same time a substantial amount of silane is lost by evaporation. Siloxanes are often dissolved in alcohol or hydrocarbon (approx. 10-20% active substance) and, nowadays also in the form of water-borne systems ("micro-emulsion"). Of siloxanes, less is lost by evaporation. Once the concrete surface is water-repellent (hydrophobic), the water absorption is strongly reduced (photograph 1).

FIG. 5 Diagrammatic representation of the chemical bond of the hydrophobic agent with concrete

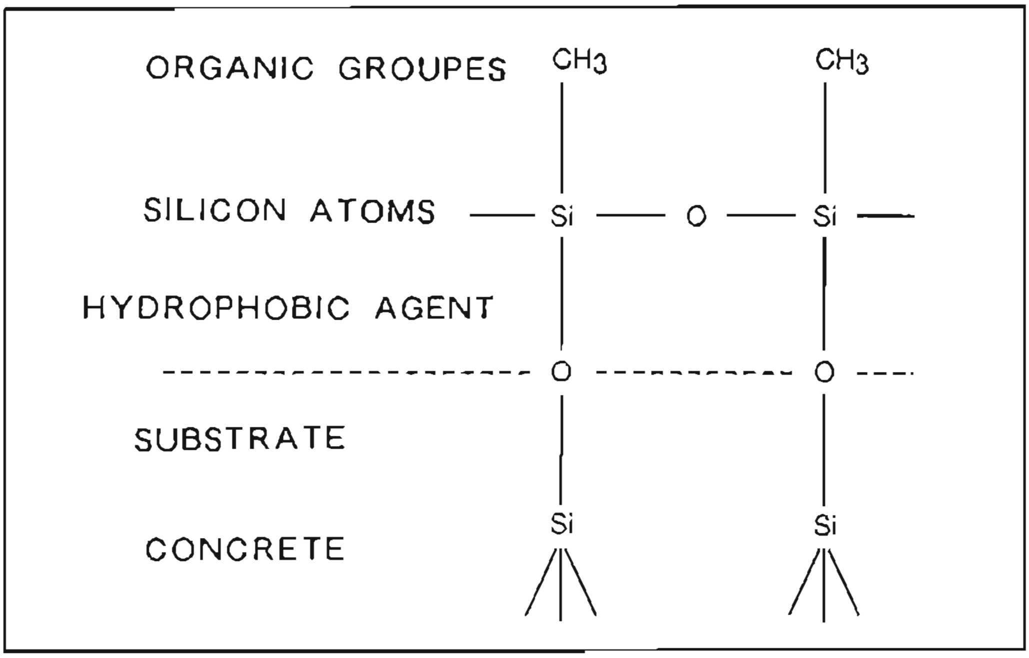
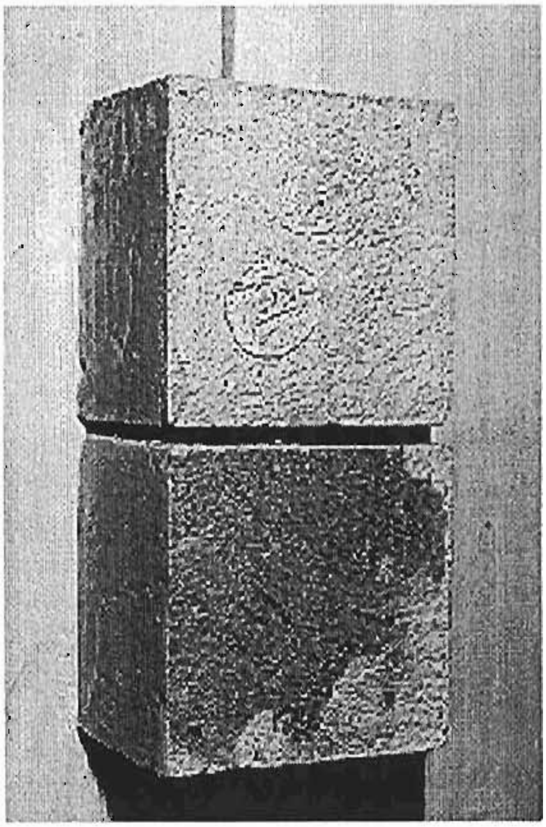


PHOTO 1 Top, hydrophobic concrete surface with water drop; bottom, immediate absorption of water by non-hydrophobic concrete



REQUIREMENTS FOR HYDROPHOBIC AGENTS

What requirements should a good hydrophobic agent for concrete meet?

