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Requirements for the Application of Water Repellent Treatments in Practice

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Abstract

In practice water repellent agents are often sprayed on the concrete surface. This technique implies that impregnation of concrete structures is a simple technology. But in reality complex physical and chemical interactions between cementitious matrix and silicon organic compounds are taking place during the transport of water repellent agent into the covercrete. These reactions strongly determine the performance of an impregnation. Therefore, these effects must be taken into consideration if requirements for applications in practice are to be defined. In this contribution the transport of different types of water repellent agents into concrete made with varying w/c ratios has been investigated. Penetration profiles and suction profiles have been determined in order to characterise the performance of surface treatments. With the obtained results a scientific basis for the formulation of requirements concerning impregnation is provided.

1 Introduction

In practice treatments with water repellent agents are often judged as a simple technology. But in reality the performance of an impregnation is determined by several physical and chemical interactions which take place during transport of water repellent agents into the covercrete. For this reason these effects must be taken into consideration if requirements for pre-investigation, application and quality control in practice are defined [1-3].

For the development of a stringent and efficient quality control penetration profiles and suction profiles have been determined. With the results of this investigation parameters such as effective penetration depth and minimum content of active substance have been defined for the first time.

With the obtained results a scientific basis for the formulation of requirements concerning impregnation is provided. Civil engineers can use these proposed parameters for planning an impregnation.

2 Experiments

2.1 Preparation of concrete specimens

For the experimental investigations test specimens have been prepared according to SIA 162 [4]. The mixture of the investigated concrete is as follows. The maximum aggregate size is 16 mm. The content of Portland Cement CEM I 42.5 is 350 kg/m^3 for all mixtures. The w/c ratio is 0.35, 0.40, 0.45 and 0.50, respectively. After demoulding the concrete specimens are stored at 20° C and 70% r.h... for 28 days. From these concrete elements specimens with the dimensions 70 x 70 x 75 mm^3 are cut.

2.2 Capillary suction experiments

For the impregnation of the specimens capillary suction experiments with different commercial products, i.e. propyl triethoxysilane, iso-butyl triethoxysilane and n-octyl triethoxysilane have been carried out, following a specific procedure. First, the side-faces of the specimens have been coated with epoxy resin. For conditioning the coated specimens are stored at 50° C and 45% r.h.. in a climate chamber until weight constancy. The specimens have been immersed into different commercial water repellent agents over 24 hours, while their uptake of liquid has been regularly measured .

2.3 Analytical methods

2.3.1 Suction profiles

In order to determine the suction profiles the step-cutting method is applied. The treated specimens are immersed into water for 24 hours. Over this period the water uptake through the impregnated covercrete has been determined through weighting. Then the first 1 mm thick layer is cut off using a specially designed milling tool. After re-conditioning at 50° C and 45% r.h. for 3 days the specimens are again immersed into water. The procedure as described above is repeated until the water uptake is comparable to the uptake of untreated concrete. With these values the water uptake in kg/m^2 has been calculated and plotted against the square root of the duration of contact.

2.3.2 Determination of penetration profiles by means of FT-IR-spectroscopy

For the determination of the penetration profiles FT-IR-spectroscopy has been used. Fundamentals of FT-IR-spectroscopy are described in [5]. For analysis the specimens have been treated as follows. Starting from the surface which was in contact with the water repellent agent, thin layers with a thickness of 2 mm have been cut using a specially designed milling tool. The very fine concrete powder was collected and dried at 105° C until weight constancy. For FT-IR-spectroscopy samples are prepared by using KBr-technique. With these KBr-discs FT-IR-spectra with 10 scans in the range of 2900 to 3000 cm^{-1} are taken. The FT-IR-spectra are evaluated through the baseline method which is implemented in the software of the FT-IR spectrometer. Details of this method are described in [6,7].

Through the analysis of standard samples with various contents of active substance for each investigated silane, specific calibration curves can be constructed. With these calibration curves the content of active substance in weight-% related to the weight of concrete can be calculated.

3 Results and Discussion

3.1 Suction profiles

3.1.1 Principles

Depending on their usage concrete structures (e.g. tunnels, bridges, buildings) are exposed to external impacts such as chloride attack, freeze-thaw cycles or leaching by soft water. For preventing damages due to these impacts an effective water repellent treatment must completely cut off the capillary water uptake and therefore, humidity only penetrates as vapour into the impregnated concrete.

