Water Repellent Treatment of Building Materials
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A New Application Technology for Water Repellent Surface Treatment

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Abstract

Nowadays silanes and siloxanes are comonly used for the impregnation of cement-based materials. For the performance of an impregnation under practical conditions the penetration depth is crucial. With traditional application technologies the maximum penetration depth is approximately 1-3 mm. Investigations and practical experiencies have shown that the minimum penetration depth must be higher than 6 mm. In this paper a new concept will be presented which is called "box technology". It will be shown that this concept can be used for planning by civil engineers to improve penetration depth to values higher than 6 mm for concretes with W/C ratios of 0.35 to 0.50.

Keywords: penetration depth, box-technology, FT-IR-spectroscopy

1 Introduction

The uptake of aqueous salt solutions of concrete and frost damage can be avoided by surface treatments with water repellent agents. The real performance of a water repellent treatment, however, is strongly dependent on the penetration depth and the content of the active substance i. e. silicon resin in the covercrete [1].

The maximum penetration depth of water repellent agents depends on material properties and the used application technique. With traditional application technologies such as spraying or painting the maximum penetration depth is approximately 1 – 3 mm. Practical experiences have shown clearly that these values often are not sufficient for a proper performance of an impregnation over a long period [2]. Therefore, new application technologies must be developed to improve the penetration depth of water repellent agents up to 5 - 6 mm.

2 Factors determing penetration depth

The penetration depth of water repellent agents depends strongly on materials properties such as porosity of the covercrete which is essentially given by water/cement ratio and curing conditions. The moisture content of concrete and the viscosity of the agent play an important role too. But there is a lack of knowledge about factors such as contact time between water repellent agent and concrete surface or the type of applied water repellent agent and their influence on penetration depth.

Therefore, we have studied the uptake of different water repellent agents by capillary suction for different concrete mixes. Results of this preliminary study are shown in fig. 1 and fig 2. The results show clearly that an increase of contact time leads to an increase of the absorbed amount of water repellent agent, especially for 100% silanes and as has been measured to an improved penetration depth too. Furthermore, the uptake of emulsions of water repellent agents is hindered compared to the water uptake. For the development of new application techniques these results may be taken into consideration. Starting from this point of view we have developed a new application technology which is called box-technology.

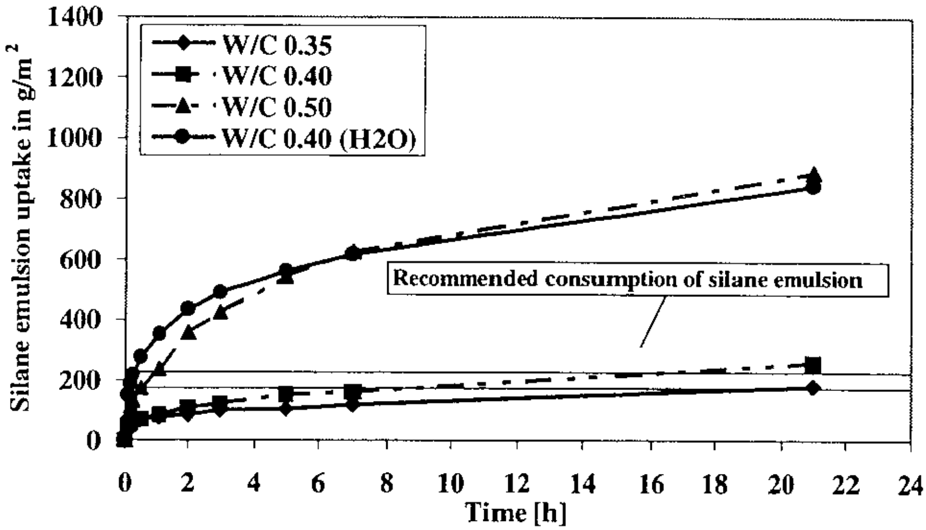

Figure 1: Uptake of a 100% silane and water by concrete mixes with different w/c ratio

