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Gel Impregnation of Concrete - Theoretical Results and Practical Experiencies

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Abstract

The technique with gel impregnation was developed in Stockholm in 1994 and has been used in field applications on over 200,000 m^2 of concrete surface in Scandinavia since 1995. It is based on the fact that the penetration depth and the amount of absorbed active silane substance increases with the contact time between silane and concrete surface. With the appropriate choice of applied gel thickness it is possible to get capillary penetration during a time spans longer than a fortnight. As a consequence, this type of application results in a deep penetration of silanes even when applied on dense concrete. In recent years a large number of cores have been drilled out from Stockholm bridges to evaluate the quality of impregnations made with gel and with liquid silanes. The study has shown that the use of the gel achieves a far deeper and a more uniform penetration than that resulting from liquid silane application. The introduction of this new technique offers for the first time a method to achieve a satisfactory hydrophobization on high quality concrete, such as is used for bridges, with only a single application. In general, at least 5-mm penetration dephts are achieved.

1 Introduction

Hydrophobization with silanes is an effective way to make a concrete surface water repellent thus preventing water and salts from penetrating into the concrete. In Stockholm silane treatments of concrete have been performed since the middle of the 1960's.

Originally water repellent agents were prepared as dilute solutions in white spirit or alcohol. With these formulations, penetration depths of only a few tenth of a millimeter could be obtained in high quality concrete such as that used for bridges. In 1993, with the use of concentrated agents the average penetration depth increased to a few mm in field applications. However, this resulted in large variations in penetration depth as well as areas with no penetration at all. It was therefore necessary to develop a new approach which lead to the development of what we called the "gel impregnation" method.

2 Requirements on penetration depth

The reasons for requiring a deep penetration of the hydrophobization agent are:

- To achieve a satisfactory protective effect. The protective effect against intruding salts and water increases with penetration depth of the impregnation. This is particularly obvious up to about 5 mm penetration depths [1].
- To ensure the protective effect when cracks occur in the concrete. P. Lunk and F.H. Wittmann have studied the influence of cracks on the protective effect showing that a treatment with shallow penetration depth loses its protective effect even with very narrrow crack widths [2]. It was also found that the ability of the impregnating agent to bridge cracks without a decrease in the protective effect grows with penetration depth.
- To ensure the protective effect in connection with graffiti removal when the impregnated surface is cleaned.
- To ensure the protective effect when the concrete surface is cleaned by washing with tensides [3]. It has been argued that tenside-based detergents may destroy the protective capacity of some treatments.

To meet these requirements at least a 5-mm penetration depth (typical value = mean value minus one standard deviation) is recommend for a satisfactory outcome.

A silane treatment applied with insufficient penetration depth results in inferior protection as well as higher vulnerability to losing its protective capacity if and when cracks develop in the concrete, or if it is cleaned from graffiti or washed with tensides.

3 Characteristics of the gel

To achieve such deep penetration into high quality concrete, such as that used for bridges, it is normally necessary to:

- Use silanes with small molecules and with low evaporation.
- Use silanes with the molecules operating separated as individual molecules and not packed together into large particles as in the case of water-based emulsion systems.
- Allow the concrete enough time to absorp the silanes by capillary forces into the concrete, i.e., at least 24 hours.

Based on these requirements the technique where the silanes were applied in the form of a gel was developed in the laboratory in Stockholm in 1994. The technique is based on the fact that the penetration depth and the amount of absorbed active silane substance increases with increased contact time between silane and concrete surface.

The gel contains only a few per cent of a thickening agent, the rest being made up by small molecular size silanes, e.g., isobutyl triethoxy-silane or isooctyl triethoxy-silane. It a consistency similar to cosmetic skin cream. The gel can be sprayed onto the concrete in varying thickness to optimize penetration. The silanes are gradually removed from the gel by the concrete through capillary forces until the gel is completely free from silanes. Dry flakes of the thickener will remain on the surface where they can be left or easily removed by brushing.