According to Crank, water transport in porous media by diffusion as well as by capillary suction can be described with a diffusion equation [8], formulated in eq. (1) and (2), respectively.

Diffusion:

$$j_D = -\lambda \cdot \Delta p \quad (1)$$

with:

j_D = Density of moisture transport flux [kg/m^{2}s]
λ = water vapour diffusion coefficient in air [kg/msPa]
p = Water vapour partial pressure [Pa]

Capillary suction:

$$j_K = -D_w(w) \cdot \nabla w \quad (2)$$

with

j_K = Density of moisture transport flux [kg/m^{2}s]
$D_w(w)$ = Capillary transport coefficient[m^2/s]
w = water content [kg/m^3]

With these formulations the moisture transport into concrete is commonly described as follows (eq. 3):

$$j_w = j_D + j_K \quad (3)$$

The performance of an impregnation can be correctly characterised only through suction profiles. In fig. 1 an idealised suction profile is shown, for which the density of moisture transport flux j_W is plotted against the distance from the surface. It has been proposed to subdivided the curve into three sections.

- Section I: Diffusion (j_W=j_D)
  In section I humidity is transported only as vapour through the hydrophobic surface near zone into the concrete.
- Section II: Diffusion and capillary suction (j_W=j_D+j_K)
  Section II represents the part of the treated concrete which is only partially impregnated. Therefore, both diffusion and capillary suction takes place.
- Section III: Capillary suction (j_W=j_K)
  The concrete in deeper zones represented by section III is comparable to untreated concrete. Here capillary suction is the dominating transport process. .

For proving the proposed model the transport rate through the impregnated marginal zone of treated concrete and untreated concrete has been investigated. For this purpose drying and wetting experiments have been carried out. The results of these tests are presented in fig. 2. The impregnated specimens immersed into water were

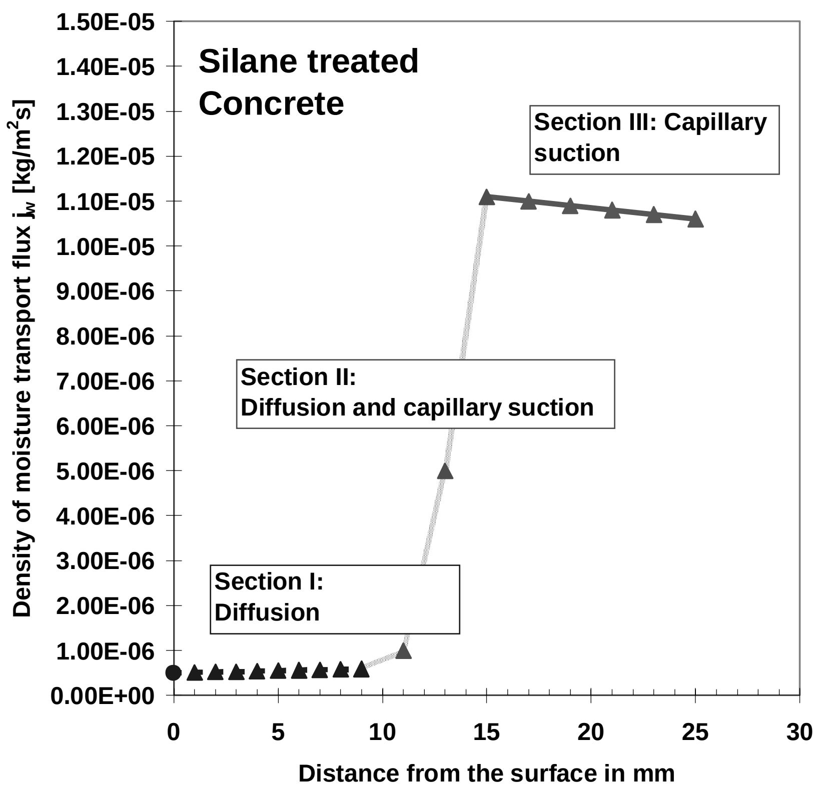

Figure 1: Idealised suction profile for concrete treated with silane

previously stored at 45 r.h. until weight constancy. The values for j_W for these specimens are approximately 1.0E-6 to 1.5E-6 kg/m^{2}s. In a second series treated specimens were stored in water until the non-impregnated part of the specimens were saturated. Afterwards surfaces of the specimens were covered with aluminium foils leaving free only the treated surface. These specimens were then stored at 20° C in an air-conditioned room with 45% r.h. The weight loss of the drying specimens was registrated through weigthing. The values of j_W calculated with the result of these experiments are in the range between 1.5E-6 to 2.0E-6 kg/m^{2}s. In a third series untreated specimens were immersed into water and the capillary uptake of water has been noted. Depending on the w/c ratio of the specimens values for j_W are in the range from 6.0E-6 to 1.5E-5 kg/m^{2}s.

