Water Repellent Treatment of Building Materials
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Protective Coatings with Water Repellent Agents

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Abstract

In many cases, service life of reinforced concrete structures is severely limited by carbonation of the covercrete or by chloride penetration until the steel reinforcement. Today, concrete with high resistance with respect to chloride penetration can be produced by internal water repellent treatment. This would, however, not necessarily be an economical solution if the entire mass of concrete in a structural element had to be internally treated. An interesting alternative is to separate the assignments of concrete in a structural reinforced concrete elements. The load bearing capacity of the element is provided by conventional structural concrete according to this concept. The required durability, however, is guaranteed by a protective cement-based layer. It is shown in this contribution that a protective layer with internal water repellent treatment provides concrete elements with optimal curing conditions in the first place. The same protective layer acts later as an efficient chloride barrier. This coating can be designed in such a way that chlorides never penetrate through the layer to reach the underlying load bearing structure during the imposed service life. The durability of reinforced concrete structures can be considerably increased and can be accurately designed by the application of an appropriate and optimized protective layer.

Keywords: concrete, durability, cement-based protective coating, chloride barrier, internal water repellent treatment

1 Introduction

If cement-based materials are exposed to water a series of corrosive processes can take place. One dominant process or a combination of different processes may eventually limit the expected service life. The corrosive attack of water with respect to concrete can be subdivided at least into three different types.

First, pure water in permanent contact with cement-based materials acts as a solvant. The binding matrix consisting of $Ca(OH)_2$ and CSH-gel is gradually dissolved by hydrolysis [1]. The rate of dissolution can be considered to be a realistic indication of long-term durability of concrete in moist environment [2]. Second, gases of the environment may be dissolved in the aqueous pore solution of concrete. In this way, acids are formed, for instance by dissolution of CO_2 and SO_2, which react rapidly with the hydration products of Portland cement. In the third type of corrosive attack water acts essentially as a vehicle and transports dissolved compounds, such as chlorides, into the porous system of cement-based materials. Capillary suction is the driving force for this mass transfer.

It is obvious that all three types of corrosive attack just mentioned act from the surface of a structural element. Water repellent treatment always means a strong interference with the humidity exchange of a porous material with its surrounding. Capillary suction, in particular, may be drastically reduced. Concrete is a cheap mass product and internal water repellent treatment would be prohibitively expensive if applied to the entire volume of a structural element. Traditional surface treatment of concrete with a water repellent agent leads to a very small penetration depth. The penetration depth can be considerably increased by new application technologies [3, 4]. An interesting alternative is presented in this contribution, i.e. the application of a mortar layer with internal water repellent treatment. This method of applying a protective coating has proven to be an efficient surface refining process.

In this contribution, the modification of a few selected properties, such as rate of drying and uptake of salt solution by internal water repellent treatment, is outlined. The influence on durability of water repellent protective coatings will be discussed.

2 Preparation and basic characterization of specimens

In order to study the influence of an internal water repellent treatment on properties of concrete, a standard mix of fresh concrete has been prepared. The composition of this reference concrete is given in Table I.

Table 1: Composition of the reference concrete

Component	Content in kg/m^3
Sand, 0-4 mm	829
Small Aggregates, 4-8 mm	368
Coarse Aggregates, 8-16 mm	645
Portland Cement CEM I 42.5	350
Water (W/C = 0.5)	175

1 % and 3 % related to the cement content of the following water repellent agents have been added to the fresh mix:

- -calcium stearate
- -siloxane emuslion
- -silane emulsion A
- -silane emulsion B

Silane emulsions A and B are similar but produced by two different companies. Properties of fresh and hardened concrete with and without water repellent agents have been determined [5, 6]. The addition of water repellent agents influences the workability, the rate of liberation of heat of hydration, stiffening characteristics, strength, fracture energy, and modulus of elasticity. In addition, the pore size distribution is significantly modified.

