Hydrophobe III -
3rd International Conference on Surface Technology with Water Repellent Agents,
Aedificatio Publishers, 133–142 (2001)

Penetration Depth of Hydrophobic Impregnating Agents for Concrete

M. Bofeldt and B. Nyman
Sycon Stockholm Konsult, Stockholm, Sweden

Abstract

A laboratory study was carried out in order to understand and correlate the parameters controlling the penetration depth of a hydrophobic impregnating agent while investigating the effect concrete quality has on the penetration depth of the agent. Silane-based impregnating agents were used for all tests in the investigation. Penetration depths of hydrophobic agents for concrete were investigated using specimens of various concrete compositions. These were based on different w/c-ratios, air content and type of cement as well as on the addition of silica fume to the concrete mix. Effects of surface treatments with an anti-graffiti system and artificial traffic soil as well as the presence of a leached-lime surface deposit were also investigated. The compositions were studied at three different RH values: 65, 75 and 90 %. The penetration depth achieved by using new application technologies such as impregnation with silane-based cream and gel emulsion, compared to conventional impregnation with liquid agents, was evaluated. Results showing the effects of absorption time, RH and quality of the concrete are graphically presented. Absorption time, w/c-ratio and RH appeared to be the most influential parameters affecting penetration depth. Impregnation with gel resulted in very high penetration depths, comparable to absorption times between one and three days. Impregnation with cream also resulted in high penetration depths, compared to conventional impregnation with liquid, and corresponds to a ten-minute absorption time. Better results were achieved with a gel than with a cream.

1 Introduction

Concrete is used for most infrastructure constructions. These are often exposed to the weather which frequently leads to serious moisture damages. Hence, a method to avoid or reduce moisture damages is to impregnate the concrete with a water repellent agent.

The quality of an impregnation depends on the type of impregnating agent used, the treatments or coverings at the concrete surface and the concrete's ability for capillary uptake of these agents. The capillary suction is determined by the concrete mix, moisture content in the concrete and capillary suction time, i.e., the absorption time allowed for the impregnating agent.

In a preliminary investigation, carried out on just a few specimens, the penetration depth was evaluated as a function of moisture content and capillary suction time [1]. To elucidate and define the parameters that determine the penetration depth, including the quality of the concrete, Sycon Stockholm Konsult performed a more comprehensive laboratory investigation in the course of which a larger number of specimens were examined.

Eleven different combinations of concrete composition and surface treatment were investigated in this laboratory study. For each combination three different RH values of the concrete were used and ten different absorption times, from 20 seconds up to 7 days. In addition, the effects of surface treatments or deposits - such as an anti-graffiti product, articial traffic-soil and leached-lime - on penetration depths were investigated. The water repellent impregnation was tested as a liquid, cream and gel.

This report is a shortened and summarized version of the complete written report currently available in Swedish [2]. A full English version will possibly be available later. Further work on the absorption of hydrophobic liquid is currently being executed, using the same parameters as those mentioned in this report.

2 Concrete composition

2.1 Remarks

Seven different types of concrete were used in the tests. This allows for determining if and how the concrete composition affects the agent's penetration depth. The different types of concrete resulted from using: two types of cement (low alkali and Portland); differences in w/c-ratio, addition of an air-entraining agent, and of silica fume to the concrete mix. Finally, one of these compositions was submitted to an investigation concerning the effects of surface deposits - leached-lime, applied artificial traffic-soil, and anti-graffiti treatments, applied before or after the impregnation - on the penetration depth.

Table 1: Variation in concrete composition and description of surface treatment

Compo-sition	w/c - ratio	Type of cement	Air-content	Silica fume	Surface treatment
C1	0.4	CEM I 42.5 BV/SR/LA[1]	5.0%	5% of cement weight	
C2	0.4	CEM I 42.5 BV/SR/LA	5.9%	-	
C3	0.5	CEM I 42.5 BV/SR/LA	6.0%	-	
C4	0.5	CEM I 42.5 BV/SR/LA	-	-	
C5	0.5	CEM II /A-L 42.5 R[2]	-	-	
C6	0.5	CEM II /A-L 42.5 R	-	-	Artificial traffic-soil
C7.1	0.5	CEM II /A-L 42.5 R	-	-	Chemical-based anti-graffiti system applied after impregnation
C7.2	0.5	CEM II /A-L 42.5 R	-	-	Chemical-based anti-graffit system applied before impregnation.
C8	0.5	CEM II /A-L 42.5 R	-	-	
C9	0.6	CEM II /A-L 42.5 R	-	-	
C10	0.7	RCEM II /A-L 42.5 R	-	-	

[1] Low alkali cement, [2] Portland cement

2.2 Surface-treated specimens

The traffic-soil used in the investigation is artificially produced by Sycon Stockholm Konsult and is supposed to simulate natural traffic-soil sediment on concrete, for example tunnel walls or columns next to roads. The artificial traffic soil contains silica fume, asphalt, oil, colloidal carbon, salt, water and sodium silicate.

