Hydrophobe IV
4th International Conference on Water Repellent Treatment of Building Materials
Aedificatio Publishers, 145–158 (2005)

Application of Water Repellent Treatments for the Protection of „Offshore“ Constructions

M. Wittmann[1], Z. Huang[2] and A. Gerdes[1,3]
[1]Faculty of Mechatronics and Sciences, University of Applied Science Karlsruhe, Germany
[2] Harbin Institute of Technology (HIT), Harbin, China
[3]Institute for Technical Chemistry - Water and Geotechnology, Forschungszentrum Karlsruhe, Germany

Abstract

Reinforced concrete structures which are situated in the offshore region are exposed to the action of chloride containing water. In many of these structures corrosion of the steel reinforcement will be observed sooner or later. In the tidal zone or in the middle of the see repair measures are extremely difficult to be carried out. By means of preventive surface protection techniques it might be possible to extend the service life of reinforced concrete structures considerably. Because of recent important technological improvements it seems promising to apply surface impregnation with water repellent agents for preventive protection. For a reliable design and subsequent quality control of this protective measure, however, it is mandatory to know the relation between penetration depth of the water repellent agent and the effectiveness of the corresponding chloride barrier. In this contribution some results of tests to determine the penetration depth of newly developed water repellent agents in different types of concrete will be presented in the first place. In addition results of measurements of the breakthrough pressure and of the chloride penetration resistance of concrete treated with a water repellent agent will be described.

1 Introduction

Concrete structures are exposed during service life to significant chemical strains because of the impact of chloride-containing water. Typical examples are bridges, tunnels, port facilities and offshore wind energy plants [1]. Until now these buildings were normally unprotected on the attacks of the sea water. Under these conditions a chloride-induced corrosion appeared frequently, that in some cases even caused the loss of stability.

For special requirements additional preventive surface protection methods were planned. As result of many negative experiences with water repellent treatment these are generally based polymer coatings. Treating with water repellent agents as single surface protection method has played a subordinated role and was applied according to the guidelines of the "German committee of reinforced concrete" rather as a part of the different surface-protection-systems [2].

In recent years water repellent treatment was employed successfully as preventive surface protection method in tunnel- and bridge-construction, to avoid the penetration of dissolved thaw salts [1,2]. Precondition among other things was the realisation, that for a functioning chloride barrier a sufficient penetration depth and a minimal of reactive substances in the cover-crete is needed [3]. For characterising the effectiveness of treatment with water repellent agents the term "effective penetration depth" was defined. It is equivalent to the thickness of the zone, close to the surface, in which the reactive content is suffice to inhibit the capillary suction completely [4].

In [3] it was shown, that the penetration profile is chiefly determined through the contact time between water repellent agent and concrete surface. The long contact time, that is necessary for a highly effective penetration depth nowadays high-viscosity water repellent agents or adequate application techniques (Table 1) [5] are used. That's why more efficient penetration depth can be achieved in applying high-viscosity water repellent agents or multiple application of low-viscosity water repellent agents with 100% compared to the observed 0.5-1.0 mm of former systems [3-5].

Based on the described technological improvements the question emerged whether or not a water repellent treatment heaving a high depth can be applied successfully on offshore constructions as chloride barrier. Therefore it is necessary to clarify, which effective penetration depth is sufficient to prevent the chloride uptake by structures which are exposed to the sea.

This context will be of importance for further applications as e. g. for surface protection systems or for traffic-constructions. A "performance-orientated"

Table 1: Water repellent treatment systems

Non-aqueous systems
Low-viscosity silanes with contents up to 100%
High-viscosity silanes with contents up to circa 95%
Aqueous Systems
Water dilutable Micro- and Macroemulsions
High-viscosity emulsions with contents up to circa 90%

Table 2: Water repellent treatment systems in this study

Denotation	Type	Content [%]	Amount of application [g/cm^2]
S	Low-viscosity silane	100	150
C	High-viscosity emulsion	Circa 70	400
G	High-viscosity silane	Circa 80	1000

choice of a suitable surface protection system in consideration of technical, ecological and economical aspects would then be possible.

