Water Repellent Treatment of Building Materials
Proceedings of Hydrophobe II
Zürich, September 1998, Aedificatio Publishers pp.63-76

The Behaviour of Cracks in Water Repellent Concrete Structures with Respect to Capillary Water Transport

P. Lunk[1] and F.H. Wittmann[2]
[1]MBT Switzerland, Zurich,
[2]Institute for Building Materials, ETH Zurich, Switzerland

Abstract

In practice, water repellent impregnation has been established as an effective surface protection system against water and de-icing salt attack. Cracks in concrete, whether impregnated by a hydrophobing treatment or not, are unavoidable and can therefore lead to serious damage. In absorption tests on laboratory samples, the significant influence of cracks on the penetration behaviour of capillary water has been determined and quantified. The experimental results show that the water uptake depends on the crack width and the penetration depth of the water repellent agent. There exists a maximum threshold crack width depending on the penetration depth of the water repellent agent which can maintain the water repellent behaviour. Finally practical conclusions of the present work are drawn.

Keywords: cracks, capillary water transport, critical crack width

1 Introduction

Reinforced concrete structures which are subject to de-icing salt applications or located in marine environments are likely, after a certain period of exposure, to exhibit signs of distress due to ingress of chlorides and the corrosion of the reinforcing steel. This normally becomes apparent with the formation of cracks, frequently accompanied by rust staining and ultimately spalling of the concrete cover.

There are various methods of protecting and repairing concrete. The selection of a method depends on a large number of factors, e.g. the degree of damage, the design life, costs of repair, application methods. In practice, hydrophobing impregnation has been established as an effective surface protection system against water and de-icing salt attack [1-4]. Cracks in concrete, whether impregnated by a hydrophobing treatment or not, are unavoidable and can therefore lead to damage [1].

In this paper results of absorption tests on laboratory samples are presented. The significant influences of cracks on the penetration behaviour of capillary water have been determined and quantified.

2 Experimental

An experimental programme was undertaken to obtain absorption data for standard concrete and water repellent concrete with cracks. The influences of crack type, crack width and penetration depth of the hydrophobing agent were determined. In this paper the investigation of the influence of crack width and penetration depth of the hydrophobing agent will be presented only. All results were given in [1]. The concrete mix used is detailed in Table 1.

The concrete samples were reinforced with a steel type S500b, 6 mm diameter, and they had with following dimensions, 50x300x150 mm^3. Three different hydrophobing agents were used to impregnate one surface of the sample before absorption testing. The hydrophobing agents and the properties are detailed in Table 2. Afterwards, in the water repellent surface, cracks with a width of of 0.2 mm, 0.4 mm and 0.8 mm were created by a 3-point bending test. Details of the experimental set-ups are amply described in [1]. Figure 1 shows a schematic illustration of the geometry of the sample.

For absorption testing water repellent samples with the dimensions 50x200x150 mm^3 were prepared. The surface in contact with fluid was 50 x

Table 1: Composition of the standard concrete

water/cement ratio [-]	cement content [kg/m³]	water content [kg/m³]	sand and gravel [kg/m³]
0.50	350	175	1887

Table 2: Some details of the hydrophobing agents

no. [-]	type of hydrophobing agent [-]	active substance [%]	mean penetration depth s [mm]
1	siloxan	7.5	2.5
2	silan	40	5.0
3	silan	100	7.5

