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Impregnation of Concrete Structures – Introduction to a PhD-project

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Abstract

Moisture is the source of most damages in concrete bridges, such as frost damages and reinforcement corrosion just to mention some examples. Impregnation with silanes and siloxanes has been shown to give a good protection against moisture during at least eight to ten years. Both experiments and field investigations indicates this. However, most of the research is only verifying this and does not explain why. This project aims at analysing how common impregnation substances work in concrete and to develop explanation models. As a first step it is important to get reliable data on how the moisture diffusion coefficient is affected by hydrophobic treatment. Factors that will be investigated are, e.g., how the water/cement ratio and impregnation depth will influence the moisture transport. One of the goals with this project is to create a computer model to predict the moisture and chloride content over time if the geometry, material properties and environmental conditions of the concrete structure are known.

1 Introduction

Moisture is the source of most damages in concrete bridges, such as frost damages and reinforcement corrosion just to mention some examples. Hydrophobic impregnation with silanes and siloxanes has been shown to give a good protection against moisture during at least eight to ten years [1, 2]. Both experiments and field investigations indicates this. However, most of the research is only verifying this and does not explain why.

Measures prolonging the service life of a concrete structure will lead to savings of natural resources and thus both economical and environmental savings for the community. This PhD-project “Impregnation of concrete structures” was started in February 2004 by the Royal Institute of Technology and the Swedish Cement and Concrete Research Institute. The purpose is to develop explanation models to the promising results that have been obtained from the empirical research during the last decade and by doing this also create a better knowledge about when and how to apply a water repellent in order to benefit as much as possible from the product.

2 Background

The importance of keeping the moisture below a certain critical level is well illustrated on the right hand side in Figure 1 when considering the reinforcement corrosion as the limit of service life. The corrosion rate is highly dependent on the relative humidity (RH) inside a reinforced concrete structure and a proper treatment with a water repellent could in some cases make a big difference just by lowering the RH. In a more general way the purpose of a treatment with a water repellent agent is to prolong the service life of the structure. The initiation time (left hand side in Figure 1) is affected by carbonation and/or chloride transport. The diffusion rate of carbon dioxide and thus the carbonation rate are low when the moisture content is high. Transport of chloride ions into the concrete require on the other hand a continuous water phase in the pore system. After the initiation period the moisture, temperature and the access of oxygen are the decisive factors.

The point of using the water repellent is to reduce the RH, dry out the concrete. The effect of a successful treatment is that the RH decreases which in turn means that the chloride diffusion is slowed down but also that the CO_2-diffusion will go faster. Which one of these two factors will set the limit of service life of the concrete structure?

It is nothing new about trying to protect building materials from moisture with surface treatments. As a matter of fact we have been doing it for thousands of years. At the beginning oil and fat were used and today we are using dif-

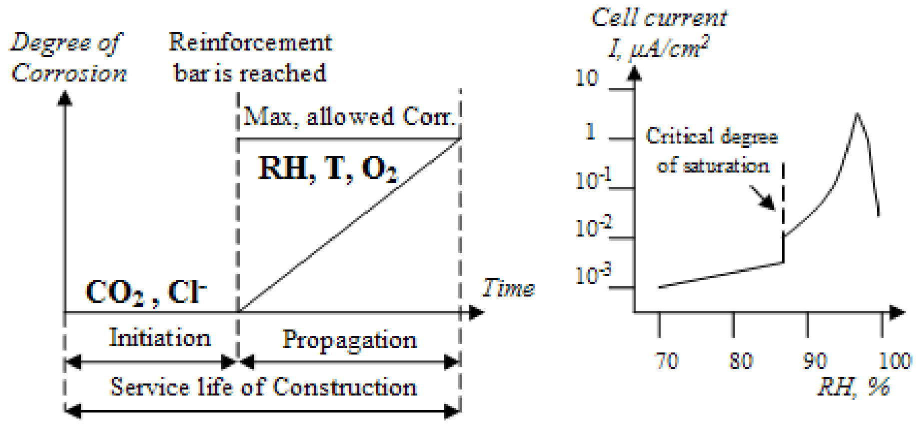

Figure 1: On the left: Corrosion model after [3] that describes the factors which affect the time to initiation and the time of propagation. On the right: The corrosion rate as a function of RH for a concrete specimen with w/c-ratio 0.9 (after [3])