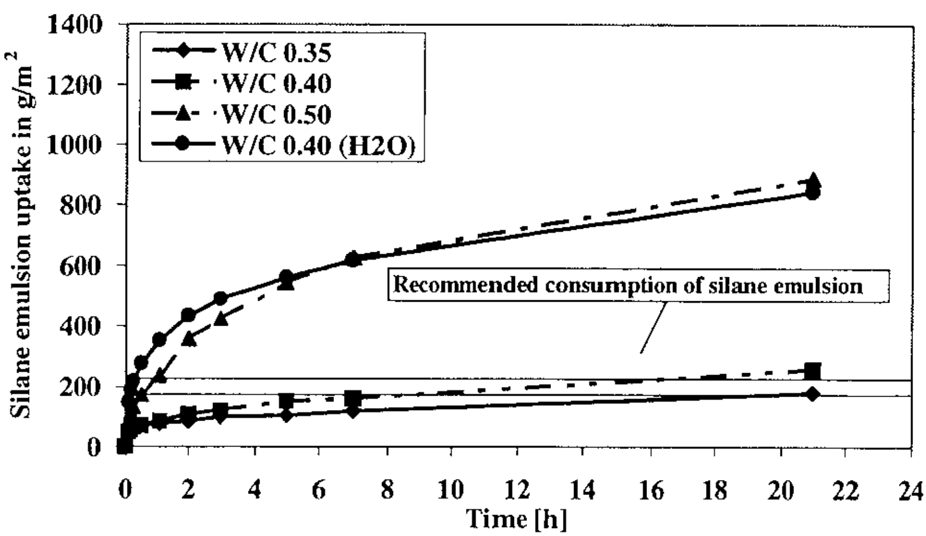

Figure 2: Uptake of a water repellent emulsion and water by concrete mixes with different w/c ratios

3 Box-technology concept

The box-technology concept can be subdivided into four steps. In the first step the goals to be achieved by the impregnation must be defined, especially the penetration depth and the reduction of capillary suction. In the second step the absorption rate of different types of water repellent agents must be determined by application of a modified Karsten's pipe, which is shown in Fig. 3. The modified Karsten's pipe consists of three different parts. First, a cap (A) with an o-ring as a seal (B) and a ventilating screw (C). The inner diameter of the cap is 8.5 cm. The cap can be fixed with three screws tightly on the wall. Second, coupling elements (F) which connect the cap to burettes with different volume scales from 2.5 ml to 25 ml (D,E).

The penetration profile can be analysed by FT-IR-spectroscopy. The principles of this technique are described in detail in [3]. With these results the minimum contact time for a given penetration depth can be calculated. In the third step the impregnation is carried out using the box shown in Fig. 4. Finally, the success of the impregnation must be checked by a rigorous quality control. For this purpose the penetration profiles and the liquid uptake of the impregnated concrete must be determi ned by using FT-IR-

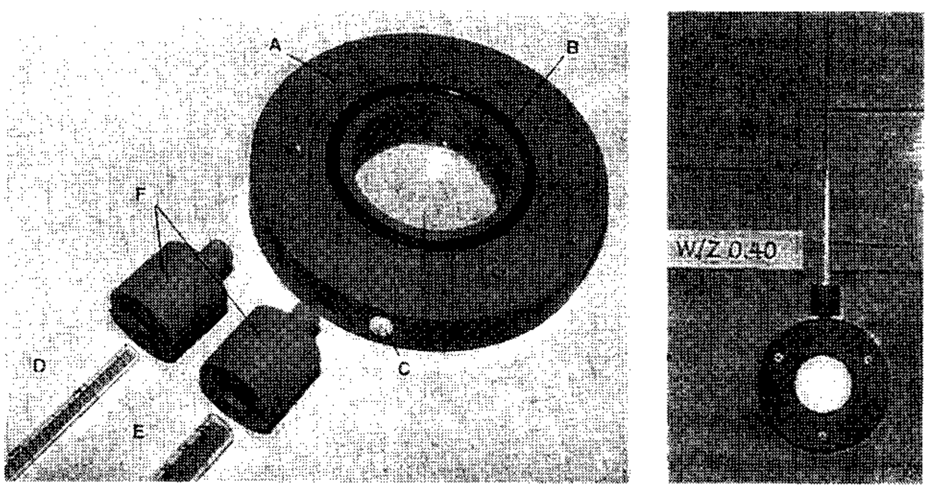

Figure 3: View of the different parts of a modified Karsten's pipe and of the pipe as attached to concrete surface