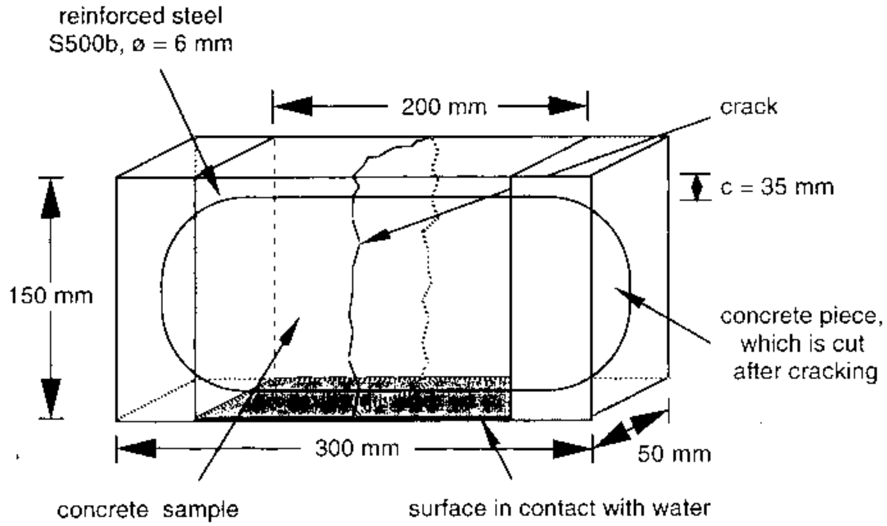

Figure 1: Schematic illustration of the geometry of the sample

200 mm². The samples were stored at 20°C and 75% R.H. Further details of the conditioning are given in [1]. Before capillary suction started, four faces of the sample were sealed with a dense polymer, while the two end faces remained free. This ensured 1-dimensional movement of moisture.

Vertical absorption test were performed with tap water. Samples were tested over a 24-hour absorption period. A computer-controlled weighing was used to determine the water gain. Details of the experimental set-ups are amply described in [5].

3 Results

Concrete samples with different impregnation depths without crack and with bending cracks were investigated. The crack width was 0.2 mm, 0.4 mm and 0.8 mm; the crack length was between 130 mm and 150 mm. The penetration depth of the hydrophobing agent was 2.5 mm, 5.0 mm and 7.5 mm. In Figures 2 - 4 the water gain as a function of the square root of time is given for the three concrete samples with different water repellent treat-

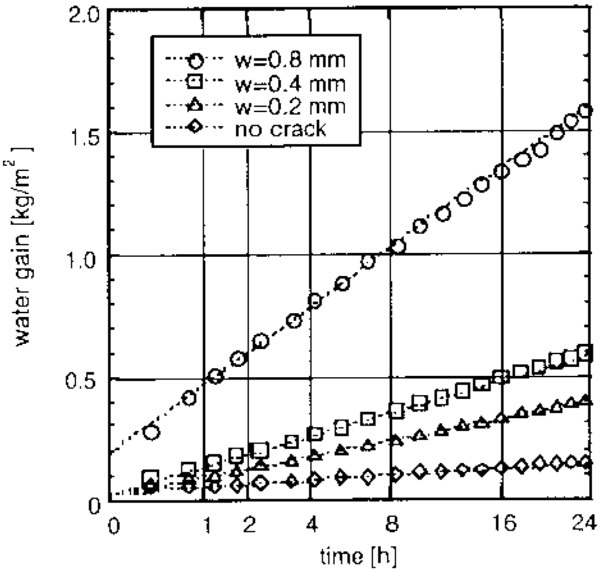

Figure 2: Water gain as function of square root of time for water repellent concrete with no crack and different crack widths. The penetration depth of the hydrophobing agent is 2.5 mm.

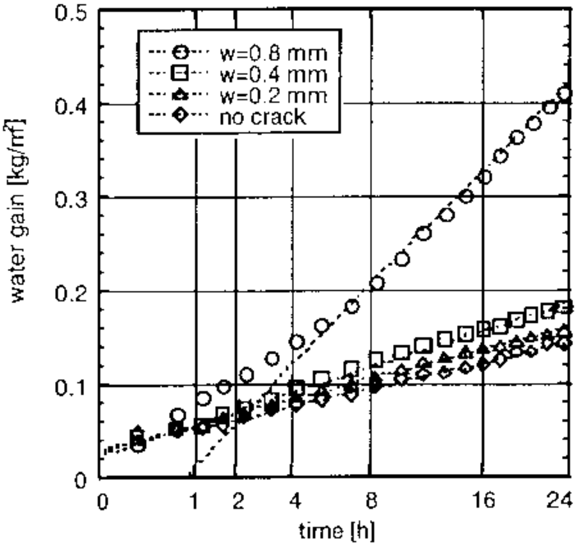

Figure 3: Water gain as function of square root of time for water repellent concrete with no crack and different crack widths. The penetration depth of the hydrophobing agent is 5.0 mm.