Silanes concentrated in a gel allow the substrate to absorb the individual silane molecules by capillary forces over time spans longer than a fortnight. This type of application allows silanes to penetrate deep into the substrate even when this is a dense concrete [4-7].

4 Laboratory tests

The influence of contact time between the silane (isobutyl triethoxy) and the concrete surface, as well as the moisture content in the concrete, on the resulting amount of absorbed silane and penetration depth has been examined in laboratory tests. The results are presented in figure 1 and figure 2. It is evident that the treatment quality increases considerably with higher contact times. This knowledge was the base for the development of the gel [5,7]. Comparative laboratory tests with different silane agents have shown that the penetration depths achieved by gel impregnation are about 4 times higher than what can be achieved with other, often used, silane products currently available on the market [8].

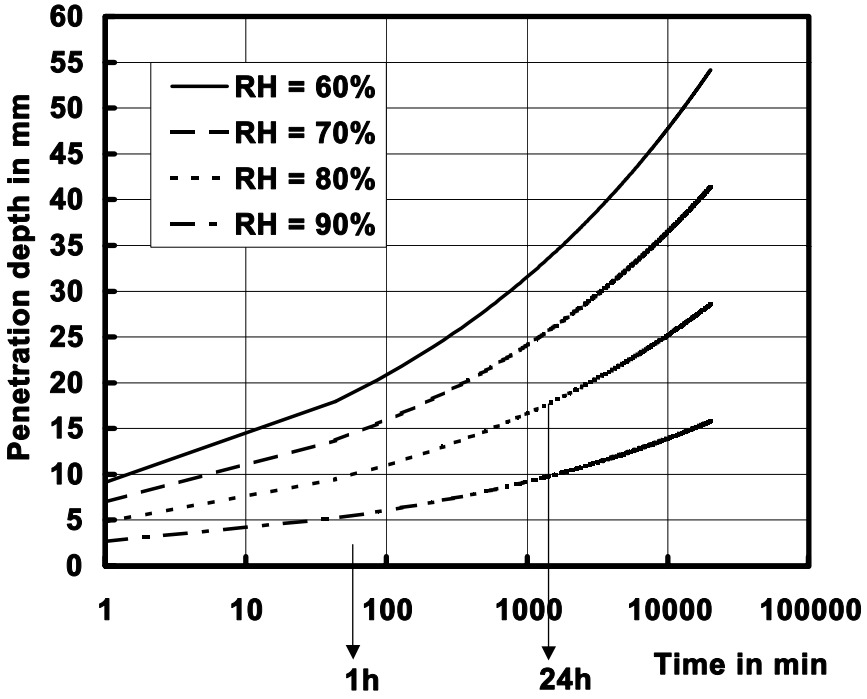

Figure 1: Penetration depth as a function of duration of contact

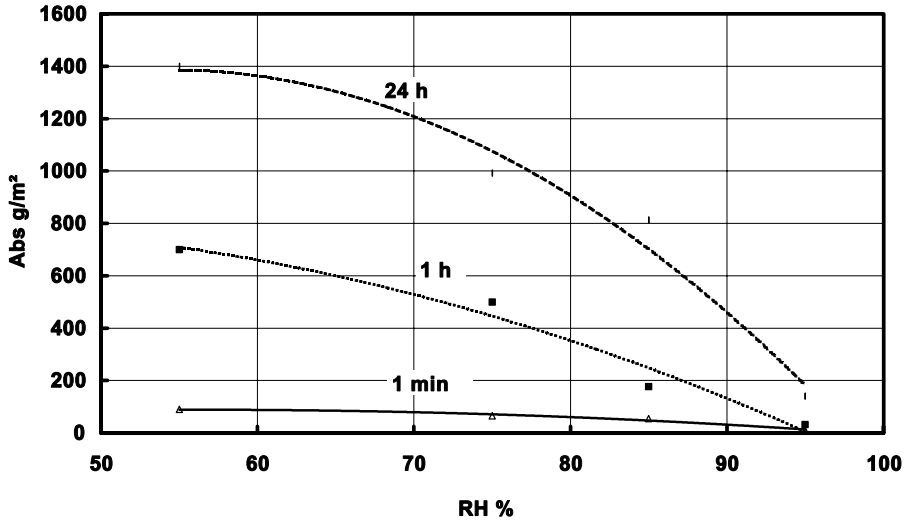

Figure 2: Uptake of silane as a function of relative humidity

5 Evaluation of field applications

There is no generally accepted method to determine the quality of an impregnation treatment. The quality of a treatment is a function of the penetration depth and the quantity of absorbed active substance. To determine the amount of active substance is currently extremely complicated and is only made in research work or in case of a dispute between buyer and contractor regarding the quality of a treatment.

In Stockholm, penetration depth is used to evaluate the quality of the treatment. Normally the penetration depth is determined on core-drills of Ø 50-mm diameter. The penetration depth is determined every 10 mm, mean value and standard deviation are then calculated.