In this context, the parameters which indicate the moisture exchange of a concrete specimen with ist surrounding are of primary interest. Drying of concrete can be realistically described by non linear diffusion theory. Diffusion coefficients have been determined from results of drying experiments by inverse analysis. In Fig. 1, typical results as obtained for the reference concrete are shown. In this case, the diffusion coefficient is initially high, that means at elevated moisture content and then drops as moisture is lost

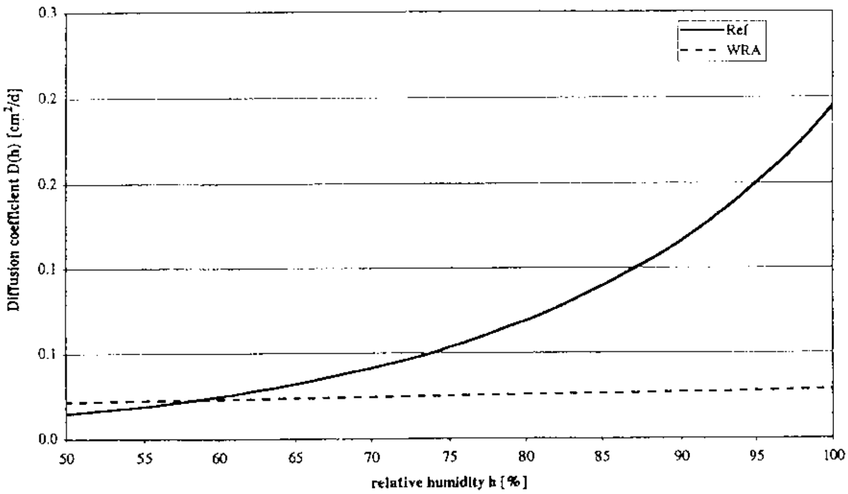

Figure 1: Diffusion coefficient of a reference concrete (Ref) and concrete prepared with 3% of siloxane emulsion related to the cement content (WRA) as function of relative humidity

due to drying. In the same diagramme, the diffusion coefficient observed on concrete with 3 % of siloxane emulsion is shown. In contrast to results obtained on reference concrete, the diffusion coefficient of concrete with water repellent agent is practically constant over the humidity range under investigation. This indicates that moisture transport is based on one simple mechanism in the later case.

Water absorption by capillary suction can be appoximately described by the following simple law:

$$\Delta W(t) = A\sqrt{t} \quad (1)$$

A in Eq. (1) is a material parameter which has to be determined experimentally. The values of A for the different types of concrete are compiled in Table II. It can be seen that capillary suction is reduced to values between 6.3 % and 15.3 % as compared with the reference concrete by the addition of different water repellent agents.

Table 2: Capillary water absorption coefficient A of the reference concrete and of mixes with 3 % of different water repellent agents

Type of water repellent agent added	Water absorption coefficient [kg/m² h$^{1/2}$]	%
Standard concrete (no addition)	1.31	100
Calcium stearate	0.083	6.3
Siloxane emulsion	0.200	15.3
Silane emulsion type A	0.084	6.4
Silane emulsion type B	0.112	8.5

3 Assignments of a protective coating

3.1 General

In many modern engineering disciplines, refining processes of the surface play a decisive role. The potential provided by advanced surface technology has so far, however, been widely neglected in concrete technology. Widespread damage of concrete structures can be considerably reduced by appropriate cement-based surface coatings.

Cement-based coatings can be specifically tailored in order to protect structural elements against imposed aggressive environmental conditions. Following the concept of separation of assignments [7], conventional structural concrete has to provide a structural element with mechanical properties to reach the required load bearing capacity exclusively. All environmental loads are then taken up by a protective coating.

In the following, two examples chosen from the huge variety of possible protective coatings are considered only.

3.2 Retardation of drying

Let us consider a structural element with a characteristic thickness of 200 mm. It is assumed that the surfaces of this element are exposed to air with a relative humidity of 60 % at 20 °C. By means of the diffusion coefficient given in Fig. 1 the time-dependent spatial moisture distribution can be simulated as function of drying time. Typical results for drying times of 3 days, 7 days, 14 days, 1 month, 3 months, 1 year, and 3 years are shown in Fig. 2. It can be seen that the moisture content in the first two centimeters is rather quickly reduced. This leads inevitably to incomplete hydration in the surface near zones. But it is just this part of the structural element (covercrete) which should protect the reinforcement from corrosion which remains finally most permeable.

Sometimes, curing compounds are applied with doubtful success to prevent early drying of concrete elements. A more effective alternative may be the application of a mortar layer with internal water repellent treatment.