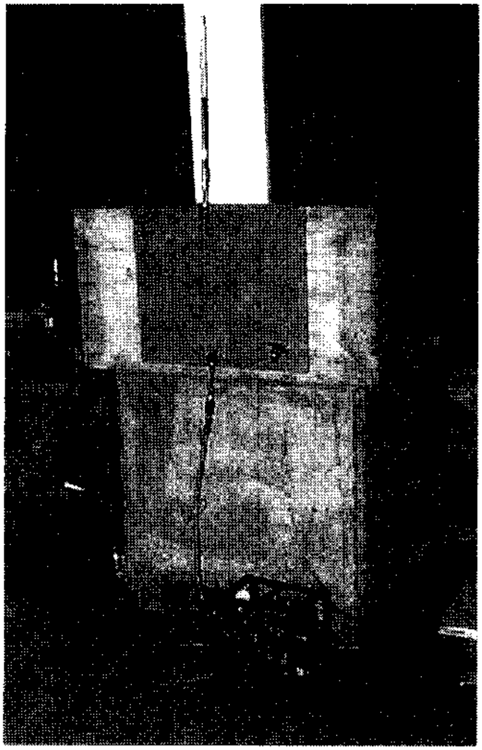

Figure 4: Prototype of a box fixed on the wall by vacuum

spectroscopy and by using the modified Karsten's pipe respectively. The results of the quality control must reach the values postulated in the first step. Otherwise, the application must be repeated and/or modified.

4 Experimental

For the experimental investigations test specimen have been prepared according to SIA 162 [4]. The composition of the investigated concrete is as follows. The maximum aggregate size is 16 mm. The content of Portland Cement CEM I 42.5 is for all mixes 350 kg/m^3. The notation of the mixes and the water/cement ratios are given in Table 1. For the impregnation of concrete two different types of commercial water repellent agents have been used. For the experiment a non-diluted silane (100%) and an aqueous silane emulsion (50%) have been used. In this investigation the concept of

Table 1: Notation and water/cement ratio of the investigated concrete

Notation	water/cement ratio
A	0.35
B	0.40
C	0.45
D	0.50

impregnation by box-technology has been applied to different concrete mixes (A-D).

The experiments have been carried out in the following way. For the measurement of the absorption of water repellent agents the cap of the modified Karsten´s pipe is fixed on the wall. Depending on the expected sorptivity of the concrete a scaled burette is chosen and connected to the cap. Then the modified Karsten´s pipes are filled with a selected water repellent agent. The uptake of the concrete is measured as a function of time. With these results and the penetration profiles determined by FT-IR-spectroscopy the water repellent agent with the highest penetration rate has been choosen and the minimum contact time for a penetration depth of at least 6 mm has been calculated.

In the second step the box shown in figure 4 is fixed by vaccum on the surface of the concrete and filled with the selected water repellent agent. After the minimum contact time the box is removed and the application is terminated by a protection of the surface against evaporation.

In the third step the success of the impregnation has to be checked. For this purpose the penetration profiles are determined by FT-IR-spectroscopy and the water uptake of the impregnated surface is measured by using the modified Karsten´s pipe.

In the next chapter first results for an application following the box technology concept are given.