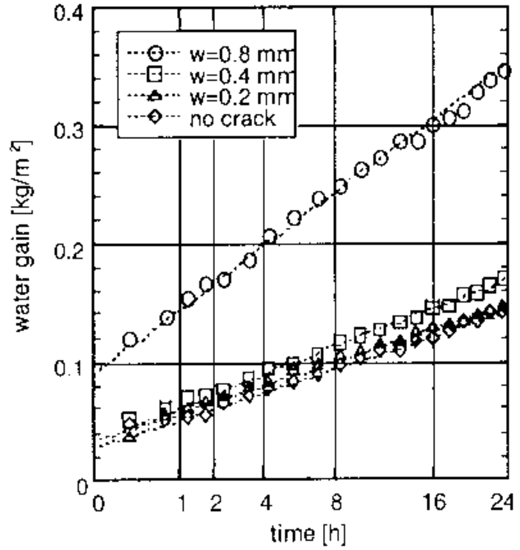

Figure 4: Water gain as function of square root of time for water repellent concrete with no crack and different crack widths. The penetration depth of the hydrophobing agent is 7.5 mm.

ment. Mean values of experimental data from three samples are represented with different markers. The dotted line is calculated by linear regression according to DIN 52617 [6].

The experimental results show that the water uptake depends on the crack width and the penetration depth of the hydrophobing agent. In general with increasing crack width and decreasing penetration depth of the hydrophobing agent a higher water gain can be expected.

Cracks with a width up to 0.2 mm in water repellent concrete with a penetration depth of the hydrophobing agent of 2.5 mm result in a dramatical increase of water uptake comparing to water repellent concrete with no crack. Here, water repellent concrete with a crack width of 0.8 mm shows the same penetration behaviour as an identical concrete without hydrophobing treatment and no crack. Furthermore, it has been shown that water repellent concrete with crack width of 0.8 mm can not prevent the water uptake for a long time. At a penetration depth of 5.0 mm and 7.5 mm, an increase of water uptake has been determined with a crack width of 0.8 mm.

Table 3 gives the statistical relations of Figures 2 to 4. The slope of the dotted lines in these figures were used to calculate the water absorption coefficients. These are shown in column 3 of Table 3.

Table 3: Compilation of the water absorption coefficients of water repellent concrete with different penetration depths of the hydrophobing agent and different crack widths

penetration depth of the hydrophobing agent s [mm]	crack width of a bending crack in the water repellent surface w [mm]	water absorption coefficient A [$kg/m^2 \cdot h^{0.5}$]
2.5	0	0.024
	0.2	0.078
	0.4	0.116
	0.8	0.288
5.0	0	0.023
	0.2	0.028
	0.4	0.032
	0.8	0.106*
7.5	0	0.023
	0.2	0.024
	0.4	0.028
	0.8	0.053

* Water absorption coefficient was calculated based on the results between 8 and 24 hours

4 Discussion

It has been shown, that the penetration behaviour of water repellent concrete with cracks is influenced mainly by the penetration depth of the hydrophobing agent. In Figure 5 the relationship between water absorption coefficient and crack width is given. An exponential function is used for the mathematical description of the water absorption coefficient with increasing crack width.

$$A = A_{0,\text{hyd.}} \cdot e^{\beta \cdot w} \qquad (1)$$

where A is the water absorption coefficient of water repellent concrete with a crack width w, $A_{0,\text{hyd.}}$ is the water absorption coefficient for water repellent concrete with no crack, w is the crack width and β is the deviation coefficient.

The best fit of Equation (1) and experimental results is represented by dotted lines (Fig. 5) and shows a good correlation. Additionally the threshold value of the water absorption coefficient according to DIN 18550 [7] is indicated. Paints with a water absorption coefficient $A < 0.1$ kg/(m^2·h$^{0.5}$) are characterized as watertight.

In Figure 6 the relationship between the water absorption coefficient and the penetration depth of the hydrophobing agent is given. An exponential function is used for the mathematical description again.

$$A = A_{0,\text{hyd.}} + (A_{\text{crack}} - A_{0,\text{hyd.}}) \cdot e^{-\gamma \cdot s} \qquad (2)$$

where A_{crack} is the water absorption coefficient for concrete without hydrophobing treatment and with cracks, s is the penetration depth of the hydrophobing agent and γ is the deviation coefficient.