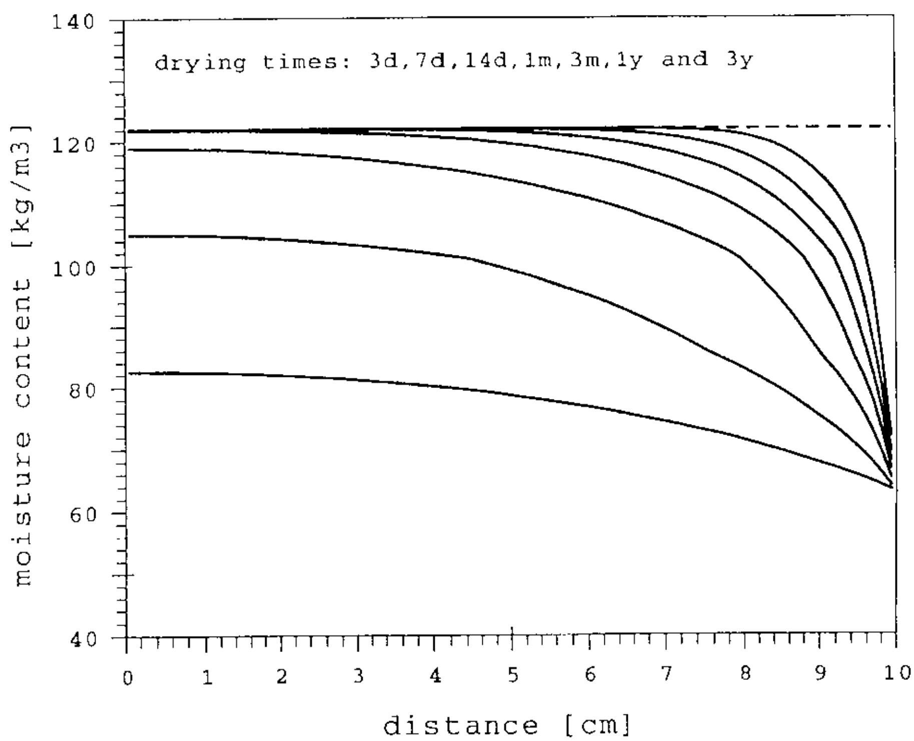

Figure 2: Moisture distribution in a concrete slab exposed to 60 % RH at 20 °C as determined for different drying times between 3 days and 3 years

The drying of a coated concrete element can also be simulated. Typical results are shown in Fig. 3. In this case, it is assumed that the structural element built with the same concrete as the above mentioned example (see Fig. 2) has an initial thickness of 160 mm and is then covered on both opposite sides by 20 mm of a protective coating containing 3 % of siloxane emulsion immediately after demoulding. The diffusion coefficient of the cement-based coating has been determined and is also shown in Fig. 1.

Results shown in Fig. 3 clearly indicate that the structural concrete undergoes practically no drying within the first month. Hydration of cement will continue unhindered and the concrete will reach full maturity under these conditions throughout the volume.