A comparision of the values for j_W calculated for wetting and drying experiments shows that the rate of moisture transport into impregnated concrete which is in contact with water is only determined through diffusion.

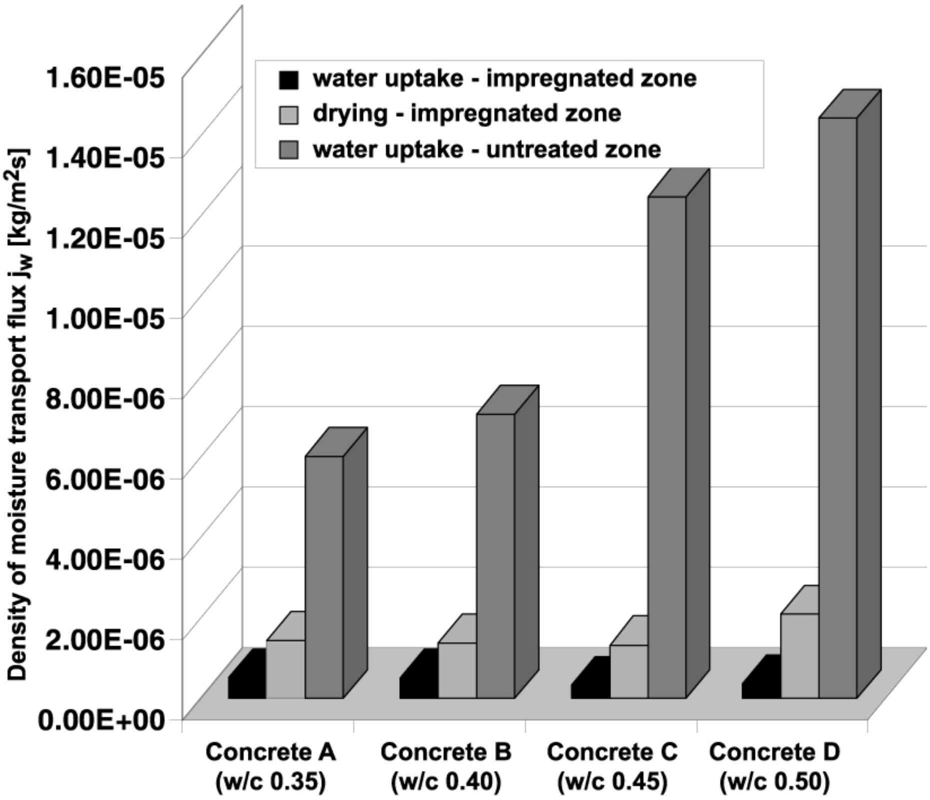

Figure 2: Comparison of the calcuated values for the density of moisture transport flux j_w

3.1.2 Definition of the parameter „effective penetration depth"

Starting from this point of view the parameter „effective penetration depth" can be defined as the thickness of the marginal zone through which the moisture transport takes place only through diffusion.

Practical requirements for the performance of an impregnation have already been formulated. According to the regulations of the DAfStB the reduction of capillary water uptake must be higher than 50% and in the Netherlands the reduction of capillary uptake must be higher than 80% [9,10]. In fig. 3, which shows typical capillary suction profiles, both values are represented through dotted lines.

It is obvious that both requirements are not sufficient to prevent capillary water uptake with certainty. Therefore, both regulations must be revised in order to guarantee the long-term performance of an impregnation. However, it should be mentioned here that the values of j_W depend on serveral factors such as w/c ratio or experimental conditions. For this reason the requirements concerncing j_W must in practice be formulated specifically for the respective construction.