The primary objective is to minimise the water absorption of the concrete. Accordingly, the water absorption of concrete treated with the agent should be determined and should be compared to the water absorption of similar but untreated concrete.

Secondly, the effect must last at least many years. To this end, it is essential that a sufficiently deep layer of concrete is hydrophobic. The hydrophobic effect is broken down by UV radiation. The breakdown occurs only in the outermost layer, as the UV light cannot penetrate the concrete. Consequently, for good durability of the water repellent effect, a certain minimum penetration depth is required. It is easy to obtain deep penetration in rather porous substrates, such as bricks. In concrete, it is not so easy to obtain sufficient penetration because of its finer pore structure.

To prevent water from accumulating under the hydrophobic surface, excessive moisture in the concrete must be able to evaporate freely. This is necessary to avoid damage due to water-pressure build-up under the hydrophobic layer or due to expansion when this water freezes, which may occur in the case of vapour-tight coatings.

The hydrophobing agent must be resistant to the strong alkalinity (high pH) of the concrete.

When the concrete after application of a hydrophobic agent, is covered by a layer of asphalt, the hydrophobic effect must resist the heat (approx. 160°C) of hot asphalt.

Considering these requirements, a set of test was designed and an experimental programme was carried out. The main requirements with respect to the reference concrete are:

- water absorption less than 20% of reference;
- penetration depth after standard application at least 2 mm;
- vapour transmission of hydrophobic concrete at least 60% of reference;
- water absorption less than 30% of reference after heating to 160°C for 30 minutes.

3 PERFORMANCE OF HYDROPHOBIC AGENTS ON CONCRETE

A total of nine commercially available (silicone-based) hydrophobic agents have been tested according to the setup. Outline 1 provides a brief description of these products.

Outline 1:

Overview of the tested hydrophobic agents:

code	type	active substance content	solvent	density g/l
A	silane	99%	none	878
B	silane	100%	none	915
C	silane/siloxane	12%	water	997
D	silane/siloxane	12%	water	998
E	silane/siloxane	20%	water	969
F	oligom.siloxane	>9%	hydrocarbon	814
G	silane	40%	ethanol	825
H	silane	20%	hydrocarbon	813
I	silane	10%	hydrocarbon	799

Tests

In the laboratory, two concrete mixtures were prepared using portland cement (CEM I 32,5 R) and blast furnace slag cement having a slag content > 65% (CEM III/B 42,5) which may be considered representative of concrete (strenght class B35) used in The Netherlands for viaducts, bridges, etc., see outline 2).

Outline 2:

Concrete composition (strength class B35) according to ENV 206 and curing of the specimens.

- cement: portland cement CEM I 32,5 R, or blast furnace slag cement CEM III/B 42,5 (>65% slag)
- cement content: 320 kg/m^3;
- water-cement ratio 0,50;
- maximum grain 32 mm;
- sand-gravel ratio: 60% gravel, 40% sand;
- admixture: superplasticizer, 0.5% m/m by mass of cement;
- curing: 3 days in formwork covered with plastic foil at 23°C, then in climate room with air of 20°C and 65% RH.