A typical value of the penetration is then calculated:

$$Q = m - \sigma \quad (1)$$

with

Q	=	typical penetration depth
m	=	mean penetration depth
σ	=	standard deviation

Q is a good representation of the quality of the treatment since the probability that the penetration depth is below Q is only 15%.

Results from quality control carried out on Stockholm bridges have shown that the standard deviation σ is greater when the application was made with liquid silane rather than with silane-gel. Thus a greater average penetration depth must be achieved with a liquid treatment than with a gel to ensure the required and specified penetration depth.

In recent years a large number of core-drills have been taken from Stockholm bridges to evaluate the quality of impregnation. The study has shown that the penetration depths achieved were far greater when a gel had been used and that the treatment was more uniform in comparison to that achieved by the use of a liquid silane. The results from these tests are shown in figure 3. The hydrophobization agent used was isobutyl triethoxysilane both as a liquid and as a gel. The liquid was applied in two steps and the gel thickness varied between 0.3 and 1.0 mm. The quality of the impregnation is defined as typical impregnation depth, *Q*, according to eq. (1). For gel treatments, Q varies between 3.8 and 29.2 mm with a mean value of 10.1 mm. The corresponding values for liquid treatments is a variation between –4.4 and +6.0 mm with a mean value of 1.2 mm. Negative values indicate that more than 15% of the values have no measured penetration at all. It can be seen that an impregnation with liquid rarely exceeds a 5-mm impregnation depth, while it is often only a few millimeters. With gel, the average penetration generally exceeds the 5-mm impregnation depth.