5 Results and Discussion

5.1 Definition of requirements for the impregnation

A penetration depth of at least 6 mm is required for concrete independent on the water/cement ratio. This value can be estimated from results of Wittmann and Alou [5]. They have investigated the frost resistance of concrete after impregnation with a water repellent agent. They found that the frost resistance of an impregnated specimen characterized by loss of material is considerably better as compared to an untreated specimen for approximately 60 frost cycles. After that the loss of material increases rapidly for the treated specimen and reaches values comparable to values determined for untreated concrete. After Wittmann and Alou this is most probably due to an increased transport of water through the impregnated concrete the thickness of which can be estimated to be approximately 1 to 2 mm. An impregnated concrete zone of 6 mm should avoid this break-through of water.

According to international standards the reduction of water absorption should be higher than 80% as compared to the untreated concrete [1]. For this purpose the water uptake of the untreated concrete has been determined by using the modified Karsten´s pipe and the water absorption coefficient has been calculated. Results are given in table 2.

5.2 Choice of a suitable water repellent agent

For the determination of the uptake of water repellent agents and the calculation of the necessary contact time the modified Karstens´s pipe is used. Results of this measurement are shown in figure 5 and 6. It is obvious that the values of absorbed silane (100%) are approximately five times higher than the values of the aqueous silane emulsion. The exact reason for this behaviour is not known yet and investigations to clarify this question are still in progress. Furthermore, the uptake of water repellent agents depends on the water/cement ratio of the cementitious material. With increasing water/cement ratio the amount of absorbed water repellent agents increases as can be anticipated.

The results described above are confirmed by the penetration profiles determined by FT-IR-spectroscopy shown in fig. 7 and 8. The penetration

Table 2: Penetration depth of the investigated water repellent agents in mm for concrete mixes with different w/c ratio

Type of concrete(W/C)	0.35	0.40	0.45	0.5
Silane (100%)	7	9	13	12
Aqueous silane emulsion	0.5	1.5	2.5	1.5

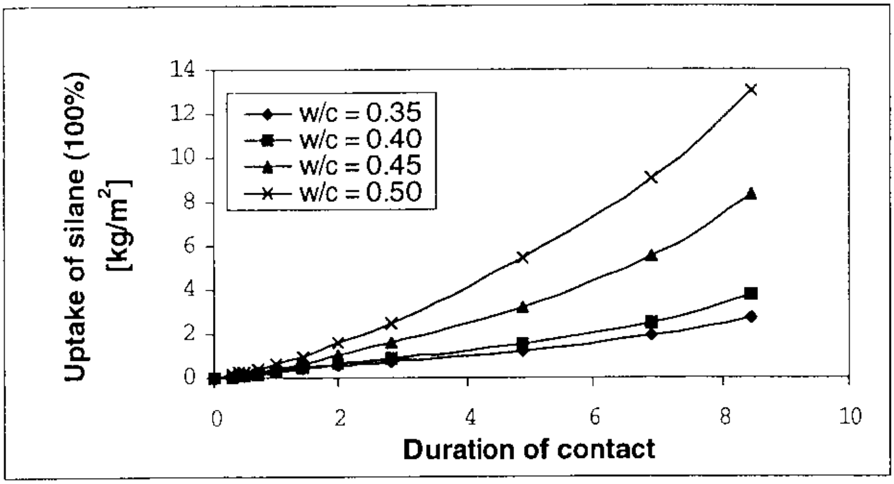

Figure 5: Absorption of Silane (100%) as a function of the square root of time

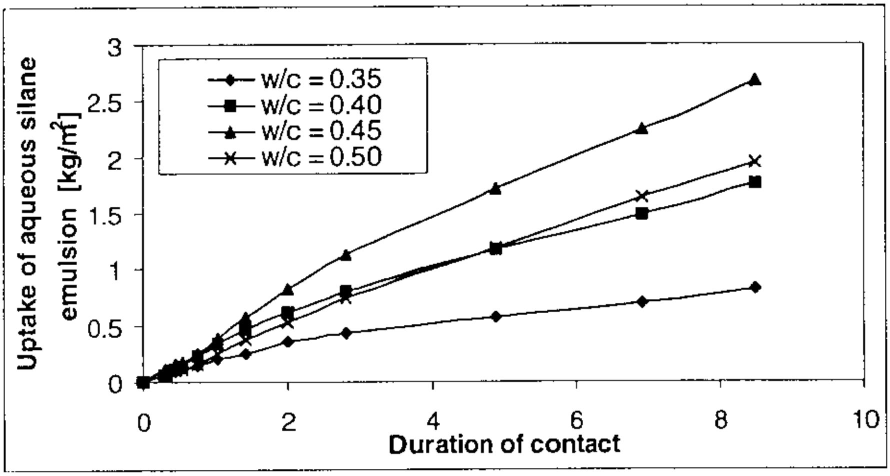

Figure 6: Absorption of aqueous silane emulsion as a function of the square root of time