Equation (2) with fitted parameters is represented by dotted lines in Fig. 6 and shows a good correlation. Additionally, the threshold value of the water absorption coefficient according to DIN 18550 [7] is drawn. For water repellent concrete this value is more general. In practice, a water absorption coefficient $A < 0.50$ kg/(m^2·h$^{0.5}$) is often used. Based on this value and over a period of 24 hours, the penetration behaviour of water repellent concrete with a crack width $w \leq 0.4$ mm and a penetration depth of the hydrophobing

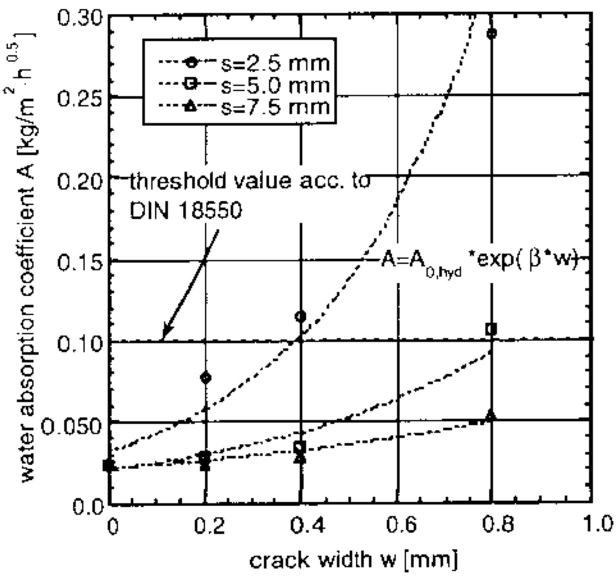

Figure 5: Water absorption coefficient A as a function of crack width wfor water repellent concrete with different penetration depths of the hydrophobing agent

agent of several millimetres is very similar to a water repellent concrete without cracks.

Franke and Bentrup [8] have investigated the influence of cracks in water repellent masonry on the protection against driving rain. They found that the hydrophobing effect is maintained over the total service life if the crack width is lower than 0.5 mm .

It seems that there exists a maximum threshold crack width depending on the penetration depth of the hydrophobing agent which can maintain the hydrophobing behaviour at the surface. In Figure 7 the relationship between the water absorption coefficient and the ratio of crack width to penetration depth of the hydrophobing agent is given. Here too, an exponential function is used, which describes the characteristic behaviour of the material.

$$A = A_{0,hyd.} \cdot e^{\delta \cdot w/s} \tag{3}$$

where A is the water absorption coefficient for cracked water repellent concrete, $A_{0,hyd.}$ is the water absorption coefficient for water repellent concrete without crack, w is the crack width, s is the penetration depth of the hydro-

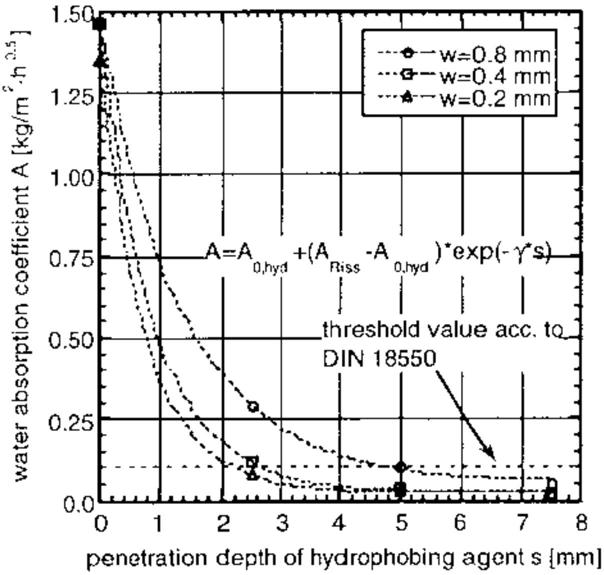

Figure 6: Water absorption coefficient as a function of penetration depth of the hydrophobing agent for concrete with different crack widths

phobing agent and δ is the deviation coefficient. In [1] the value of δ has been determined experimentally to be 8.6.

Equation (3) with the fitted parameters is represented by a dotted line and shows a good correlation. Additionally, the threshold value of the water absorption coefficient according to DIN 18550 [7] and the value of a standard concrete without hydrophobing treatment and no crack are shown.