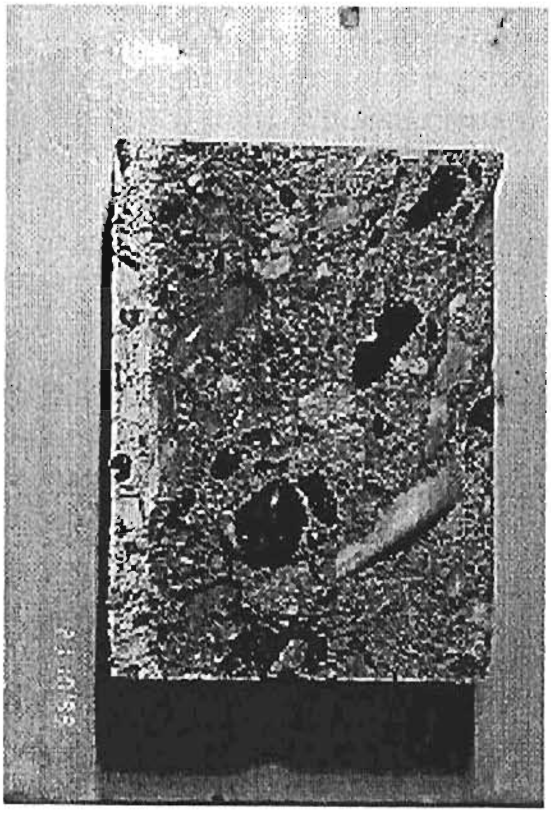
With this concrete, slabs were cast which were subsequently sawn into specimens having an outer surface of 100 x 100 mm^2. This resulted in specimens either with a "finishing" (top) faces or "formwork" (cast) faces.
The specimens were stored at 20°C and 65% RH for approximately 6 weeks. Then the hydrophobic agent was applied to the specimens by dipping one face about 3 millimeters in the liquid for 5 seconds and repeating the treatment after 10 minutes. To allow curing of the hydrophobic agent, the specimens were stored for 14 days at 20°C and 65% RH before carrying out the tests.
Non-treated specimens were exposed to the same conditioning before they were tested as reference specimens.

The water absorption of the specimens was determined by placing them with the treated face (or the same face for the controls) in a layer of water and weighing them at intervals of 1, 2, 3 and 24 hours. The water absorption of the treated specimens was expressed as a percentage of that of the reference specimens and is reported as the (relative) water absorption.

The heat resistance was measured by placing the specimens during 30 minutes in a preheated furnace at 160°C. After cooling of the specimens, the (relative) water absorption was determined.

The penetration depth of the hydrophobing agent was measured by splitting the specimens and moistening the broken surface. The hydrophobic zone then shows up much lighter than the wet concrete (photograph 2).

PHOTO 2 Split specimen after wetting, with the hydrophobic side on the left



The alkali resistance was tested on specimens made from cement-rich mortar with portland cement (for high alkalinity) which were subsequently subjected to hydrophobic treatment. The alkali resistance was evaluated by measuring the water absorption of these specimens and comparing the results with those of untreated specimens.

The vapour transmission was determined by measuring the evaporation rate of treated and non-treated specimens. After storage for 2 weeks at 20°C and 80% RH, a hydrophobic agent was applied as previously described. After another storage for 2 weeks in 20°C and 65% RH, the specimens were wetted via the face opposite the hydrophobic face. After that, the five non-treated faces were coated with a dense coating, allowing evaporation only through the hydrophobic face. Evaporation was determined in 20°C and 65% RH from weight loss after 1, 4, 7, 14, 21 and 28 days.

To identify the tested products, the density was determined and the infrared spectrum was recorded. From the density, a simple check is possible, for instance on site, whether the agent presented is indeed the product that has been tested (and approved), or whether it has been diluted with a solvent.
The infrared spectrum is a much more accurate method for identification; it is like a fingerprint. It may be assumed that if the IR spectrum deviates, the agent has apparently a different composition and the test result does not apply to this particular product.

RESULTS

The main results of the tests are shown in table 1 for portland cement concrete and in table 2 for blast furnace slag cement concrete. From a first comparison of the results it is immediately apparent that the performance of the individual agents is different for portland cement concrete and blast furnace slag cement concrete. In addition, there is a striking difference between the performance on finishing and formwork faces.