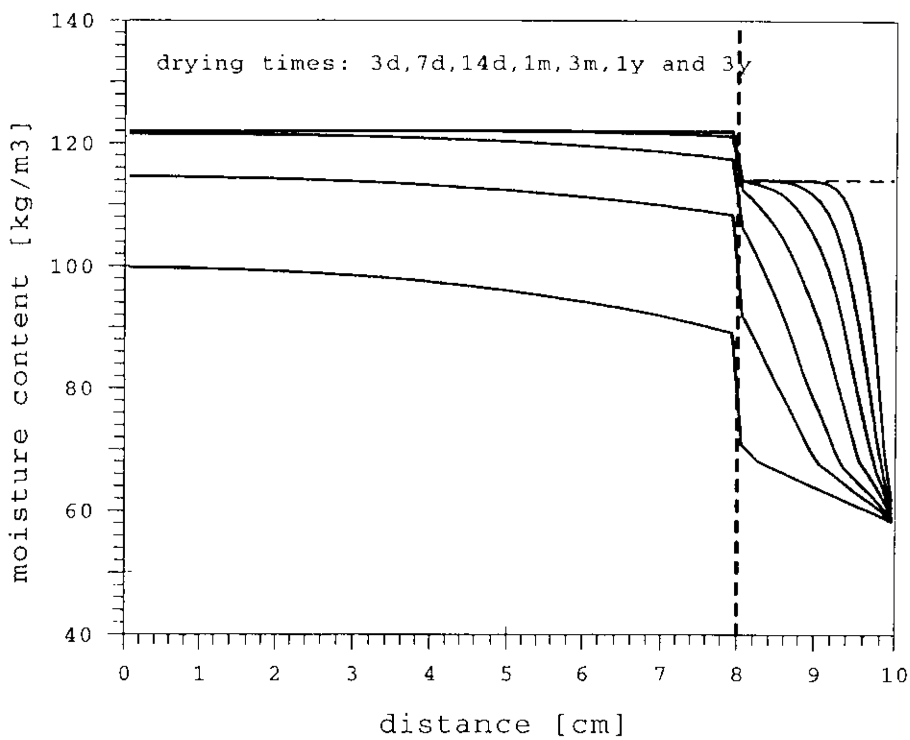

Figure 3: Moisture distribution in a concrete slab covered with a protective coating with internal water repellent treatment if exposed to 60 % RH and 20°C at different drying times between 3 days and 3 years

3.3 Absorption of aqueous solutions

One of the major reasons for damage and deterioration as observed on reinforced concrete structures is the penetration of corrosive salts such as chlorides through the covercrete until the steel reinforcement. The most efficient vehicle for this salt migration is water. Structural elements in contact with aqueous solution of deicing salt or in the immediate vicinity of road surfaces covered with salt solution are particularly endangered [8, 9]. In conventional structural concrete, the penetration depth of chlorides increases with time and reaches 20 to 30 mm in a comparatively short period depending on the water-cement ratio and the curing conditions.

Surface impregnation of concrete elements usually leads to a penetration depth of the agent of 1 to 2 mm. This thin layer is unable to provide a long-term protection [10]. If, however, a cement-based protective coating with internal water repellent treatment is applied it might be possible to prevent chloride penetration into a structural element totally for a required period, i.e. the desired service life.

In Table II, the reduced capillary absorption coefficients are given for concrete with internal water repellent treatment. Samples of these different types of cement-based materials have been exposed cyclicly to an aqueous sodium chloride solution with a concentration of 3 %. After one day of contact with the solution, samples were allowed to dry for one day. Unidirectional uptake has been observed.

Results are shown in Fig. 4. After seven cycles, the capillary uptake of solution the untreated reference concrete tends to stabilize around a value of approximately 9 kg/m^2. The internally treated samples absorb about 10 % only after the same number of cycles.

It is well-known that chloride solutions undergo a sort of filtering effect when they penetrate into micro-porous materials such as concrete. This means that the water front penetrates considerably faster and deeper than the dissolved ions [8]. Therefore, results shown in Fig. 4 do not allow us to estimate the penetration depth of chlorides immediately. Chloride profiles have been determined after seven cycles of exposure to aqueous sodium chloride solution. From the exposed samples, thin layers have been cut, these slices have been milled, and subsequently, the chloride content has been determined by ion chromatography. Results are shown in Fig. 5. Under these conditions, chloride ions penetrated more than 35 mm into the reference concrete while the penetration depth of most internally treated materials