Figure 8 gives a simplified illustration of water uptake into water repellent concrete with cracks. The moisture transport can be divided into two transport mechanism - water vapour diffusion and capillary water transport. This process can be explained, in the simplified way by three steps.

- Step 1 (Fig. 8, top): The water repellent concrete with a crack is in contact with moisture from the air. Depending on the relative humidity, water molecules are condensed on the surface of the edges of the crack behind the water repellent zone.
- Step 2 (Fig. 8, middle): The water repellent concrete with a crack is in contact with water. This water cannot penetrate into the crack directly, because the surface is water repellent. The crack mouth is

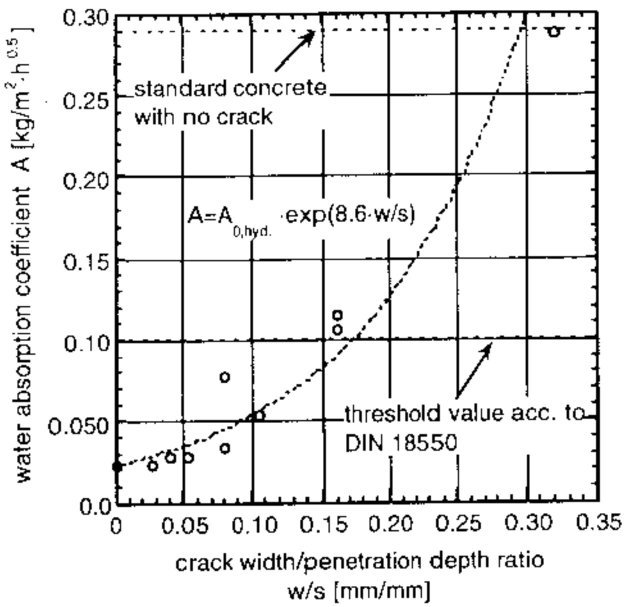

Figure 7: Water absorption coefficient as a function of the crack width / penetration depth ratio

now in contact with 100% R.H. and therefore more water molecules are condensed in the crack behind the water repellent zone. With increasing wetting-time a closed water film is created and even capillary condensation may take place. It should be noted here that the driving rain and wind pressure may push water through the water repellent zone.

- Step 3 (Fig. 8, bottom): The closed water film grows and expands across the surface. Depending on the penetration depth of the hydrophobing agent, a link between the water behind the water repellent zone and the water on the surface can be established. If this water link is built up, the edges of the crack without hydrophobing treatment are in direct contact with water. Capillary suction starts immediately. In this way salt solutions are als able to penetrate through the water repellent zone.