ferent types of coatings or impregnation with silanes or siloxanes. Nowadays the primary impregnation agent consists of alkylalkoxysilane and the alkyl group consists of three to eight carbon atoms. It is therefore natural that the focus in this project is set on the products that are used today and the effect they have on concrete properties.

3 Different aspects of a treatment with silane

In a simplified way you could divide a silane treatment into four different aspects which of course are possible to subdivide into several more each. In a general way a separation is important to do in order to get the whole picture of what is happening when a concrete structure is treated with a silane. The following separation is one way of dividing the impregnation process into smaller parts:

- Transportation of silane into concrete
- Bonding of silane to CSH-gel, forming of silicon resin
- Function of silicon resin
- Property changes with age

In order to benefit as much as possible from the advantages of a hydrophobic treatment, you have to conduct phenomenological studies on the transport mechanisms of impregnation substances into concrete, how they influence and interact with the concrete's microstructure and to investigate the interaction between microstructure, transport processes and the surface protection of the impregnated concrete.

When we are considering the fourth point, property changes with age, anyone who has hiked in the Swedish mountains knows that their boots won't show the same hydrophobic properties after a day in rain and mud. It doesn't matter if the boots are protected of Gore Tex or treated with the most expensive waterproofing agent earlier in the morning. This is probably the same case for a silane treatment of concrete even though the mechanical stresses aren't quite the same.

In this project the main focus is on the function of silicon resin but also the property changes with age will be investigated.

4 Important factors for the success of an impregnation with silane

As mentioned above a lot of research has confirmed that the use of impregnation is one way to lower the RH in a concrete structure and act as a chloride barrier and thereby prolong the service life of the structure [4]. However it is important to know that the success is highly dependent on that the impregnation agent penetrates the structure and doesn't remain on the surface in order to work properly. For example this is important to avoid that shallow cracks penetrate the hydrophobic layer.

To achieve the result desired there are three important factors that have to be taken into consideration [5, 6]:

- Higher w/c-ratio - Deeper penetration/more active substrate
- Lower RH inside concrete - Deeper penetration/more active substrate
- Longer capillary suction time - Deeper penetration/more active substrate

The direct consequence of these three relations is that a horizontal surface of a poor concrete in a dry environment is easy to treat with a water repellent agent. On the other hand a vertical surface of a high performance concrete in a humid environment is more difficult. Unfortunately the second is a more common situation in highway environment. Examples are the walls of a highway tunnel or a bridge column.

5 Function of Silicon Resin

A common way of illustrating how a water repellent agent is working is shown in Figure 2. By measuring either the contact angle of a water droplet