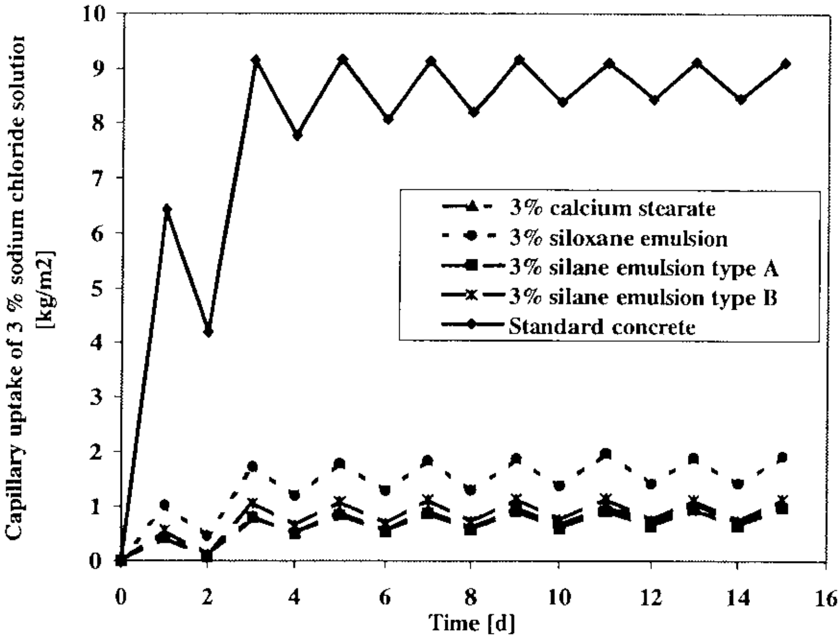

Figure 4: Capillary absorption of sodium chloride solution (3 %) into internally treated and reference concrete as function of time when exposed to two days cycles of wetting and drying

reaches values around 5 to 6 mm. If these cement-based materials are applied as protective coatings to reinforced concrete structures with a thickness of 20 mm these structures will be protected for a sufficiently long period of time. This means the aim to keep the structural concrete free of chlorides can be achieved.

Further research is needed to optimize internally treated protective coatings and to provide a solid basis for reliable design for a given service life.

3.4 Surface treatment of internally treated mortars

In sections 3.2 and 3.3 it has been shown that internally treated mortars can be applied to achieve optimal curing conditions and to prevent chloride penetration. The amount of water repellent agents added to the fresh mortar or concrete is limited because excessive dosage will influence the hardening process and the mechanical properties of the hardened material in a nega-

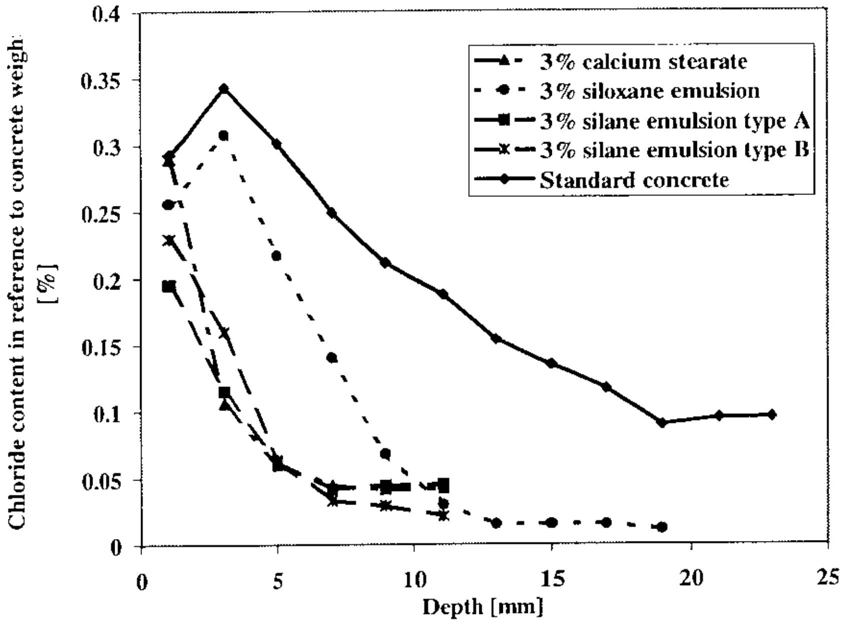

Figure 5: Chloride profiles as determined in internally treated and reference concrete samples after 7 cycles of wetting and drying

tive way. Therefore, it might be of interest to apply additional surface treatment to mortar or concrete treated internally with a water repellent agent before.

Samples pretreated internally with silane emulsion A have been surface impregnated at a later stage with pure silane. In Fig. 6, the concentration of the water repellent agent in an internally treated sample is shown. Within the accuracy of the analysis, silane concentration is constant along with the exception of the surface- near zone. The increased content of water repellent agent near the surface is due to the well-known border effect of concrete. Close to the surface, the cement content is higher than in the bulk material. It turned out that the pretreated concrete absorbed more silane as compared to the reference concrete at equal contact time. In Fig. 6, the penetration profile of the silane is also shown. The observed penetration depth could not be reached in an untreated reference sample. As a consequence, we may conclude that internal water repellent treatment facilitates surface impregnation at a later stage.