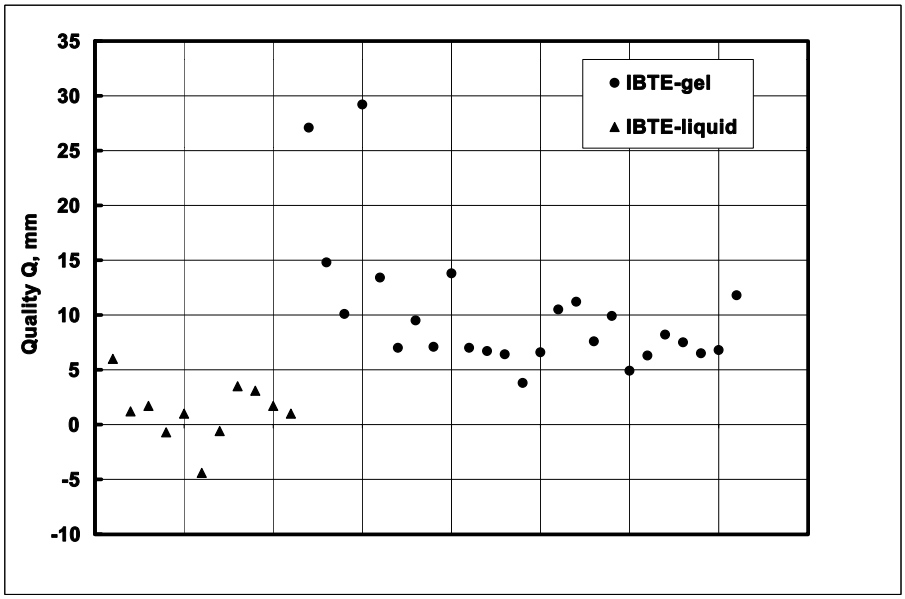

Figure 3: Results of a field study

6 Application technology

6.1 Surface preparation

It is necessary to prepare the surface in a proper way before the gel can be applied to the concrete. In general, this is achieved by high-pressure water- or sand-blasting. If high-pressure water has been used, it is very important to let the surface dry for at least 7 days. Also if the concrete surface has been exposed to rain, it should dry for at least 12 hours.

6.2 Equipment

To apply the gel special equipment is necessary: an Airless sprayer, a wet film thickness measuring device, a drill-mixer and the usual personnel safety equipment. The airless sprayer should have a spray nozzle, size 20-35, depending of the size of surface that is to be treated (fig. 4).

6.3 Application

The gel is applied in the desired thickness, from 0.25 mm to 2 mm, depending on the concrete quality or existing demands or regulations (fig 5). During gel application, a running control should be made with wet-film thickness measuring device to secure that the prescribed or required layer is being applied (fig 6). After appli-

Figure 4: Airless sprayer

cation, the surface should be protected from heavy driving rain that could flush the gel away. The gel will allow the capillary uptake of the hidrophobization agent by the concrete for 4-17 days depending on applied amount and external conditions. When the procedure is finished, only a thin dry clay layer will be seen on the concrete surface. Vacuum cleaning, brushing and water washing can easy remove this dry layer (fig. 7). This layer can also be left on the surface for eventual removal by weather and wind.

6.4 Control of the impregnation procedure

For control of the penetration depth core-drill samples are taken from the treated surfaces (fig. 8). Recommended core diameter is 50-mm and at least 3 samples should be taken per treated 1000-m^2. On smaller objects, fewer samples can be taken. It is important to be aware that this sampling cannot be done right away, because the samples can still contain non-reacted silanes due to the increased penetration depth. From our experience, at least 4 weeks should be allowed from the application date on a good quality concrete before the samples are taken. The results are very easy to see on the sample due to the high water repellency and the achieved depth of impregnation (fig. 9).