TABLE 1 Main test results obtained from portland cement concrete

Product	Consumption, (l/m²)		Water absorption in 24 hours (% of controls)		Water absorption after heat treatment at 160°C (% of controls)		Penetration depth (mm)	
	fin	form	fin	form	fin	form	fin	form
A	0.15	0.09	24	12	21	17	3	1
B	0.16	0.05	13	8	8	14	2	0
C	0.13	0.07	34	29	100	60	0	0
D	0.10	0.06	18	16	48	57	0	0
E	0.20	0.09	14	10	12	10	2	0
F	0.16	0.11	15	11	81	90	1	0
G	0.12	0.08	29	19	69	58	0	0
H	0.17	0.09	13	12	68	47	3	0
I	0.17	0.10	23	13	98	60	0	0
Requirements	-		< 20		< 30		≥ 2	

fin: finished surface
form: formwork (mould) surface

TABLE 2 Main test results from blastfurnace slag cement concrete

Product	Consumption, [l/m²]		Water absorption in 24 hours [% of controls]		Water absorption after heat treatment at 160°C [% of controls]		Penetration depth [mm]	
	fin	form	fin	form	fin	form	fin	form
A	0.82	0.20	15	18	15	21	2	1
B	0.62	0.15	10	17	11	26	4	2
C	0.30	0.16	29	30	60	85	2	1
D	0.29	0.13	25	25	62	76	2	1
E	0.53	0.19	8	17	17	20	4	1
F	0.34	0.13	16	14	81	100	2	2
G	0.33	0.17	32	40	70	69	3	0
H	0.37	0.19	20	22	33	75	3	2
I	0.42	0.19	26	26	67	77	3	1
Requirements	-		< 20		< 30		≥ 2	

fin: finished surface
form: formwork (mould) surface

Table 3 provides an overview of the total evaluation of the nine agents tested. It turns out that a number of agents did not meet the requirements. Especially the performance on formwork faces proved insufficient in many cases. On finishing faces, there were in the end three out of the nine products that proved satisfactory. If the requirement of the heat resistance is left aside, five products were satisfactory. It is to be noted, however, that two of these had been dissolved in hydrocarbons.
For environmental reasons the dutch Ministry of Transport, Civil Engineering Division, does not allow the use of hydrocarbon solvents .

In general, it may be concluded that there is a choice of several hydrophobic agents suitable for use on concrete for bridges. It became clear, however, that proper hydrophobic treatment of this relatively dense concrete is not easy. The penetration of the agent is the most critical factor, in particular for denser concrete, such as the tested formwork faces; it was substantially better on the tested finishing faces.

After evaluation of the test results, the requirements and the test setup have been laid down in an official recommendation [5].

TABLE 3 Overview of compliance to requirements of nine hydrophobic agents for concrete

Product	Portland cement		Blast furnace slag cement		Remark
	fin	form	fin	form	
A	+	-	+	-	also with asphalt
B	+	-	+	+	also with asphalt
C	-	-	-	-	
D	-	-	-	-	
E	+	-	+	-	also with asphalt
F	-	-	+	+	not with asphalt
G	-	-	-	-	
H	+	-	+	+	not with asphalt
I	-	-	-	-	

fin: finished surface	+	complies, suitable
form: formwork surface	-	does not comply, not suitable

EFFECT ON CHLORIDE PENETRATION

The effectiveness of a hydrophobic treatment against the penetration of chloride has been investigated by exposing specimens to wet-dry cycles with a salt solution. The cycles simulate in an accelerated manner the alternating load on the concrete by (wet) deicing salt and drying, as encountered in practice.

Of the specimens, only finishing faces of both portland cement and blast furnace slag cement concrete were treated with a hydrophobic agent containing 100% silane (B) and a 20% silane-siloxane agent (E) dispersed in water. During the test, treated and non-treated control specimens were exposed for 24 hours to a 10% NaCl (by mass) solution and then dried during 6 days at 20°C and 50% RH. The chloride penetration profiles were determined after 6 and 12 months in steps of 4 mm.