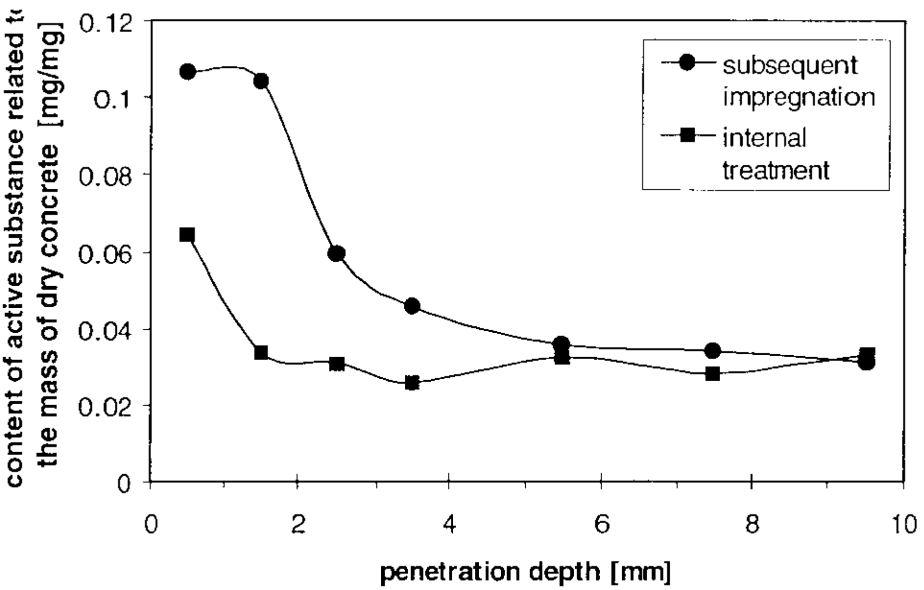

Figure 6: Distribution of the water repellent agent in an internally treated concrete sample. In addition, the silane profile as observed in a pretreated sample after surface impregnation is shown

4 Conclusions

The penetration depth of water repellent agents is limited to very small values if conventional application technologies are applied. The protection of structural concrete elements therefore remains rather uncertain, and in many cases it is insufficient. By means of the so-called box technology much better and reliable results can be obtained [4].

Another interesting alternative is a cement-based protective coating with internal water repellent treatment. These water repellent coatings offer a series of new protection techniques. They can be applied as efficient chloride barriers and, at the same time, they provide excellent curing conditions for the coated concrete. In particularly aggressive environment, the protective coating with internal water repellent treatment can be further surface impregnated with pure silanes. Silane penetration is facilitated by internal pretreatment. The application of water repellent protective coatings allows us to build reinforced concrete structures with accurately designed durability.

References

[1] F. H. Wittmann and A. Gerdes, *Korrosion zementgebundener Werkstoffe unter dem Einfluss eines elektrischen Feldes,* Int. Z. Bauinstandsetzen **2**, 455-480 (1996)

[2] H. Saito, S. Nakane, S. Ikari, and A. Fujiwara, *Preliminary experimental study on the deterioration of cementitious materials by an acceleration method,* Nucl. Eng. Design **138**, 151-155 (1992)

[3] R. F. Hager, *The revolution in concrete protection: impregnation by creming;* another contribution to this volume

[4] A. Gerdes, *A new application technology for water repellent surface treatment*; another contribution to this volume

[5] A Gerdes, *Protective coatings of concrete structures for high durability,* WTA Report Series No 15, pp. 157-169 (1997)

[6] S. Bischof, *Massenhydrophobierung von Beton*, Diploma thesis, Institute for Building Materials, ETH Zürich (1997)

[7] A. Gerdes and F. H. Wittmann, *Oberflächenschutzsysteme für das Erstellen von hochbeständigen Betonkonstruktionen*, Int. Z. Bauinstandsetzen **3**, 515-534 (1997)

[8] P. Lunk, *Kapillares Eindringen von Wasser und Salzlösungen in Beton*, Building Materials Reports No. 8, Aedificatio Publishers (1997)

[9] P. Lunk and F. H. Wittmann, *Behaviour of cracks in concrete structures treated with a water repellent agent with respect to capillary water and salt transport*; another contribution to this volume

[10] F. Wittmann, *Hydrophobieren, Trocknen und Frostbeständigkeit des Betons, in Hydrophobieren - Grundlagen und Anwendung*, A. Gerdes Herausgeber, WTA Report series No. 10, Aedificatio Publishers (1996)