Figure 5: Application of a gel film with a given thickness

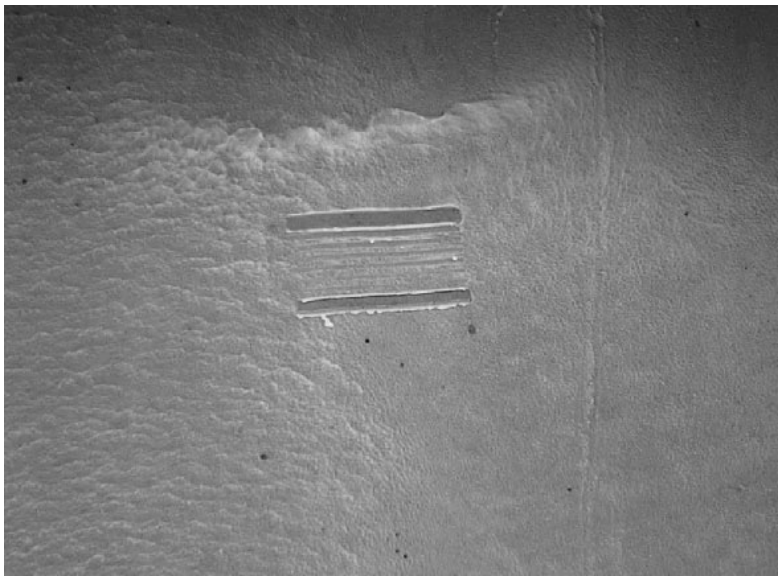

Figure 6: Measuring of the film thickness

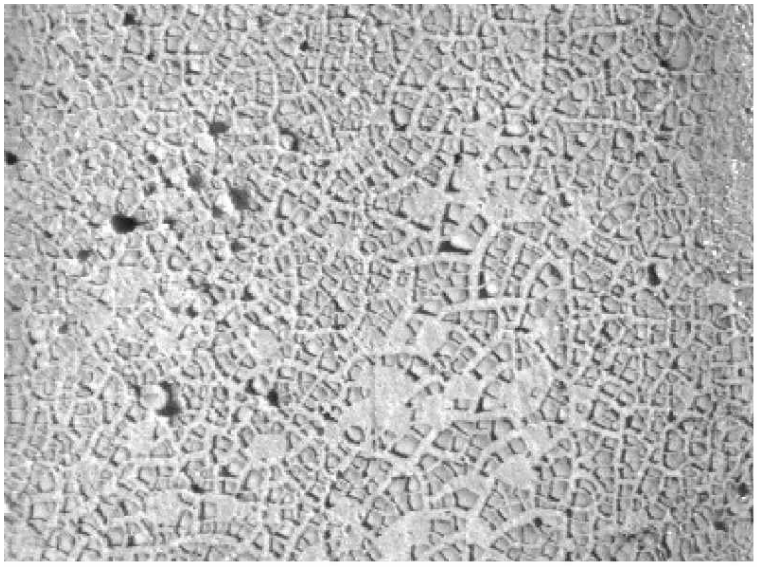

Figure 7: Gel layer on the concrete surface after drying

Figure 8: Core drilling

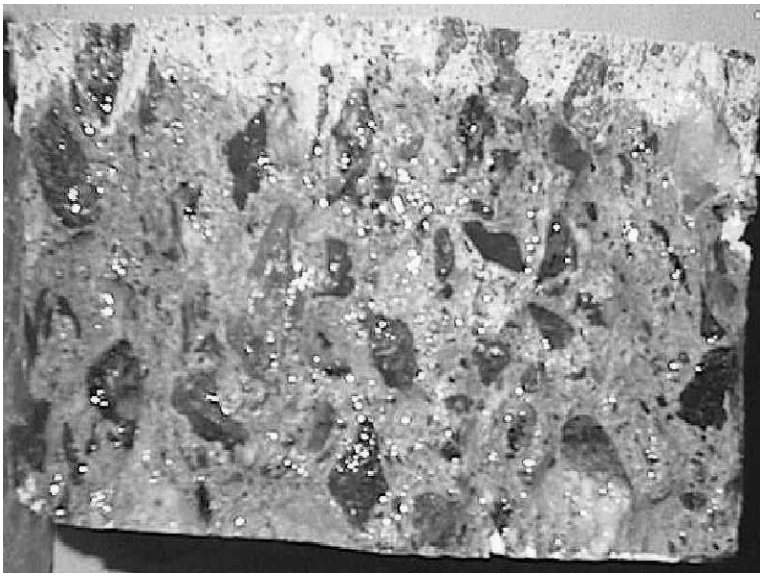

Figure 9: Determination of the penetration depth

7 Field experience

7.1 Experience from field application with the StoCryl HG 200 impregnation gel

Since 1995, over 200,000-m^2 of concrete surfaces in Scandinavia have been impregnated with gel. In the year 1995, about 10,000-m^2 of column, beam and wall surfaces were impregnated in-depth to protect against chlorides. In the year 2000, over 60,000-m^2 were treated. The reason for this increase in activity on both government and private owned constructions is due to the good results obtained. From the beginning, the main objective was to protect concrete against water and chloride penetration.