After 12 months, the chloride content at a depth of approx. 20 mm in hydrophobic concrete is less than 0.5% by mass of cement; in non-hydrophobic concrete this is about 2.6%, as shown in table 4 and fig. 6 and 7. This means that the hydrophobic treatment has reduced the chloride penetration by a factor of 5 to 6. This reduction corresponds quite well to the reduction of the water absorption found for concrete treated with these products.

TABLE 4 Chloride penetration after 12 months exposure to weekly deicing salt/drying cycles

Cement type	Hydro-phobic agent code	Average chloride content by mass of cement after 12 months exposure				
		0-4 mm	4-8 mm	8-12 mm	12-16 mm	16-20 mm
OPC	B	1.3	1.2	0.8	0.6	0.5
	E	0.9	0.5	0.5	0.5	0.4
	Control	3.1	3.2	3.1	2.8	2.8
BFSC	B	1.4	0.9	0.9	0.7	0.4
	E	1.2	0.3	0.2	0.1	0.2
	Control	5.2	5.0	3.7	3.0	2.4

FIG. 6 Chloride-penetration in blanc and hydrophobic portlandcement concrete after 12 months

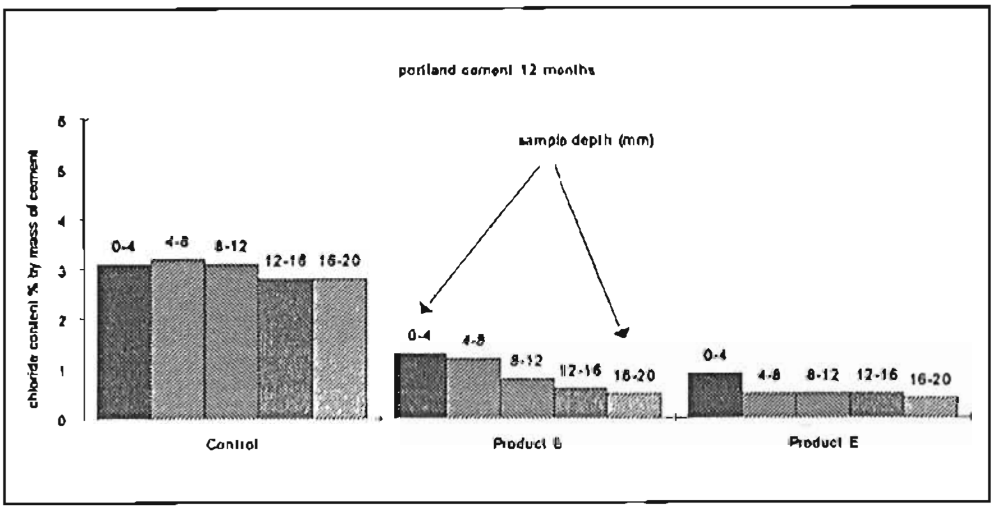
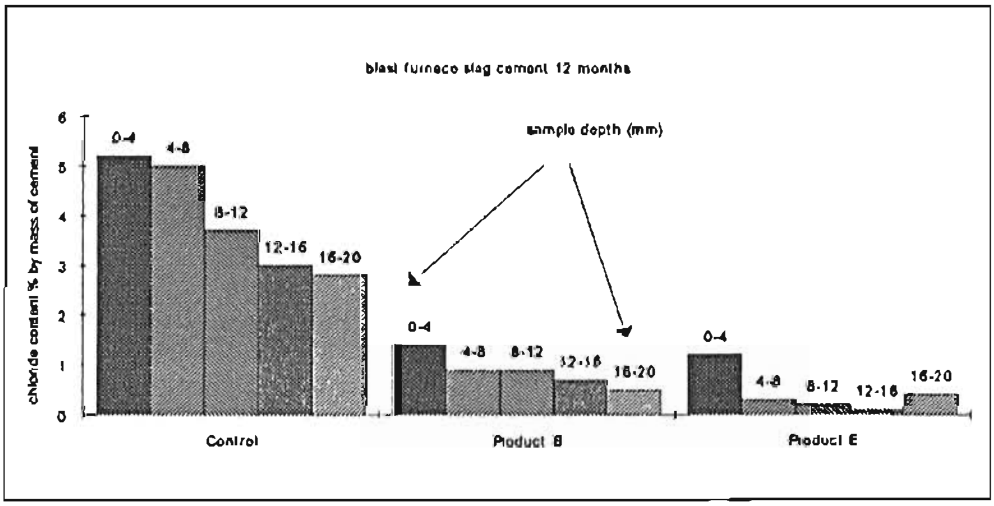