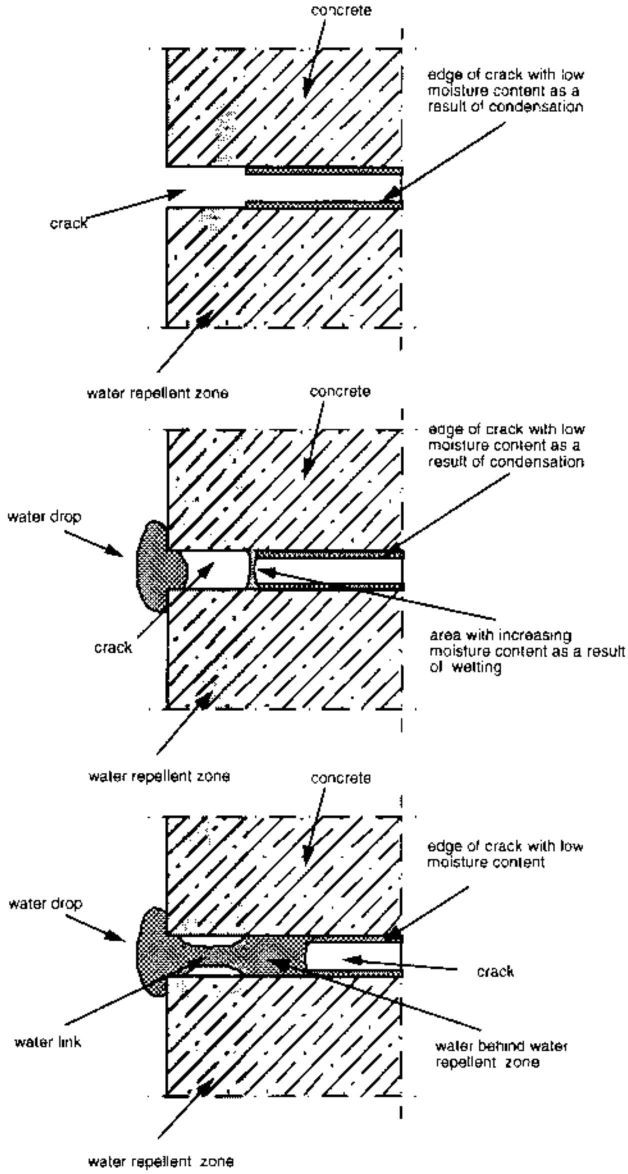

Figure 8: Schematic illustration of water uptake into water repellent surface treated concrete with cracks,

step 1 (top): water repellent concrete in contact with moisture from the air,

step 2 (middle): water repellent concrete in contact with water (wetting),

step 3 (bottom): water uptake of water repellent concrete through the impregnated zone

5 Conclusions

The work outlined in this paper represents only part of a much wider research programme [1]. In this project the influence of cracks in concrete without hydrophobing treatment and water repellent concrete has been evaluated. The following conclusions can be drawn:

- Capillary suction has a decisive influence on the durability of concrete, especially regarding the resistance to chloride ingress.
- Increasing of capillary suction can results from:
  - a.) cracks (especially regarding separation cracks) caused by direct loading or resulting from imposed deformations (hygral and thermal dilatation).
  - b.) microcracks caused by no or inefficient curing.
- Cracks in water repellent concrete structures have to be considered separately.
- A maximum threshold crack width depending on the penetration depth of the hydrophobing agent exists which can maintain the hydrophobing behaviour.
- A functional correlation between the water absorption coefficient and the ratio of crack width to penetration depth of the hydrophobing agent is determined, which describes the penetration behaviour of water repellent concrete with cracks.
- Usual penetration depths of the hydrophobing agent of 2-3 mm in practice can not prevent a capillary transport of water and salt into cracks with width up to 0.2 mm over a long period of time.

Acknowledgement

Part of this work has been financially supported by Bundesamt für Strassen, Astra, Bern. This support is greatfully acknowlwedged

References

[1] Wittmann F.H., Lunk P. and Müller T.: *Feuchtigkeits- und Ionentrans port bei gerissenen Stahlbetonbauteilen*, Eidgenössisches Departement des Innern, Bundesamt für Strassenbau, (in preparation)

[2] Hassan K.E.-G. and Cabrera J.G.: *Protection of Concrete against Chloride Penetration using Water Repellent Surface Treatments*, Int. Z. Bauinstandsetzen, **2**, 161-177 (1996)

[3] Giudici I., Gerdes A. and Wittmann F.H.: *Einfluss einer Hydrophobierung auf das Eindringverhalten von Chloridlösungen in Beton*, in: F.H.Wittmann and A. Gerdes, editors, 4.th Int. Colloquium on Material Science and Restauration, TAE Esslingen, 317-334 (1996)

[4] Wittmann F.H. and Müller T.: *Beständigkeit einer Hydrophobierung, Ergebnisse einer Bestandsaufnahme*, Eidgenössisches Departement des Innern, Bundesamt für Strassenbau, Heft **523**, Bern (1996)

[5] Lunk P.: *Kapillares Eindringen von Wasser und Salzlösungen in Beton, Dissertation*, ETH Zürich (1997), published in Building Materials Reports, No **8** (1997)

[6] DIN 52617: *Bestimmung der kapillaren Wasseraufnahme von Baustoffen*, Berlin, (Mai 1987)

[7] DIN 18550: *Putz, Begriffe und Anforderungen*, Berlin, (Januar 1985)

[8] Franke L. and Bentrup H.: *Einfluss von Rissen auf die Schlagregensicherheit von hydrophobiertem Mauerwerk und Prüfung der Hydrophobierbarkeit*, Bautenschutz + Bausanierung, **14**, 98-101 und 117-121 (1991)