One of the earlier large constructions which were treated with this system were the Kings' Bridges in Stockholm, where Stockholm Konsult had noticed a high concentration of chlorides and also ASR (alkali silica reaction) in the concrete. Due to the initial good impregnation depths achieved with gel application it was decided to use this system. The result was very good, even if the bridges are exposed for rising waters all the time (fig. 10).

Apart from the good results achieved, the one step application spares application time and cost, especially for difficult access areas. This is exemplified by the railway bridge south of Stockholm, over which all trains going south in Sweden must pass. By using the gel method in one application it was possible to lower the costs

Figure 10: King's bridge in Stockholm

of the train-rental and the needed closing-time of the busy railway tracks (fig. 11 and 12).

Other constructions where a good impregnation is necessary are parking garages and harbors. These older constructions were often made with low-quality concrete and are subject to a high-chloride environment (fig. 13). Impregnation with gel has also been used on constructions where the community or government doesn't allow any changes on the concrete surface because of cultural interest (fig. 14).

7.2 Combined system from field application with gel as primer

In Sweden, good results have been obtained in both laboratory tests and field application from the use of StoCryl HG 200 gel as primer in a painting system (fig. 15) or in an anti-graffiti system (fig. 16 and 17). The good penetration depth achieved with StoCryl HG 200 gel impregnation assures the safety of the paint even if a crack should appear later on in the construction. Also for anti-graffiti system especially the reversible one it is really important to achieve a good penetration because otherwise the subsequent mechanical cleaning (water or sand blasting) of the concrete surface for graffiti removal will break-down the surface impregnation.

Gel impregnation as preventive protection for reinforcement

Since 1997, the community of Stockholm had used StoCryl HG 200 gel as preventive protection for undersides of bridges to protect against corrosion on reinforcement bars. Good practical results had been achieved. If the construction is

Figure 11: Railway bridge in the south of Stockholm

Figure 12: Treatment of the railway bridge

Figure 13: Harbour

Figure 14: Parking garage

Figure 15: StoCryl HG 200 gel as primer in a painting system

Figure 16: StoCryl HG 200 gel as primer in a an anti-graffiti system

Figure 17: StoCryl HG 200 gel as primer in a an anti-graffiti system

exposed to considerable rising damp or a leak from above, a concrete damage will appear fast due to the corrosion of the reinforcement (fig. 18).

8 Conclusions

The technique with gel impregnation was developed in Stockholm in 1994 and, since 1995, has been used in field application in Scandinavia on over 200,000 m^2 of concrete surface. The technique is based on the fact that the penetration depth and the amount of absorbed active silane increases with longer contact times between the gel and the concrete surface. By appropriate choice of the applied gel thickness it is possible to obtain capillary penetration of the hydrophobization agent for time spans longer than a fortnight. Therefore the silanes can penetrate deeply even in dense concrete.

In recent years a large number of cores have been drilled out from Stockholm bridges to evaluate the quality of impregnations made with gel and with liquid silanes. The study has shown that the penetration depth resulting from the user of a the gel is far greater as well as more uniform when compared with liquid silane application.

The introduction of this new technique offers for the first time a method to achieve a satisfactory hydrophobization on high quality concrete such as that used

Figure 18: StoCryl HG 200 gel as preventive protection for undersides of bridges

for bridges, with only a single application. In general, at least 5-mm penetration depths are achieved.

On the basis of the practical experience from the last 5 years of field application, several arguments can be made in favour of the gel application technique. The main arguments are listed below:

- A deep and uniform impregnation of the concrete is achieved.
- A high amount of silane remains in the construction.
- Only a one step application is necessary.
- Little dripping and waste falls from the treated concrete surface.
- The right amount to be applied is easy to control.
- Good acceptance by entrepreneurs.

9 References

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