depth in this core is defined as just the content of active substance related to the mass of dry concrete higher than 0.015 mg/mg. The penetration depths for the investigated concrete mixes are given in table 2. For all investigated concretes the penetration depth of silane (100%) is higher than 6 mm. For concrete mixes C and D silane (100%) can be detected to a distance from the

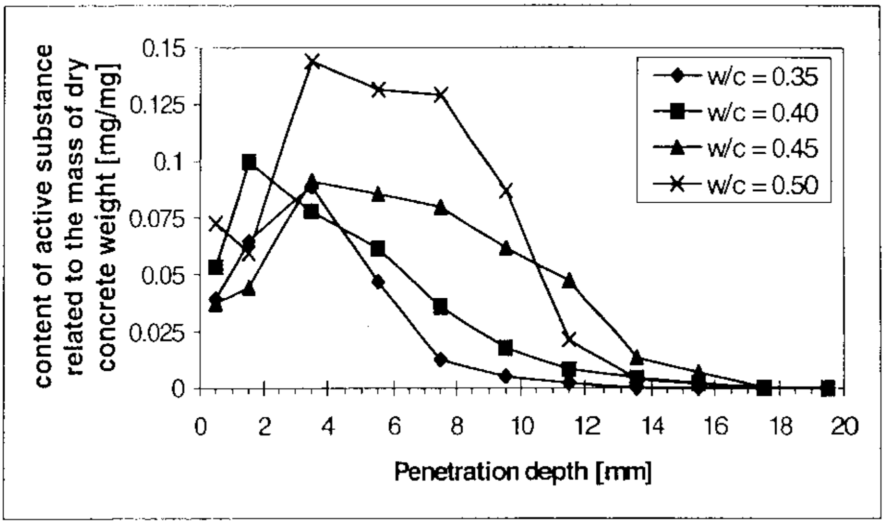

Figure 7: Penetration profile of silane (100%)

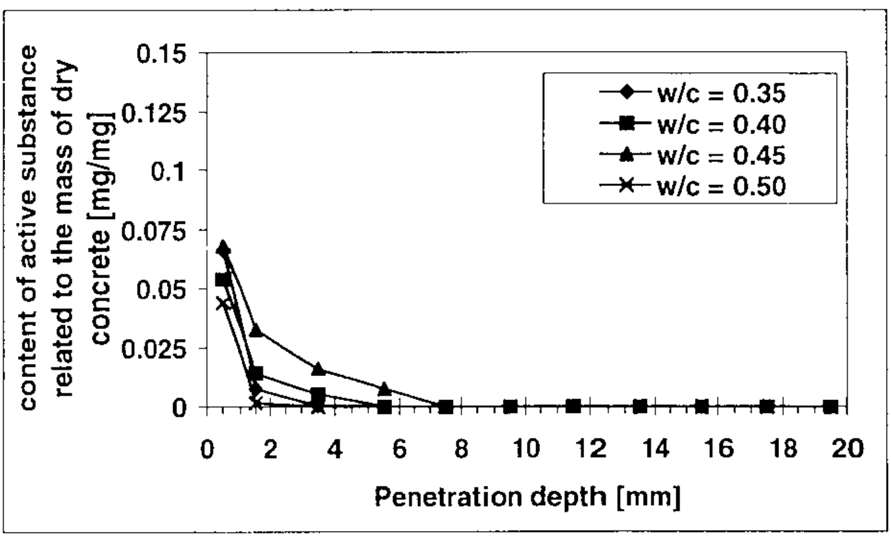

Figure 8: Penetration profiles of aqueous silane emulsion

surface of approximately 13 mm. In opposite to that the maximum penetration depth of aqueous silane emulsion is 2.5 mm. The absorbed amount of liquid and the penetration depth can be approximately calculated with the following equations:

$$m_1 = A \cdot \sqrt{t} \tag{1}$$

$$x = B \cdot \sqrt{t} \tag{2}$$

$$B = \frac{A}{\psi \cdot \rho} \tag{3}$$

m_l = mass of the absorbed liquid [kg]

A= liquid absorption coefficient [$kg/m^2\ h^{0.5}$]

t= time [h]

ρ= density [kg/m^3]

ψ= liquid capacity [m^3/m^3] ψ

B= liquid penetration coefficient [$m/h^{0.5}$]

x= penetration depth [m]

With the values of penetration depth (see table 2) and the contact time of 72 hours the penetration coefficient has been calculated. The penetration coefficient B can be transformed with equation (3) to the absorption coefficient A. The uptake of silane (100%) as a function of time has been calculated with equation (1). Results for concrete mix C are shown in fig. 9 for example (dotted line). The uptake of silane measured by using the modified Karsten ´s pipe is also shown in fig. 9. It is obvious that at the end of the experiment the real absorbed amount of silane is approximately 6 times higher as compared to the calculated volume. This difference can be explained by the distribution of the silane in the concrete. The calulated value represents the amount of silane which penetrates in form of a cylinder with a diameter of 8.5 cm into the concrete. The difference to the measured uptake can be attributed to migration parallel to the surface combined with a loss by evaporation [6]. Therefore, for the calculation of the contact time which leads to a given penetration depth the calculated corrected value must be taken into account exclusively.

With the coefficient B calculated for all concrete mixes under investigation a diagram has been developed which allows the estimation of the contact time for a given penetration depth. This diagram is shown in fig. 10.

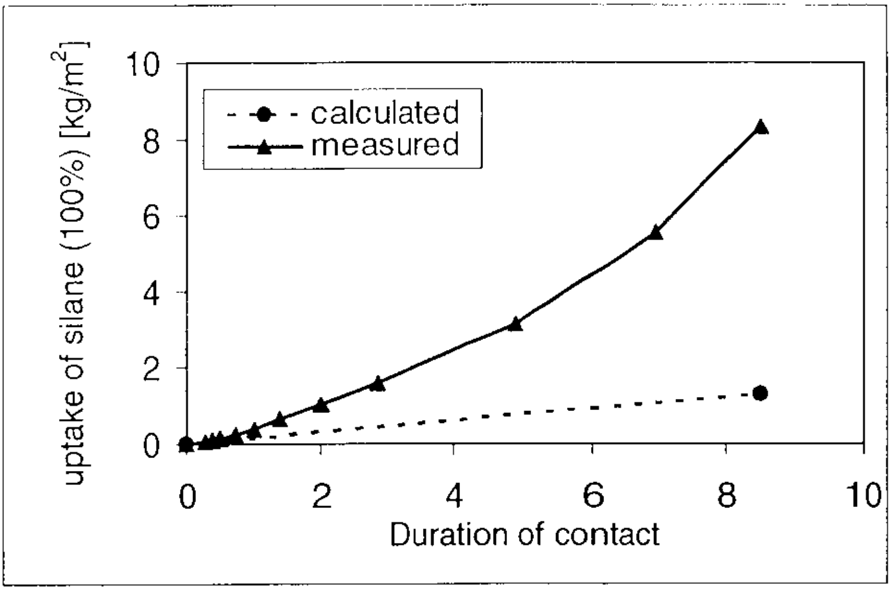

Figure 9: Calculated and measured uptake of silane (100%) as a function of the square root of time

