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Some Issues Concerning Concrete Impregnation with silanes

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ABSTRACT

Concrete protection against severe environmental conditions, such as wind-driven rain water, is often a must, even more since rain may contain marine salt. Impregnating concrete structures with silanes is a possible solution that involves producers, users and experts in concrete impregnation with chemical products. Their opinions, however, are still far apart regarding the efficiency of the impregnation and the most suitable technologies.

Having in mind users' point of view, this paper rises and discusses some questions, still awaiting for an answer, but does not present a final solution for concrete impregnation with silanes.

There are many factors coming into play, such as what type of silanes should be used? How deep the impregnating layer should be? Impregnation should be limited to the surface, or should it be deeper, especially if wind-driven rain is expected to occur?

Surface orientation should be also taken into consideration, since the success of the impregnation depends on whether the surface is vertical or horizontal at the top of the structural member or at the underside.

Further factors like entrapped air, gravity and moisture content seem to influence the impregnation with silanes, as well as the penetration of water, and should be considered.

Other questions are: is it possible to renew the impregnation by cleaning concrete surface? How is it possible to measure any changes in the water-repellent effect of the layer impregnating the concrete? Is there any influence of the silane layers on water diffusion out of concrete?

The above-mentioned unanswered questions may be the reasons why there are so many diverging opinions about the efficiency of silane impregnation.

1. INTRODUCTION

Silane (SiH_4) is a chemical compound, that has the same structure of methane (CH_4), but with an atom of silicium instead of an atom of carbon in the molecule. Like the atom of carbon in methane, the atom of silicium in silane - is placed in the centroid of a tetrahedron, whose vertexes are occupied by 4 atoms of hydrogen.

At ambient temperature silane burns naturally, since no ignition sources are required.

Silanes are more complex chemical compounds, consisting in chains of silicium atoms, having covalent links with hydrogen atoms. The easy decomposition of silanes at room temperature depends on the rather weak link among silicium atoms, this link being weaker than that among carbon atoms in the hydrocarbons.

To avoid their decomposition at room temperature, silanes are generally found on the market as emulsions or gels, that – once sprayed or placed on a surface – are subjected to the combination with the silicates (as in the case of concrete surfaces) and to oxidation, with the formation of water and silicium dioxide (SiO_2, whose tiny particles fill the voids of the

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material). Hence these chemical compounds are often used in water-repellent products, and have been proposed for the protection of concrete surfaces and stone walls.

Protecting the stone walls of a 100 years old church in Sweden close to the North Sea (Skagerak) , whose granite blocks were jointed by means of layers of hydraulic-lime mortar, was the starting point of this paper. The protection of the structure was required by its exposure to heavy winds and rain.

In this context, impregnation of concrete with silanes was studied and questions arose about the reliability of this technique. Contradicting opinions from engineers about the efficiency of the impregnation and the depth of the protective layer came up as well.

Furthermore, neither the recent tests and the state-of-art studies by Johansson (2006), and Johansson et al. (2006), nor the companies manufacturing and selling impregnation products provide the end users with all necessary information.

In this paper, the author present their opinions on several still-open questions and, whenever possible, gives their ideas, having in mind the end users.

As previously mentioned, many are the opinions concerning the protection provided by the impregnation of concrete surfaces with silanes in a moist environment. Some researchers believe that the water-repellent ability is good, while others have doubts about the efficiency of the impregnation. There are also different views on how deep the impregnated layer should be and to what extent the penetration depth may guarantee the impregnating effect.

Because of the many aspects still open to investigation, many efforts are today devoted to the research on concrete impregnation, even more since - beside the possible benefits - the technology still arises many questions, without answers, that are crucial for the applications.

Depending on the properties of the specific silanes adopted in concrete impregnation, the penetration should be minimal (i.e. limited to concrete surface), or extended to the walls of the capillaries. (The coating on the walls tends to close the capillaries and to increase concrete resistance to water diffusion). Today´s opinion is that the duration of the impregnation is about ten years. Renewing the impregnation makes the capillaries more closed and favours a further reduction of the diffusion, that may even be totally blocked.

Some people think that the solution containing the silanes should be aimed at covering the concrete surface. In this way the silanes do not have the time to penetrate into the capillaries, since their molecules rapidly react with the silicates contained in the concrete. Thereby concrete surface becomes hydrophobic, the capillaries are undisturbed and water vapour diffusing from inside the concrete can evaporate through the open capillaries. Others think that the waterproofing layer should be preferably 20mm deep, in order to better prevent water intrusion.