The specimens with composition C7.2 were treated with an anti-graffiti system containing a protective wax emulsion-based agent (AGS 3502) and a decontamination (AGS 10) agent prior to impregnation. This was to investigate any negative effects these chemicals might have on the impregnation (i.e. penetration depth). For comparison, specimens with composition C7.1, had the same anti-graffiti treatment applied after impregnation to investigate any possible damage developed by the chemicals.

The effects of leached-lime deposits on the concrete surface were investigated using specimens with composition 8. These deposits usually cause an increase in the permeability of the concrete, which should lead to higher penetration depth, although the thin layer of lime - eventually calcium carbonate - at the concrete surface might possibly decrease the penetration of the impregnating agent.

3 Laboratory investigations

3.1 Introduction

All water repellent agents used in this study are based on octylsilane. They are formulated as a liquid, StoCryl HP 200/Conservado-101; a gel, StoCryl HG 200; and a cream - in spite of the name - StoCryl HC 100/ Conservado-201/C1-gel.

3.2 Specimens and testing program

3.2.1 Specimens

The specimens are concrete cubes with edges 150-mm in length. These are sawed into 8 test cubes with edges approximately 72-mm in length. The 4 specimens (72 mm-cubes) belonging to the upper part of the 150 mm-cubes were used to measure the penetration depth. This measurement was performed on any of the sides that were in contact with the casting mould during the concrete’s hardening.

3.2.2 Testing program

The test specimens were conditioned at different RHs: 65%, 75% and 90%. For each concrete composition, C1-C10, impregnation with a liquid water-repellent was carried out at four different absorption times: 20 seconds, 1 hour, 1 day and 3 days. Six specimens were used for each combination (3 different RH values and 4 different absorption times), making a total number of 72 specimens [see Table 1].

For compositions 2, 3, 4, 5, 9 and 10, an additional 6 differing absorption times were used: 2, 10 and 30 minutes, 2 and 4 hours, and 7 days. In this case, only 3 specimens were used for each combination (3 RH values and 6 absorption times), involving another 54 specimens. The total number of specimens impregnated with liquid water repellent was 1116.

Gel and cream impregnating agents were tested for concrete compositions 2, 3, 4, 5, 9 and 10. In this case, 3 specimens were used for each RH, i.e., a total of 9 specimens for each composition. The time variable was not included because the absorbtion process continues as long as there is any gel or cream left on the concrete surface. The absorption time depends on the thickness of the gel and cream covering. The thickness of gel covering was 0.8 mm and thickness of cream covering was 0.4 mm.

A total number of 54 specimens was used for impregnation with gel and the same number of specimens for impregnation with cream.

Altogether, 1224 concrete specimens were tested to measure the penetration depth on 264 different combinations of concrete composition, RH, absorption time and type of impregnating agent.

3.3 Conditioning of concrete specimens

The specimens were stored in climatic chambers at 20 °C and at relative humidities of 65, 75 and 90 % RH. Specimens tested for absorption times of 20 seconds, 1 hour, 1 day and 3 days were conditioned for approximately 8-11 weeks, depending on concrete composition. Concrete tested for other absorption times, including impregnation with gel and cream, were conditioned for some shorter time, approximately 5-8 weeks.

During conditioning, the weight of the specimens was carefully monitored to follow their stabilization. When weight changes of about 0.04 gram/day were reached, the specimens were considered to have stabilized at the particular RH.

The concrete of composition 6, to be treated with artificial traffic-soil, and the specimens of composition 7, to be treated with an anti-graffiti system prior to impregnation, were also stored in climatic chambers, but until only their weight changes were approximately 0.06 gram/day. At that time the surface treatment was applied. After surface treatment the specimens were again stored in climatic chambers for another 3 to 4 weeks before impregnation. Since the surface treatment added some weight to the specimens, no reference weight could be used and no further weight control was carried out.

3.4 Impregnating procedure

Impregnation with the liquid agent was performed by total immersion of the specimens in a container holding the impregnating agent. At the specified times, the specimens were taken out of the container and allowed to dry in normal indoor air. All specimens impregnated with liquid agents, including those with surface treatment, were impregnated this way.