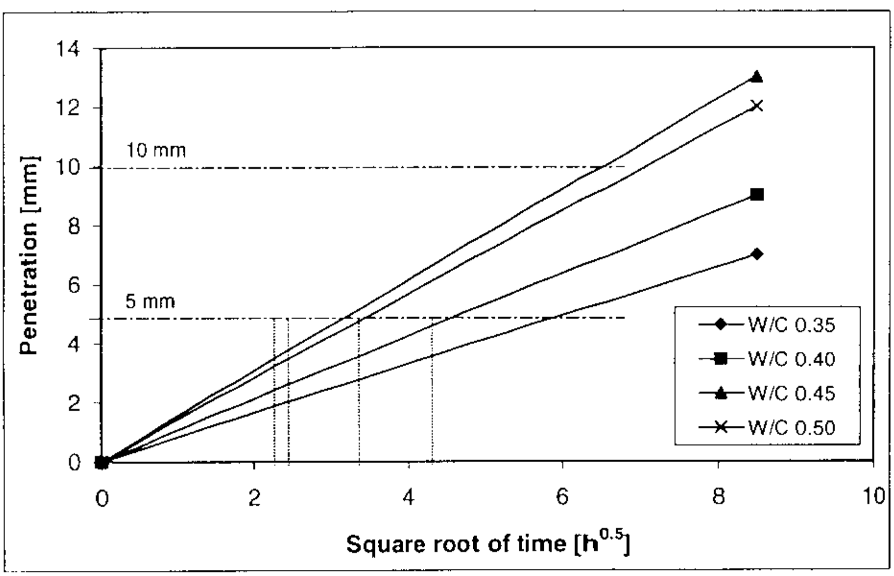

Figure 10: Diagram for the calculation of the contact time for a given penetration depth

Based on these results silane (100%) has been used. For experimental reasons a minimum contact time of 8 hours has been choosen. For the calculation of the required contact time a modified equation according to [6] has been used.

5.3 Application of the box-technology

After these preliminary investigations the impregnation of concrete elements produced with concrete mixes A-D were carried out using the box technology. The prototype of a box fixed for 8 hours by vacuum on the concrete surface is shown in fig. 4.

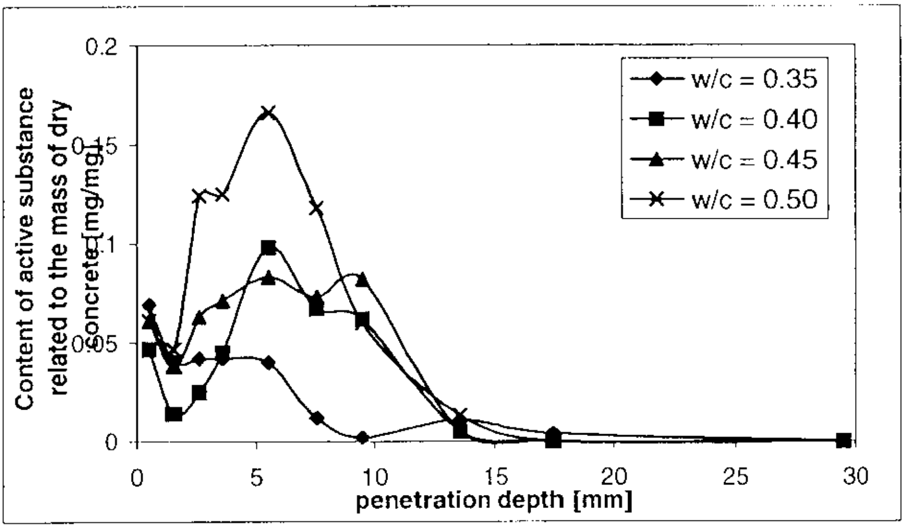

Figure 11: Penetration profiles determined after the application of the box-technology

Table 3: Water absorption coefficient A for untreated and treated concrete mixes with different w/c ratio

	Water absorption coefficient A [kg/m^{2}h$^{0.5}$]			
Concrete mix	w/c ratio 0.35	w/c ratio 0.40	w/c ratio 0.45	w/c ratio 0.5
Untreated	0.072	0.074	0.323	0.449
Treated	0.010 (= 86%)	0.009 (= 87%)	0.007 (= 98 %)	0.042 (= 90%)