Within the scope of the presented research findings in this paper, that are part of a project [6], a coherence between the utilised water repellent agent alternatively application technique and effective penetration depth for different concrete mixtures had to be elucidated. Furthermore cyclic experiments with immersion in chloride containing water, which simulate the constraints of the ebb and tide zone, were carried out to give evidence for the required effective penetration depth. In addition to that a high hydraulic pressure caused by sea waves act on the surface of concrete structures in marine environements. For the measurement of the breakthrough pressure which is necessary for water transport through the impregnated covercrete a new device has been developed.

2 Experiments

2.1 Making of specimens

For the investigations concrete-slabs according to EN 206-1 [7] were made. In the lab-concrete the maximal grain size was 16 mm. The content of the used Portland cement CEM I 42.5 for all mixtures was 350 kg/m3. The w/c-ratio for the four mixtures was 0.35, 0.4, 0.45 and 0.5. After demoulding the slabs were stored for 6 months at 20° C and 65% relative humidity. Adjacent the slabs were treated with different water repellent agents and amounts (Table 2). After a reaction time of 14 days, samples with a size of 70x70x75 mm3 were prepared. For further tests, surfaces except for the suction-surface were coated with a impervious epoxy resin, to ensure a one-axial fluid transport.

For the measurement of the breakthrough pressure carried out with a modified device for permeability tests specimens were prepared in the following way. Discs with a diameter of 90 mm and a thickness of 20 mm were prepared. The side-faces of the discs were coated with epoxy resin.

2.2 Experimental set-up

2.2.1 Immersion Tests in 3% Chloride Solution

In these experiments, the samples were put into a basin, which can be filled and cleared with a pump every 6 hours with 3 % chloride solution. In this cycle, the samples can dry for 6 hours before the basin is filled again for another 6 hours with the chloride solution. Figure 1 shows the experimental setup schematically.

After 75 and 675 cycles samples were taken and the penetration profile of the water repellent agent and the chloride penetration depth were analytically determined.

2.2.2 Measurement of the breakthrough pressure

In these experiments the breakthrough pressure were measured with a new device based on a permeability tester (Fig. 2). For the experiment the coated samples were placed between the two steel plates. After that sealing rings were fixed on the top and bottom of the disc. Finally, the steel-plates were fastened with three treaded bolts. After that the device was connected to a HPLC-pump which can work in two modes, the constant flow-mode or constant pressure-mode. For this experiment the constant flow-mode with a flow of 0.15 ml/min has been choosen. After the start of the test the pressure increase until the breakthrough pressure is reached. This time-dependent rise in pressure were recorded. For the evaluation of the results the breakthrough pressure is shown as a function of the effective penetration depth.