The gel and cream impregnating agents were applied by means of a sprinkling hose so as to completely cover the specimen surface with the formulation in question. The thickness of the cover was continuously measured to ensure identical thickness with all specimens. The absorption of the gel and the cream starts immediately after application.

3.5 Penetration depth control

To measure the penetration depth, the specimens were split and water was sprayed on. The hydrophobized part of the concrete did not absorb the water and the untreated part became darker due to water absorption. The penetration depth, between the concrete surface and the darker area, was measured every ten millimetres along the concrete surface.

4 Results from laboratory investigations

4.1 Remark

In the following diagrams the mean values of the penetration depth are presented. Minimum values are in average 2-mm lower than measured mean values.

4.2 Effect of absorption time and relative humidity

The rate of the agent's penetration is most striking during the first few minutes, when it is very rapid at the beginning of the impregnation process. It then decays nearly logarithmically. After approximately one day the penetration rate is very low and to further expand the absorption time is not very effective.

Concrete specimens conditioned at lower RH showed higher penetration depths. Differences in penetration depths at different RH values are increasingly significant with increasing porosity of the concrete. For dense concrete conditioned at 90% RH, practically no penetration depth at all was observed.

4.3 Effect of air content in the concrete

A higher penetration depth is achieved when air is added to the concrete mix. The difference, when compared to concrete with no added air, is small, but increases somewhat with increasing absorption times.

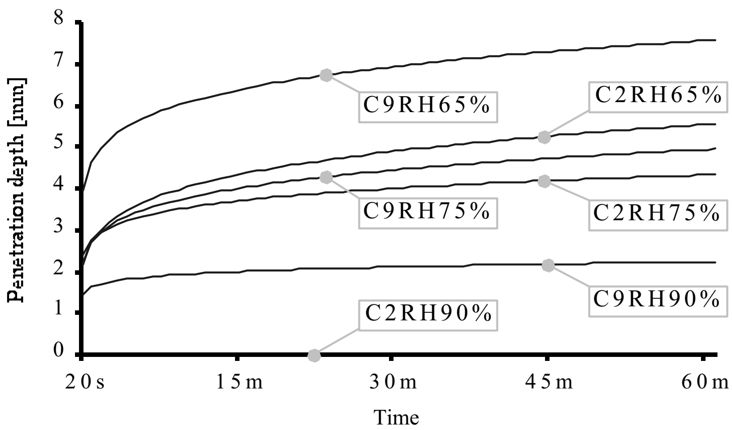

Figure 1: Penetration depth as a function of absorption time and RH during the first hour of impregnation

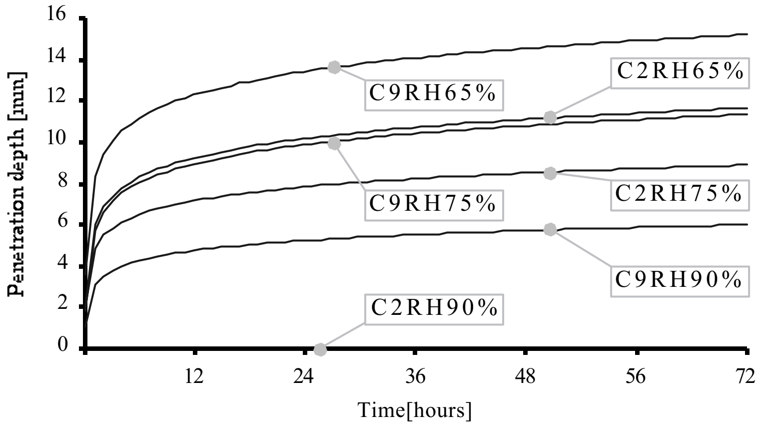

Figure 2: Penetration depth as a function of absorption time and RH during 3 days of impregnation

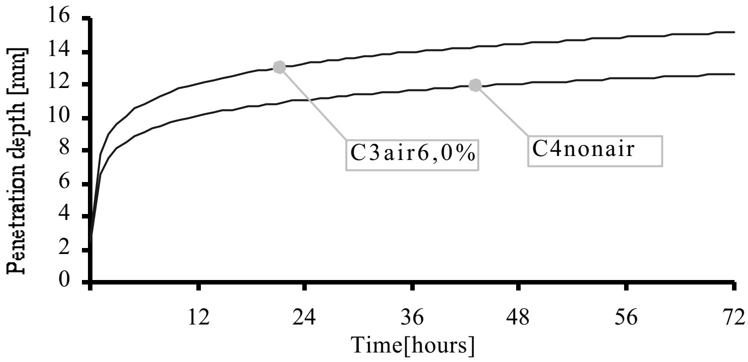

Figure 3: Effects of air in the concrete conditioned at 75 % RH

4.4 Effects of water/cement-ratio

The higher porosity in concrete resulting from a high w/c-ratio had a noticeable influence on the penetration depth. This effect gets more apparent, as the absorption time increases. The w/c ratio has a higher influence on the penetration depth than the addition of an air-entraining admixture.