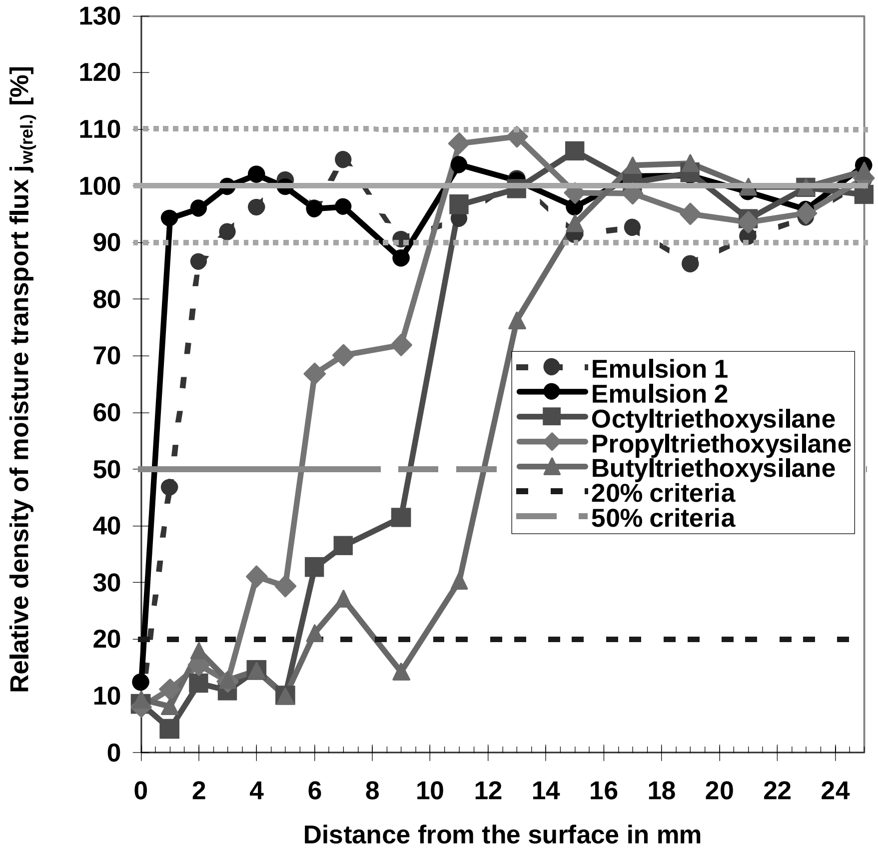

Figure 3: Suction profiles for concrete treated with different water repellent agents

3.2 Penetration profiles

3.2.1 Definition of the"minimum amount of active substance"

After their application on the concrete surface, the water repellent agents penetrate into the concrete through capillary suction. During the transport chemical reactions take place which lead to the formation of a very thin film of silicon resin which is fixed to the surface of the pore walls. To even prevent also the „tunneling" of smallest amounts of water through the marginal zone a minimum amount of active substance is necessary [11].

The minimum amount of active substance is determined as follows (Fig. 4). First, the suction profiles must be measured in order to calculate the effective penetration depth. Second, the penetration profiles must be determined by means of FT-IR-spectroscopy. Finally, the measured .content of active substance which corres-