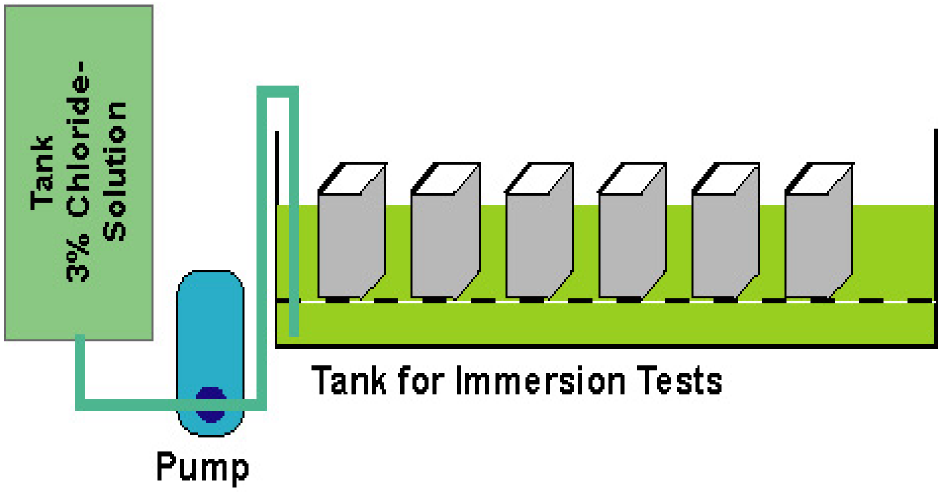

Figure 1: Experimental setup for the immersion test

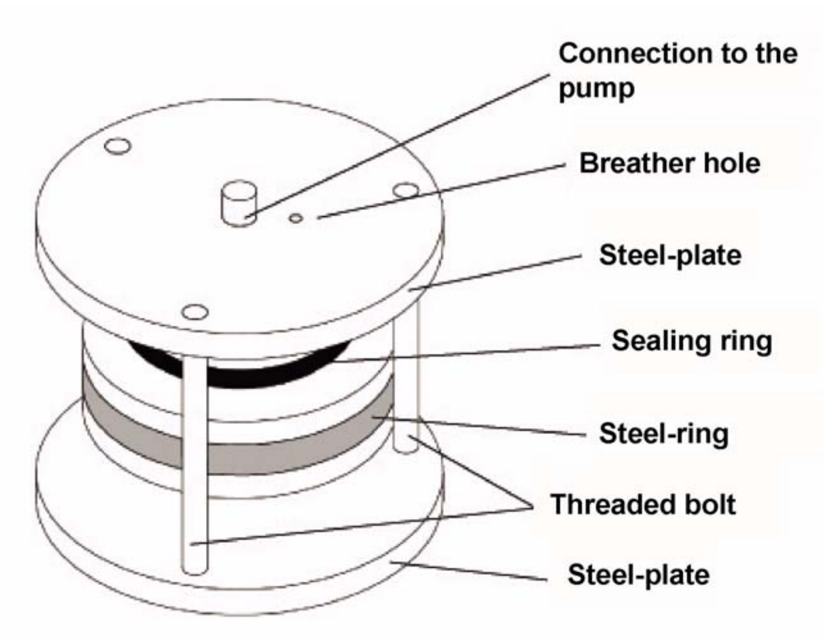

Figure 2: Device for the measurement of the breakthrough pressure

2.3 Analytical methods

2.3.1 Determination of the penetration profile using FT-IR-spectroscopy

In this test FT-IR-spectroscopy was used to determine the penetration profile [4]. For the specification of the penetration profiles the samples were milled and the concrete powder was collected, starting from the treated surface, in 2 mm steps. After that the powder was dried at 105° C until it's constant weight. For the measurement with the FT-IR-spectrometer, the concrete powder was then dissected with the KBr-moulding-technique. At this discs 50 FT-IR-spectra in the wave band from 2900 - 3000 cm-1 were recorded. The spectra are analysed with the baseline method, which is part of the equipment software. Details to this method can be found in [8]. Through plotting of the determined values as a function of the distance from the surface, a half-quantitative penetration profile can be set up. Previously determined calibration graphs allow the calculation of the reactive content in mass-% referring to the concrete weight from the measured values. The plotting of the reactive content as a function of the distance from the surface delivers quantitative penetration profiles.

2.3.2 Determination of the chloride profile

To determine the chloride content, 1 g of the concrete powder was added to 50 ml deionised water. The suspension was shaken for 2 hours and then filtered. The chloride content in the filtrate was determined by using an ion chromatograph from Metrohm. To compile the chloride profile, the identified water soluble chloride content in mass-% referring to the concrete weight was plotted against the distance of the surface.

3 Results

3.1 Effective penetration depth depending on w/c-ratio

Within the scope of this study the investigated concrete (w/c-ratio from 0.35 - 0.5) was treated with the chosen water repellent agents accordingly manufacturers' instructions. At this samples the effective penetration depth was determined by plotting the penetration- and suction profile [4].