4.5 Surface-treated concrete

The anti-graffiti agent did not seem to affect the penetration depth of the impregnation agent, but perhaps the durability of the water-repellent agent was affected. The

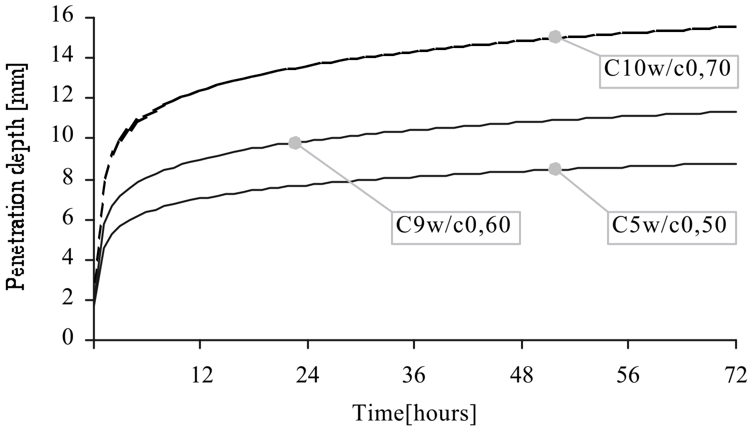

Figure 4: Effect of w/c-ratio on the penetration depth for concrete conditioned at RH 75 %.

artificial traffic-soil appeared to affect the penetration depth of the water repellent which seemed to be higher, probably because the traffic-soil was not removed from the specimens after impregnation. The soil appeared to have had a “poulticing” action, similar to a cream impregnation, allowing the concrete to absorb the impregnating agent longer than intended.

Since the formation of a consistent leached-lime deposit on the concrete surface was problematic - some specimens developed quite a lot while others did not have any deposit at all - no general conclusions on the effect this surface layer had on the penetration depth can be drawn. However, the standard deviation on the measurements was higher, which indicates some effect.

4.6 Impregnation using gel and cream agents

Impregnation with gel- and cream-formulated water repellent agents increases the contact time with the agent leading to an increased absorption. In general, the cream formulation resulted in higher penetration depth than that obtained by using a liquid agent with a 20-second absorption time (i.e., conventional impregnation applied on a vertical surface). Laboratory tests showed that an impregnation with cream is comparable to a 10-minute impregnation with a liquid.

Impregnation with gel formulations resulted in very high penetration depths, except when concrete had been conditioned to 90% RH. The gel covering was however thicker than the cream covering. Impregnating with gel formulations is comparable to a 1-day impregnation with a liquid agent. In figure 5 below the penetration depth is shown for concrete composition 3, using different application methods. The other compositions showed similar results.

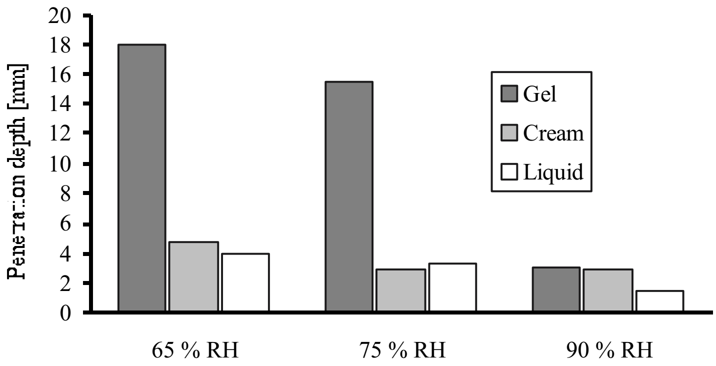

Figure 5: Penetration depth using different application methods

5 Summary and conclusions

Adding silica fume to concrete supposedly makes concrete denser and thereby lowers the penetration depth of the impregnants. In this case the silica fume has not decreased the penetration depth.