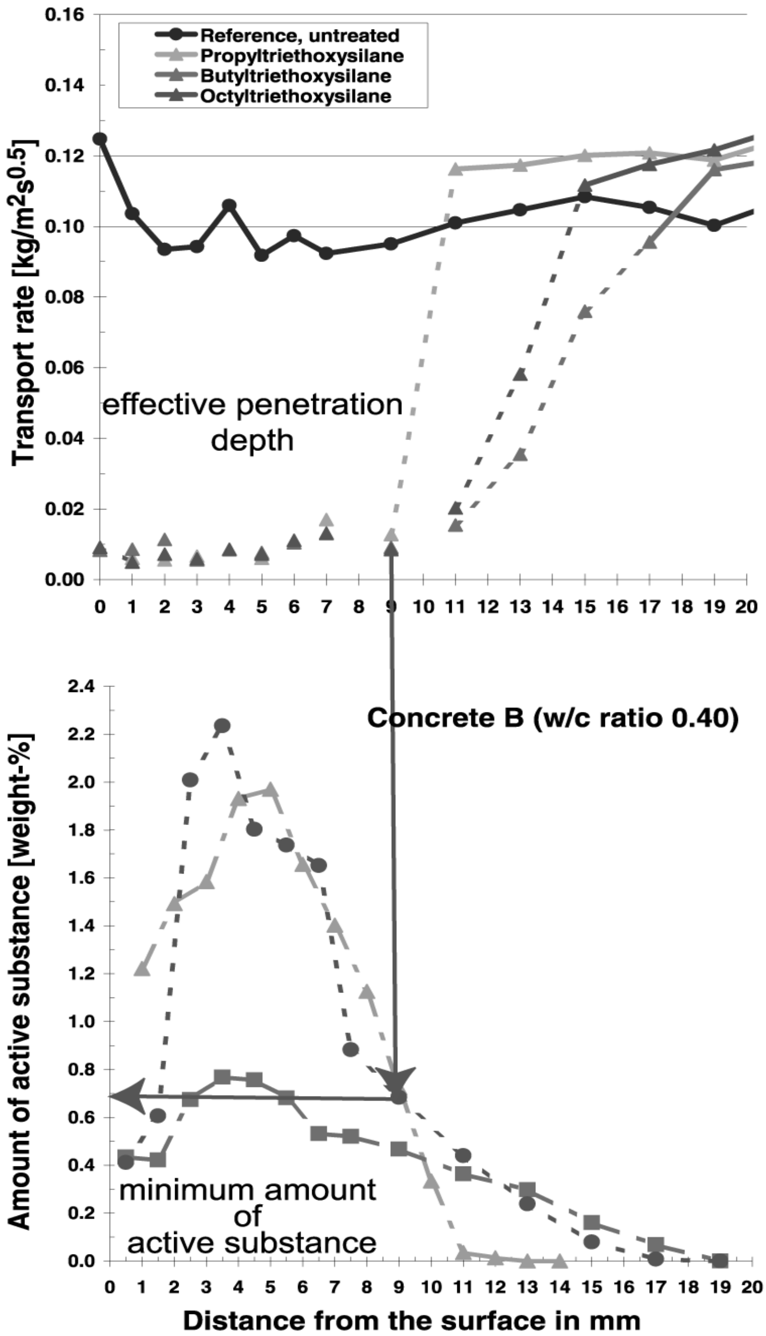

Figure 4: Determination of the minimum amount of active substance

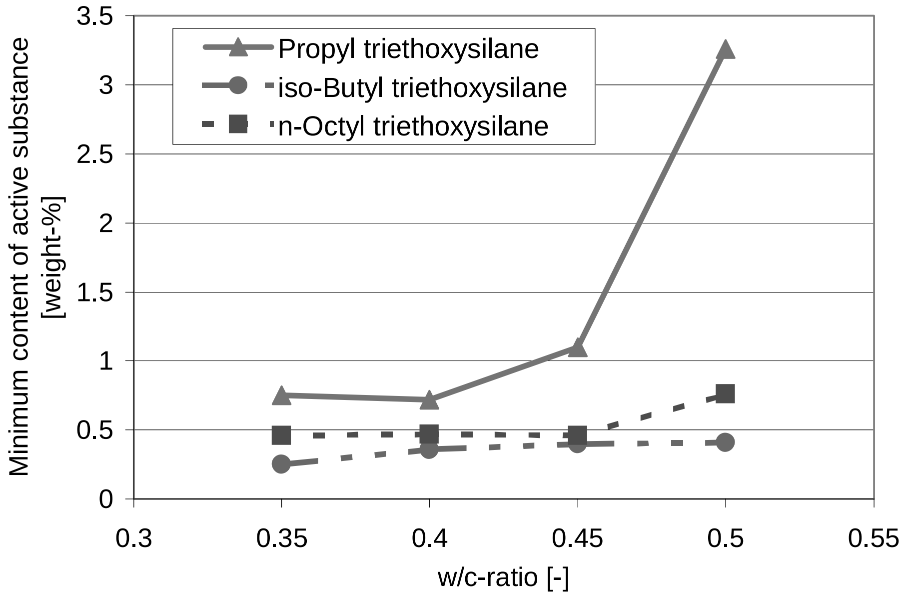

Figure 5: Minimum amount of active substance as a function of the w/c ratio

ponds to the effective penetration depth must be specified. This content represents the minimum amount of active substance.

The values for the minimum content of active substance depend on several factors, the most important being the type of silane and the w/c ratio of the treated concrete. Fig. 5 shows the minimum amount of active substance for the investigated silanes as a function of the w/c ratio of the treated concrete.

For two of the investigated silanes, i.e iso-propyl triethoxysilane and n-octyl triethoxysilane the values for the minimum content of active substance are in the same order of magnitude. With increasing w/c ratio a moderate increase of the values can be observed for both silanes. The values for propyl triethoxysilane are commonly higher then in the other systems. Remarkable is the significant increase of the value determined for the concrete mixed with w/c ratio 0.50 which is approximately 4 times higher than the value determined for the concrete made with w/c ratio 0.45. This effect can be attributed to the chemical structure of this silane, especially to the length of the carbon-chain of the non-reactive alkyl group.