Figure 3 depicts the values of the effective penetration depth as a function of the w/c-ratio. With reference to these results at first it can be stated, that with an increasing w/c-ratio a higher effective penetration depth can be achieved. The effective penetration depth for the silane (singular application) increases from nearly 0 mm (w/c-ratio 0.35) to 2.0 mm (w/c-ratio 0.5). Multiple application of these systems could lead to significant higher effective penetration depths for lower w/c-ratio. This is to be traced back to the

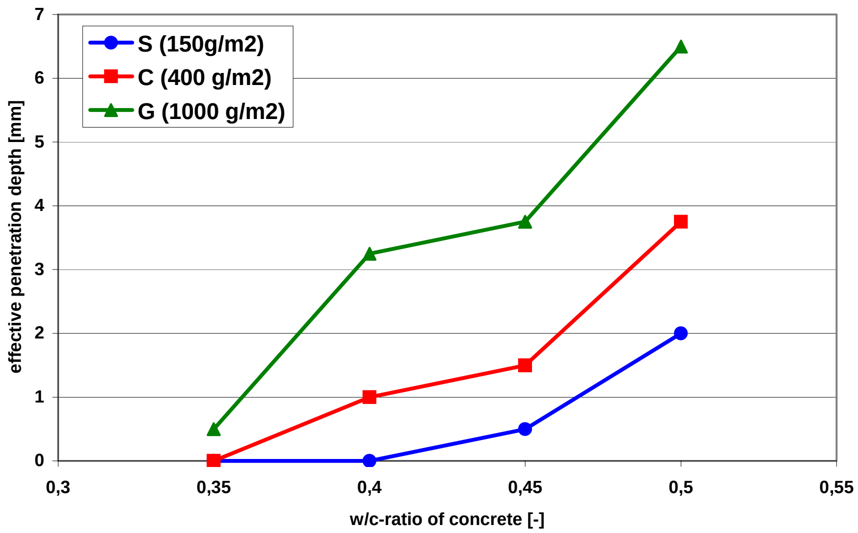

Figure 3: Effective Penetration depth in dependency of the investigated water repellent treatment system and amount of application (Pre-treatment of the samples: 20° C and 65 % relative humidity

larger proposition of reactive content. The relevance of contact time in addition to the reactive content can be shown through the graphs of the high-viscosity, aqueous (C) and the high-viscosity, non-aqueous system (G). By this means effective penetration depths for concrete with higher w/c-ratio from 3.75 to 6.5 mm can be reached.

3.2 Chloride penetration depth

Concrete, made with different w/c-ratios and treated with water repellent agents, were removed from the experimental set-up after 675 cycles. Furthermore for the comparison untreated samples were removed as well. This samples were used to determine the chloride penetration depth with chemical analysis.

Figure 4 shows the results for concrete with w/c-ratio 0.35. As shown no significant difference can be ascertained between the treated samples and the untreated reference samples in the shape of the curves. Similar behaviour is demonstrated from concrete with w/c-ratio 0.40.

The effectiveness of the water repellent treatment is dependent from the properties of the utilised system as can be seen in Figure 5, which shows for concrete with a w/c-ratio of 0.45 the chloride penetration depth. After this there is no clear difference in the curve shape between the low-viscosity

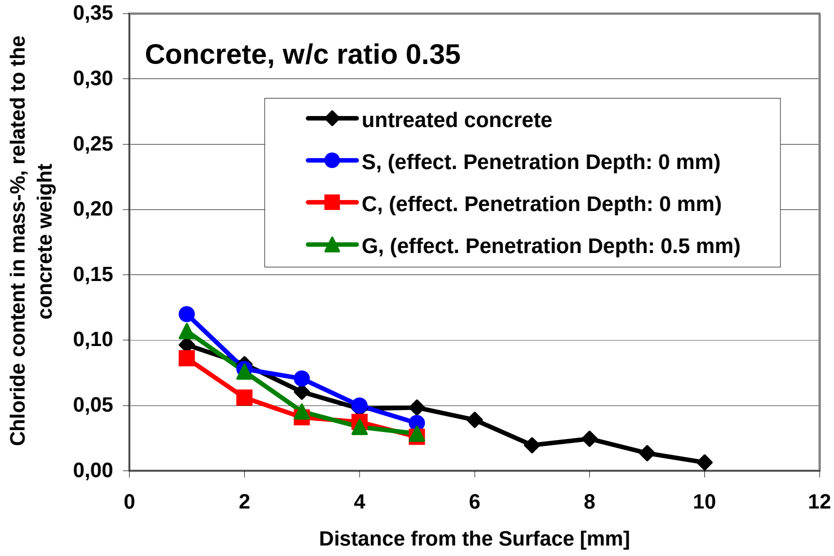

Figure 4: Chloride penetration depth of concrete, manufactured with w/c-ratio 0.35