FIG. 7 Cloride-penetration in blanc and hydrophobic blastfurnage cement concrete after 12 months



It may be concluded that the hydrophobic treatment of concrete, prepared both with portland cement and with blast furnace slag cement, strongly slows down the penetration of chloride into concrete subjected to a simulated deicing salt-drying cycles.

FURTHER RESEARCH

Further research into hydrophobic treatment of concrete is being carried out focusing on durability, deicing salt load, effect on ongoing corrosion and variations in the application. The results of these tests will be published in due course.

4 CONCLUSIONS

The following conclusions were drawn from the investigation:

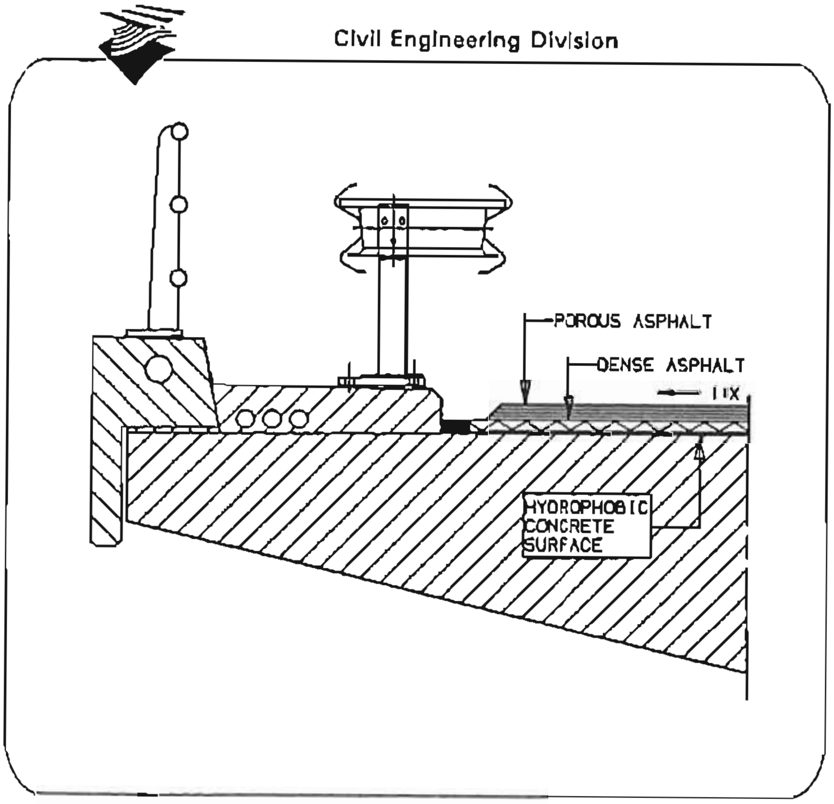
- The proposed test setup for hydrophobic agents is up to the mark and the requirements are reasonable.
- Laboratory tests show that several products on the Dutch market have a good performance on concrete such as used in The Netherlands for bridges. Various other products, however, did not perform very well. Proper identification of a hydrophobic agent is therefore very important.
- It was found that the performance was different on different types of concrete in terms of the cement type and in terms of finished or formwork face. In particular the penetration of the hydrophobic agent is better in finished faces than in formwork faces, due to the higher permeability of the former.
- Hydrophobic treatment of concrete strongly reduces the penetration of chloride under deicing salt/drying cycles. This is the case for concrete prepared with portland cement or (high slag) blast furnace slag cement.