4 Planning, execution and quality control for applying water repellent agent systems

4.1 Remark

In the following an example for applications of water repellent agents in practice are described. The procedure can be subdivided into three parts.

4.2 Pre-investigation

The project we have dealt with concerned the surface treatment on the outside wall of a new building. First areas about $1m^2$ from the wall were chosen, on which different water repellent agents were applied under strict control. From these areas cores were taken in order to determine the effective penetration depth and the corresponding minimum amount of active substance. The system with the best performance has been chosen. The values for effective penentration depth and the minimum amount of active substance determined for the test area are fixed in the contract.

4.3 Execution

In the past it was believed that it should be sufficient if the surface of concrete was treated once with water repellent agents. The performance of this treatment usually was done by using airless-spray apparatus. With this method, the maximum penetration depth of active substances was 2 mm. For this reason a various processes and products were developed with the aim to increase the penetration depth. So far water repellent treatment measures applied can be classified into three groups:

a) Prolong the contact time of diluted, low-viscosity water repellent agents through setting up an impregnation equipment which was directly fixed on the concrete wall;

b) Apply high-viscosity water repellent agents, such as creme, gel or paste by spraying or rolling technology

c) From time to time multi-application of low-viscosity of 100% silane by spraying technique

Which method should be employed depends on the individual object that is to be treated and the financial ability. For the object discussed here technique b) has been chosen as the application method with the best performance.

4.4 Quality control

A good planning and correct execution for the application of water repellent agent systems can only lead to a successful application of water repellent treatment if a corresponding quality control measure is applied at the same time.

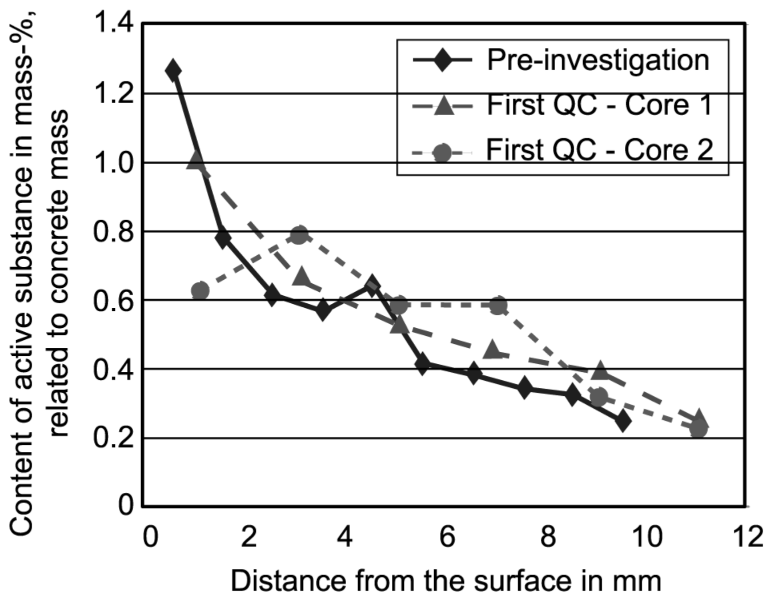

Figure 6: Results of a quality control in practice

As discussed above in principle the effectiveness of the penetration depth of water repellent agents can be characterised through the penetration profile. However this method is relatively time consuming. For a engineer it is not really practical. To overcome this short coming, FT-IR-spectroscopy can be used which is a quick, reliable and practical method.

In the case presented here after one week polymerisation, core samples were taken from the treated surface and analysed with the help of FT-IR-spectroscopy. Results are shown in Figure 6. These penetration profiles were then compared to the the reference curve which has been determined during the pre-investigation. It can be seen that the penetration profiles from the other two samples at different location of the wall are very close to the reference curve. That means the effectiveness of this application has reached the planed goal.

5 Conclusions

From the results presented here the following conclusions can be drawn:

- While planning an impregnation several factors must be taken into consideration in order to guarantee the long-term performance.
- Requirements regarding the reduction of capillary uptake of 50% and 80%, respectively are not sufficient to prevent capillary uptake with certainty. Regulations of different countries in which these values are fixed should be revised.

- The „effective penetration depth“ and „minimum content of active substance“ which have been defined for the first time are suitable to characterise the performance in a scientific way.
- To enhance the acceptance of water repellent treatments in practice the guidelines for the pre-investigation, execution and quality control presented here should be applied strictly.

6 Literature

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