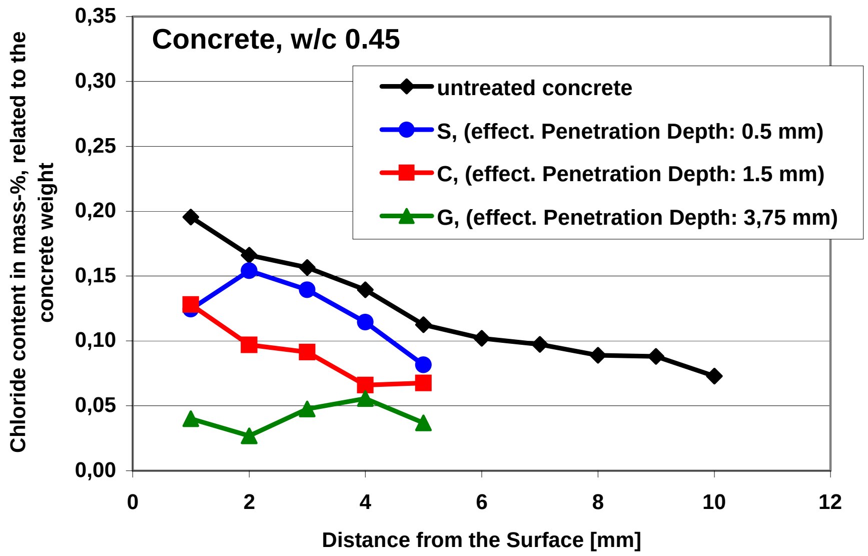

Figure 5: Chloride penetration depth of concrete, manufactured with w/c-ratio 0.45

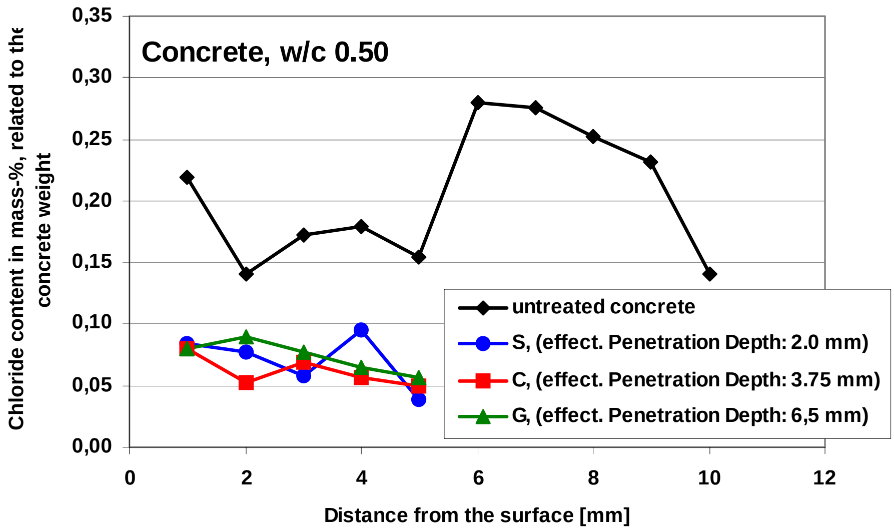

Figure 6: Chloride penetration depth of concrete, manufactured with w/c-ratio 0.50

system (S) and the reference sample. For the aqueous, high-viscosity system (C) an effectiveness becomes apparent, characterised by a low chloride content and chloride penetration depths. For the non-aqueous, high viscosity system it has to be noticed, that the chloride penetration nearly stops.For concrete with w/c-ratio 0.50 this result is discoverable for all examined systems, whereas no significant difference in the effectiveness of the various water repellent agents can be seen.