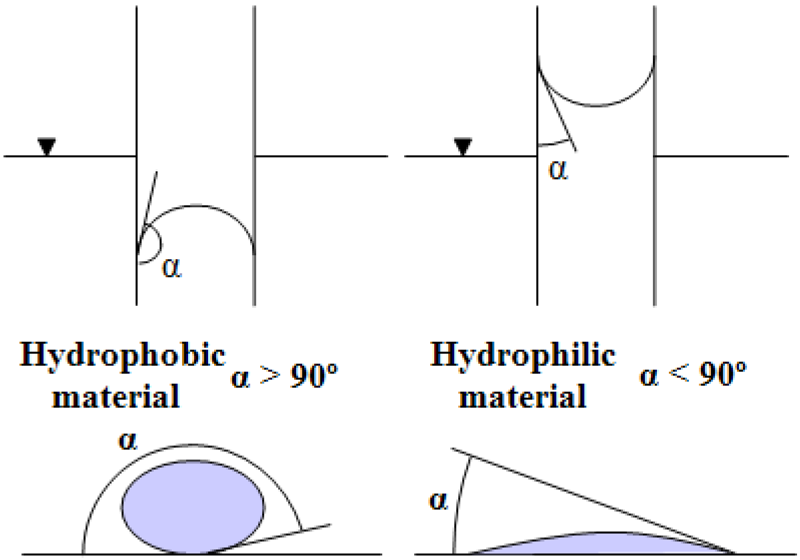

Figure 2: Two different ways of showing the function of a hydrophobic treatment by the means of a contact angle: on top capillary pores and underneath a water droplet

or the water uptake the efficiency of a treatment with a water repellent agent is determined. There are, however, certain disadvantages with this measuring method since the breath ability isn't taken into consideration. The new European standard EN 1504-2 [7] gives a better way of testing the performance since not only the water repellence on the surface is tested but also the drying rate coefficient and the efficient penetration depth.

In the case of a freeze thaw attack the failure of the treatment is quite obvious but when it comes to diffusion of chlorides or carbonation it will take longer time before the results of a bad treatment is possible to detect. If the goal is to predict what is going to happen and understand what is happening inside a hydrophobic layer of concrete it is important to know how certain material properties are affected by a silane treatment. In this project the task is to try to understand the transport mechanisms that take place inside a hydrophobic porous material, in this case impregnated concrete.

The following questions are the starting-points for the first investigations conducted.

- How is the moisture diffusion coefficient affected by silane treatment?

- How does the silane treatment affect the moisture flow in and out of a concrete surface?
- Is the silicon resin effectiveness dependent on the size of the capillary pores?
- How are the moisture fixation and the phenomenon sorption hysteresis affected by a silane treatment?

These are only some questions that need answers. If we are going to understand how the mechanisms of chloride migration and carbonation are affected by a hydrophobic treatment we must at first understand the transport of moisture.

6 Current investigations

6.1 Introduction

One of the goals with this project is to create a computer model where it will be possible to predict the moisture and chloride content over time if the geometry, material properties and environmental conditions of the concrete structure are known. To be able to do this for all scenarios and not just for a specific case there are several parameters that have to be investigated such as for example w/c-ratio, humidity, penetration depth of silane, diffusion coefficients for moisture and chlorides.

The approach is to separate the problem of an impregnated concrete piece into a two layer problem where we at first establish the material properties of the impregnated concrete and none treated concrete separately and then try to look at what is happening in the interface between. In the discussion part of [8] a minimum of active substrate is defined based on a combination of FTIR-spectroscopy analysis and capillary uptake of water. A possible way of interpret the results from this investigation is that as long as a certain amount of silane is absorbed inside the concrete specimen the function of the silicon resin will remain the same. If this is the case it should be possible to measure the material properties for each layer separately and then ad them together in order to simulate a real situation.

At the beginning of this project the focus is on testing different methods in an attempt to answer the questions that were lined up in the previous chapter. If it works out in a satisfying way and it is possible to extract relevant information from these experiments we will try to investigate more parameters. The following investigations have been started:

- Moisture fixation
- Moisture diffusion coefficient

- Direction of flow, H_2O (l) and H_2O (g), Wet and dry cup measurement with evaporation and condensation both on the silane treated and on the untreated surface
- Chloride profiles on specimens exposed in field (tunnel)

6.2 Moisture fixation

Moisture fixation will probably be different in an impregnated concrete than in an untreated concrete. For an example the sorption hysteresis should be affected. Sorption hysteresis is a well established phenomenon for hydrophilic porous materials such as concrete [9, 10] and is often explained as shown in Figure 3.