5 SOME IMPLICATIONS FOR PRACTICE

When translating the research results into practical terms, it should be kept in mind that the working conditions outdoors are often less favourable than in the laboratory. This has two effects that are relevant to hydrophobic treatment of concrete. Firstly, the concrete surface may have a lower quality (locally) than specified. If it would not be treated, this would have a negative effect on durability. Interestingly, the research indicates that the penetration of a hydrophobic agent is better in poor concrete; consequently the poorest spots receive a better protection. On the other hand, the conditions for application of hydrophobic agents on site may be less favourable than in the laboratory, thus adversely affecting the performance. In particular, the moisture content of the substrate is important. A hydrophobic agent will perform well only if it is applied to a dry concrete surface. To obtain the optimal result, the agent must be applied in two consecutive coats, "wet in wet", and in sufficient amount. The amount of liquid taken up by the concrete surface should be determined and compared to the rate found In the laboratory. If less liquid is absorbed, this indicates that the concrete is too wet to obtain the desired effect.

Two specific cases appear appropriate for the use of hydrophobic treatment. Firstly, places where due to poor execution the cover to the reinforment steel is low and/or the density of the concrete is insufficient. Here, hydrophobic treatment would be a corrective measure. This should, of course, never be used as an excuse for doing poor work! Secondly, providing additional protection may be a preventive measure. Preventive treatment may be useful for inaccessible concrete surfaces (even where proper cover depth is present) or for structures exposed to very aggressive environment. For example, consider concrete surfaces under asphalt overlays. It is hardly possible to inspect them, while the load by deicing salt solutions can be high. When using porous asphalt as a wearing course on concrete bridges, the dutch Ministry of Transport, Civil Engineering Division, recommends additional protection by applying a hydrophobic agent (fig. 8). Concrete vehicle barriers and side-walks of viaducts may certainly be considered as being exposed to very aggressive environment. Here as well, additional protection in the form of a hydrophobic treatment can be worthwhile.

FIG. 8 Detail of concrete side-walk and guard-rail on viaduct with opous asphalt



CONCLUDING REMARKS

Normally, well-designed and properly executed concrete does not need hydrophobic treatment! However, in exceptional cases, hydrophobic treatment can provide additional protection which is required to obtain a long service life.

6 REFERENCES

1 Mechelen, A.C.A. van, Polder, R.B., 1992, Hydrofoberen van betonnen brugdelen, literatuurstudie in opdracht van Bouwdienst Rijkswaterstaat, TNO Building and Construction report B-92-0587; (Hydrophobic treatment of concrete bridge components, literature study commissioned by Ministry of Transport, Civil Engineering Division), in Dutch;

2 Sergi, G., Lattey, S.E., Page, C.L., 1990, Influence of surface treatments on corrosion rates of steel in carbonated concrete, Proc. Corrosion of Reinforcement in Concrete, eds. C.L. Page, K.W.J. Treadaway, P.B. Bamforth, SCI/Elsevier, 409-419;

3 Bouwdienst Rijkswaterstaat, 1989, Zeer open asfaltbeton op betonnen brugdekken (Porous asphalt on concrete bridge decks, Ministry of Transport, Civil Engineering Division), in Dutch;

4 Polder, R.B., 1993, Overzicht testresultaten van hydrofobeermiddelen voor betonnen brugdelen volgens de voorlopige proefopzet en eisen Rijkswaterstaat, TNO Building and Construction report 93-BT-R0136 (Overview of test results of hydrophobic agents for concrete bridge components according to the provisional test setup and requirements of Rijkswaterstaat), in Dutch;

5 Bouwdienst Rijkswaterstaat, 1993, "Aanbeveling voor de keuring van hydrofobeermiddelen voor beton volgens de eisen van Bouwdienst Rijkswaterstaat", report BSW 93-26 ("Recommendation for testing hydrophobic agents for concrete according to the requirements of Ministry of Transport, Civil Engineering Division"), in Dutch.;