3.3 Results of the measurement of the breakthrough pressure

For concrete samples made with different w/c ratios and treated with different water repellent agents the breakthrough pressure has been measured. Preliminary results show that for concrete made with w/c 0.45 and 0,50, respectively, the achieved effective penetration depth is in the range of 3 to 4 mm. For these specimens the breakthrough pressure were determined. The results indicate that the water repellent treatment lead to an increase of values for the breakthrough pressure. For the untreated concrete these values are approximately 4-5 bar and for the treated concrete samples the breakthrough pressure is in the range of 10 to 12 bar. This result is very important, because the hydrostatic pressure of sea waves reaches values up to 12 bar [9].

4 Discussion of results

In the following the different aspects that are also important for the water repellent treatment, are described and discussed.

In practice today the penetration depth respectively the effective penetration depth from water repellent agents generally is determined by quality control measurements. It can be stated in many cases, that for comparable concrete that is treated with the same water repellent agent, there is a wide range of the values for the penetration depth.

This becomes apparent through the comparison of the results of this study as well in the results of a former study.

In both studies the comparable concrete samples were stored over several months at 20° C and 65 % relative humidity. Unlike to this study the samples in the former study were stored before the treatment with the water repellent agent for 48 hours at 50° C and 45% relative humidity. The following treatment with water repellent agents took place in both studies concerning the mode and the amount of the water repellent agent in the same way. The results for the former study are depicted in Figure 5. The values for the effective penetration depth for the samples in the former study are 2 to 3 times higher than the values in this study.

This behaviour is essentially founded in the treatment of the subsurface respectively in the conditions of storage because it determines relevantly the moisture content in the covercrete. If the moisture content is to high, even with a long contact time the water repellent agent can't penetrate by capillary suction. Cleaning the concrete surface with the aim to ease the penetration of the water repellent agent is therefore counterproductively, if there is not enough time for the concrete for drying out. The moment for treating a young concrete, which is after production nearly saturated with water, has to be adapted to the moisture content in the covercrete. But at the moment there are no sufficient data available to assure that matter. In the evaluation of research results, e. g. at the carbonation of treated concrete, aspects of pre-treatment of samples have to be considered stronger in the future.

The main goal of the study was to fix a minimum value for the effective penetration depth, which prevents the chloride penetration even under exacerbated conditions (wet-dry-cycles) over long periods. Firstly, it has to be recognised that the water repellent agent on concrete with low w/c-ratio even under long contact time is just able to penetrate at most 1 mm. A positive effect on chloride penetration depth through water repellent treatment with the as gel or cream called commercial systems could in fact not be

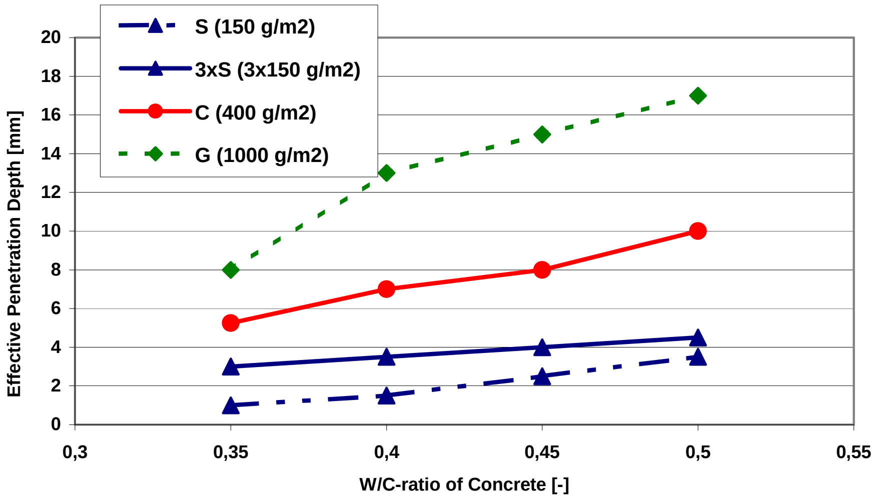

Figure 7: Effective penetration depth in dependency of the investigated water repellent treatment system and amount of application (Pre-treatment of the samples: 48 h at 50° C and 45% relative humidity)

observed. (Figure 4). It can be concluded, that concrete with a low w/c-ratio (> 0.40) is not suitable to be treated with water repellent agents that are currently available.