5.4 Quality control of the impregnation carried out with the box-technology

The quality of the impregnation has been characterized by penetration profiles as determined by FT-IR-spectroscopy and by the water absorption coefficient A as determined by the modified Karstens's pipe. The penetration profiles are shown in fig. 9. The results show clearly that the requirement of 6 mm penetration depth and a reduction of 80% of the water absorption is fullfilled for all concrete mixes under investigation. The penetration depth for densest concrete mix A (w/c ratio 0.35) is approximately 8 mm. The penetration depth for concrete mixes B-D reaches values higher than 10 mm. It is remarkable that the penetration depth after a contact time of 8 hours is significantly higher as the values calculated by applying the presented diagram (fig. 10). This deviation of the real penetration depth can be explained by diffusion after the capillary suction has come to an end. After 8 hours the pores of the first millimeters are filled with silane. At this time the viscosity of the silane is always low because the degree of polymerization is low. Due to the concentration gradient a transport from the saturated to the unsaturated volume takes place and leads to an increase of the penetration depth as compared to the calculated penetration depth. Therefore, in practice the real penetration depth is significantly higher as the calculated value. In further investigations this safety factor shall be determined.

In the first millimeter the content of active substance is also relatively low. It is most likely that the surface near zones have lost part of the absorbed agent after removal of the box by evaporation. This can of course easily be avoided by protection of the concrete surface. The investigation presented here has clearly shown that the newly developed box-technology is a suitable technique to improve the penetration depth of water repellent agents. Values higher than 6 mm can be achieved. This means a completely new potential for water repellent surface treatment.

6 Conclusion

From the results presented in this contribution the following conclusions can be drawn:

- The modified Karsten's pipe can be used for the determination of the absorption coefficient of water or water repellent agents for different types of concrete with very high or very low permeability.

- For sufficient long-term performance of a water repellent surface treatment the penetration depth must be higher than 6 mm.
- With the diagram presented here the required contact time for a predetermined penetration depth can be estimated.
- Applying the box technology a penetration depth higher than 6 mm can be achieved for most types of concrete.
- The FT-IR-spectroscopy is a powerful tool for the determination of the penetration profile and depth.

References

[1] A. Gerdes, *Nachweis der Wirksamkeit einer Hydrophobierung,* in A. Gerdes (Hrsg.), Hydrophobieren – Grundlagen und Anwendung, WTA-Report Series No. 10, Aedificatio Publishers, pp 25 – 40 (1996)

[2] A. Gerdes und F.H. Wittmann, *Quality control of surface treatments with water repellent* agents, in Surface Treatment of Building Materials with Water Repellent Agents, F.H. Wittmann, A.J.M. Siemes and L.G. W. Verhoef (eds.), Delft University of Technology, Delft, The Netherlands, 15/1- 15/7 (1995)

[3] A. Gerdes, *Assessment of Water Repellent Treatment by the Application of FT-IR-Spectroscopy,* in Surface Treatment of Building Materials with Water Repellent Agents, F.H. Wittmann, A.J.M. Siemes and L.G. W. Verhoef (eds.), Delft University of Technology, Delft, The Netherlands, 12/1- 12/9 (1995) SIA 162: *Betonbauten*, Schweizerischer Ingenieur- und Architekten-Verein, Zürich (1993)

[4] F.H. Wittmann and F. Alou, *Frost Resistance of Concrete after Impregnation with a Water Repellent Agent,* in Surface Treatment of Building Materials with Water Repellent Agents, F.H. Wittmann, A.J.M. Siemes and L.G. W. Verhoef (eds.), Delft University of Technology, Delft, The Netherlands, 32/1- 32/8 (1995)

[5] E. Wendler und R. Snethlage, *Der Wassereindringprüfer nach Karsten – Anwendung und Interpretation der Messwerte,* Bautenschutz + Bausanierung, **12**, 110 – 115 (1989)