An increase in the w/c-ratio from 0.40 to 0.50 increases the penetration depth of the applied water repellent agent by almost 80 %, as tested on concrete manufactured from CEM I cement and conditioned at 65 % RH. At higher RH conditionings, the effect of the same w/c-ratio increase was even bigger. Increasing the w/c-ratio from 0.50 to 0.60 and from 0.60 to 0.70, for concrete manufactured from CEM II cement resulted in a lower increase in penetration depth of the water repellent agent.

The addition of an air-entraining agent resulted in an insignificant increase in the penetration depth.

The RH at which the concrete is conditioned prior to impregnation has large influence on the resulting penetration depth. For concrete with a w/c-ratio of 0.40 conditioned at 90 % RH the penetration depth was nearly zero. Even on concrete with a w/c-ratio of 0.50 similarly conditioned, the penetration depth was very low. The lower the w/c-ratio of the concrete, the lower the penetration depth achieved, when these specimens are conditioned at high RH values.

The absorption time of the liquid water repellent has great influence on the resulting penetration depth.

Table 2 presents the penetration depths for four different absorption times of all the concrete compositions tested. Where the data for specimens conditioned at 90 % RH are missing, the penetration of the water repellent agent was negligibly low.

Table 2: Mean values (p.d.) and standard deviation (s) of penetration depths

	RH	20 seconds		1 hour		1 day		3 days	
	[%]	p.d. [mm]	σ [mm]	p.d. [mm]	σ [mm]	p.d. [mm]	σ [mm]	p.d. [mm]	σ [mm]
C1	65	3,5	1,2	5,5	0,8	12,2	1,1	14,3	1,2
	75	2,6	1,0	3,7	0,9	8,3	1,2	11,4	1,3
C2	65	2,7	0,8	4,9	0,9	9,7	1,2	10,7	1,4
	75	1,8	0,8	2,9	0,7	6,9	1,0	8,8	1,3
C3	65	3,9	1,1	8,7	1,0	17,4	1,5	18,8	1,1
	75	3,3	1,1	6,9	1,3	12,8	1,4	15,9	1,8
	90	1,5	1,4	4,1	2,8	3,0	2,0	5,5	3,9
C4	65	3,3	1,1	7,9	1,0	13,8	0,9	15,3	1,5
	75	2,9	1,0	5,8	1,1	11,6	2,1	12,5	2,1
	90	1,2	1,1	3,8	2,4	3,5	2,3	4,2	2,7
C5	65	2,2	0,6	5,8	1,2	9,6	1,0	12,2	1,3
	75	2,4	0,5	4,3	1,1	7,7	1,3	9,2	1,4
	90	0,7	1,0	1,1	1,2	2,2	1,8	2,9	1,6
C6	65	6,8	1,4	7,2	0,9	10,5	1,5	10,0	1,9
	75	5,5	1,4	4,1	0,8	7,7	2,1	8,8	1,1
	90	3,0	1,4	2,1	1,5	4,5	2,2	5,1	2,3
C7.1	65	4,9	1,0	5,7	0,8	9,7	1,6	10,0	1,5
	75	2,3	2,0	3,9	1,1	7,0	1,5	7,7	1,3
	90	3,0	0,6	5,1	1,4	7,4	1,9	8,3	1,3
C7.2	65	1,8	0,8	5,5	1,0	9,5	1,0	12,7	1,2
	75	1,2	0,9	3,5	1,0	7,6	1,4	9,6	1,8
	90	0,5	0,6	1,8	1,5	5,7	1,6	8,0	1,5
C8	65	4,1	1,6	8,7	1,6	16,8	1,8	14,1	3,2
	75	3,0	1,3	8,0	3,0	11,3	3,7	15,5	5,6
	90	3,9	1,4	5,3	2,1	9,9	3,2	14,9	4,8
C9	65	4,0	0,7	7,6	0,9	14,1	0,9	15,0	1,2
	75	2,2	0,5	5,3	0,9	9,5	1,4	11,9	1,3
	90	1,5	0,8	2,3	1,3	5,4	1,2	6,2	1,3
C10	65	4,4	1,0	9,6	0,9	15,4	1,5	17,9	1,1
	75	3,3	0,7	7,5	0,8	13,7	1,3	15,9	1,4
	90	2,7	1,0	5,8	1,4	9,0	1,6	10,7	1,4

6 References

1. Karlsson, F. (1997): *Bevare mig väl*, Svenska kommunförbundet.
2. Bofeldt, M. (2001): *Inverkan av RH, vct och tid för inträngningsdjup på impregnerad betong*, Royal Institute of Technology, Dept. of Structural Engineering, Stockholm.