In contrast to concrete with w/c-ratio 0.45 a lower chloride penetration depth, compared to the reference samples, is measured. With an effective penetration depth > 3.75 mm within the period of the study the chloride penetration could be inhibited completely (Figure 5).

At the tested concrete with w/c-ratio 0.5 already at an effective penetration depth of 2 mm a chloride penetration could be inhibited. This shows, that the necessary effective penetration depth is dependent on the quality of concrete. It has to be proved, if this effective penetration depth is sufficient in the long run (Figure 6).

At the moment a minimal effective penetration depth of 4 mm has to be demanded for buildings, which are exposed circular to chloride solutions. Tunnels and bridges are belonging to this group of constructions. In practice is has to be calculated with variation of the quality of concrete, so 6 mm of effective penetration depth should be required.

The presented studies are the first steps in the scope of a larger project, in which new applications for water repellent treatment will be examined. To the actual measures experiments are included in which comparable concrete is stored in seawater. The investigation of the breakthrough pressure has shown that the values reached with an effective penetration depth of 3-4 mm are in the range to 10-12 bar. These results are important because the value of the hydrostatic pressure caused by sea waves is also 10-12 bar. The experiments will be continued. By means of this data requirements for different applications in the offshore area should be developed.

5 Conclusions

From the results, shown in the contribution, the following can be concluded:

- The effective penetration depth of water repellent agents is a suitable measure to characterise the quality of a water repellent treatment.
- The transport of water repellent agents at the covercrete primarily determined by the moisture content in the covercrete. That effect has also to be considered by practical applications of water repellent treatment.
- According to the results that have been made, concrete that is made with a w/c-ratio that is < 0.40, the water repellent treatment shows no effect, because of the low "effective penetration depth".
- Because of the research results, an effective penetration depth of 6 mm for tunnel and bridge constructions is suggested.
- Finally water repellent treatment with a high penetration depth inhibits the penetration of chlorides even under hydrostatic pressure so that applications at offshore buildings would also be possible.

6 Literature

[1] Gerdes, A. Transport und chemische Reaktion siliciumorganischer Verbindungen in der Betonrandzone, Building Materials Report No 15, AEDIFICATIO Verlag, Freiburg im Br., 2001.

[2] Deutscher Ausschuss für Stahlbeton (ED.). Richtlinie für Schutz und Instandsetzung von Betonbauteilen - Teil 1 bis 3, Beuth-Verlag, Berlin, 1990.

[3] A. Gerdes and F.H. Wittmann, *Decisive factors for the transport of silicon-organic compounds into surface near zones of concrete*, in K. Littmann and A.E. Charola, Hydrophobe III - Surface Technology with Water Repellent Agents, Aedificatio Publishers, Freiburg i. Br. (2001)

[4] A. Gerdes and F.H. Wittmann, *Requirements for the application of water repellent treatments in practice*, in K. Littmann and A.E. Charola, Hydrophobe III - Surface Technology with Water Repellent Agents, Aedificatio Publishers, Freiburg i. Br. (2001)

[5] Meier S J. Grundlagen und Möglichkeiten einer Hydrophobierung von Betonbauteilen, Building Materials Report, AEDIFICATIO Verlag, Freiburg i. B., No. 21, 2002.

[6] A. Gerdes, *Preventive Surface Protection of Concrete Structures - Technical, Ecological and Economical Aspects* in: T. Ueda (ed.), Service Life of Concrete - Structures, Concept and Design, Workshop Proceedings, Sapporo, 31-40 (2005)

[7] EN 206-1: *Beton - Teil 1: Festlegung, Eigenschaften, Herstellung und Konformität*, Beuth-Verlag, Berlin (2003)

[8] H. Günzler, H.-U. Gremlich, *IR Spectroscopy - An Introduction*, Wiley-VCH, Weinheim (2002)