During the desorption process water is confined inside capillary pores with narrow entrances. Sorption hysteresis is defined as the difference in moisture content at equilibrium, at a given RH and temperature, between the absorption and desorption isotherm. In the case of an impregnated surface layer of concrete the material properties change and turn from hydrophilic to hydrophobic but what will happen with the sorption hysteresis phenomenon? This is important to know in order to understand the transport mechanisms over an interface between impregnated and untreated concrete.

6.3 Moisture diffusion coefficient

In order to succeed with a computer model it is important to have reliable material data on the moisture diffusion coefficient. By separating the problem into a two layer model and make measurements on each layer separately it will hopefully be possible to simulate the effect of different penetra-

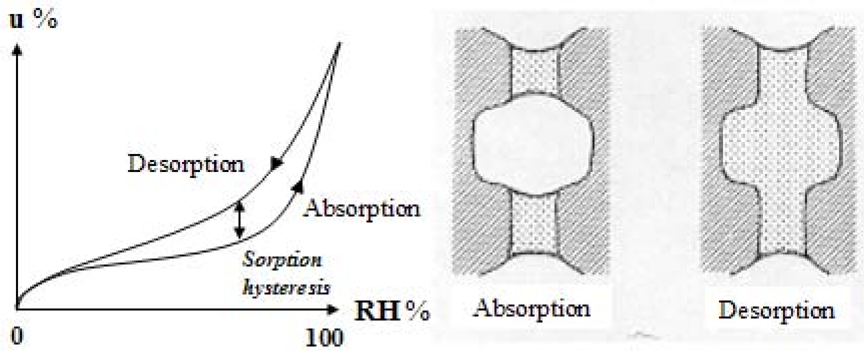

Figure 3: Sorption hysteresis is often explained as a phenomenon caused by water confined in capillary pores during the desorption process (after [11]). The figure on the left shows the moisture content as a function of RH at equilibrium [10]

tion depths. In this first development of measuring methods only two w/c-ratios and one silane are used. The results from this investigation will be presented in an accompanying paper [12].

6.4 Direction of flow, H_2O (l) and H_2O (g)

A water repellent treatment should theoretically only decrease the liquid transport while the vapour transport should be unchanged. The flow rate through a specimen should thus be significant smaller if the specimen is exposed with liquid water on the treated surface than if the untreated surface is exposed. If the specimen is exposed to a vapour gradient the flow rate should be more or less unchanged irrespective of the direction of the gradient. Before we make computer models this is important to know not only in numbers but also the mechanisms behind.

6.5 Chloride profiles on specimens exposed in field (tunnel)

In order to verify the results obtained in the laboratory we have also to conduct field experiments and in this project we are using a heavily trafficked tunnel in Stockholm exposed to de-icing salts for at least four months every year. Chloride profiles will be evaluated continuously during at least four years and measurements of RH and temperature inside as well as outside the concrete specimens will be conducted. Measurements of the chloride content in splashing water from the cars will also be taken.

7 Future

This project aims at analysing how common impregnation substances work in concrete and to develop explanation models. In more practical terms, is a reliable prediction model a realistic goal for this project?

With the collected data from laboratory and field tests in the coming four years our wish is to be able to predict the results of an impregnation with silane. For example how long will it take until chlorides reach the reinforcement, given the environmental conditions, material properties and the penetration depth of the impregnation agent?

There are also more general questions that have to be taken into consideration such as the fact that modern high performance concrete has a denser structure and the impregnation might be unnecessary for the type of structure that is cast out of this concrete. In [13], for example, the use of impregnation is questioned for low w/c-ratios after an investigation where the effect of a hydrophobic treatment was neglectable compared to the non treated specimens.

The use of stainless steel as reinforcement is also an interesting topic since the concrete cover is possible to reduce and thereby lower the weight and price of the structure. Before building a new bridge it is important to make a good economical estimation and to do that you have to know for how long an impregnation will protect it. The results from this project are likely to be a helpful tool in doing that.

8 Acknowledgement

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