The tests concerning the penetration of the silanes in the concrete are always carried out by dipping the sub-surface of the concrete sample in the solution containing the silanes, that are sucked up against gravity. The results are clear, though limited to the bottom face (*intrados*) of any given structural member, something that occurs very rarely, since generally the sides and top face (*extrados*) are exposed to the water. The intrados, however, may be covered by a film of condensed water, as it is usually the case, when the environment warms up very quickly after a spell at very low temperature. Normally, the sides and the top surface of a structural member are exposed to the rain and should be protected by means of impregnation.

Gravity has no effects on the capillary suction along the lateral surfaces of a concrete structure, but wind pressure may force the water through a too-thin impregnated layer, into the capillaries. As a matter of fact, wind-driven rain forms water films on vertical concrete walls and these films are exposed to wind pressure. The wind pressure deforms the films and pushes them through the impregnated hydrophobic layers into the capillaries, where the water molecules get in contact with the electrically-loaded capillary walls and stick to them.

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Tech-Dry Building Protection Systems (see website in References) mentions the above-mentioned risk, which increases with increasing wind pressure and may create *water bridges* through the impregnating layer. These "channels" favour water transport into the concrete. Of course, a deep impregnation may prevent this migration to happen. Furthermore, close to sea coast the water may contain wind-borne salts (*chlorides*), that follow the water into concrete pores.

Along any concrete top surface, the pressure of the rain water increases with the thickness of the water film. The deformed volume of water is forced through the impregnating layer into the capillaries. If water bridges are created through the protecting layer, capillary suction is activated. The air entrapped in the concrete pores, however, has to get out against the water intrusion and is hindered by the water trying to come in.

Cracks affect water intrusion as well, since any excessive opening of the cracks nullifies the benefits of impregnation, that cannot stop the incoming water. Subsequently, the penetration of soft rainwater dissolves the calcium contained in the hydrated cement, and - if water penetration allows the water to flow through the concrete – the hardened cement is depleted of calcium and concrete weakens.

2. WATER STRUCTURE

In Civil Engineering capillary suction is usually treated by means of empirical equations and diagrams concerning the various chemo-physical processes. In this way, a lot of information is obtained, to the detriment of the understanding. Hence, to better understand how silane impregnation works, a thorough examination of water properties and atomic structure is necessary. The water molecule consists of two hydrogen atoms and one oxygen atom covalently bounded to each other (because of *electron sharing*). The negative electrons tend to be located between the positive atomic nuclei. This means that the two hydrogen nuclei become outwardly positive poles. The oxygen nucleus becomes a negative pole, because of the surrounding surplus of negatively-charged electrons (Fig.1).

Water molecules are mutually bonded by the electrical attraction between poles having opposite sign (*hydrogen bonding*). The binding is quite weak but sufficient to hold together the volume of water in the form of droplets. In liquid water, the bond is continuously broken and re-established because of *thermal vibrations*; as a result, the molecules can occupy the entire available space. In solid water (*ice*) there are less thermal vibrations, and the hydrogen bonds do not break and the molecules cannot occupy the entire space (this is an explanation of why the volume of ice is larger than that of liquid water, by 9%, for a certain given mass).

Because of their electric polarity, water molecules are attracted by the electrically-charged ionic structures, and this is the case of concrete.

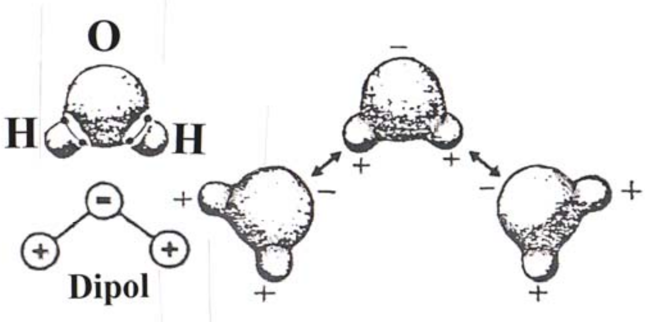

Figure 1 - Simplified structure of water molecules.

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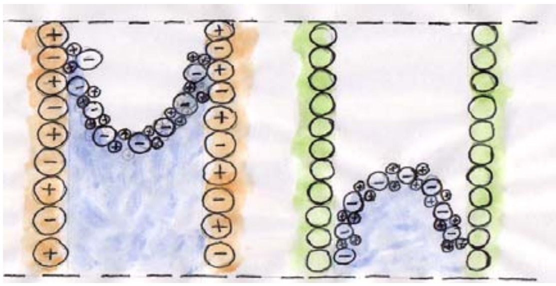
The ions strongly bind water molecules among themselves. Ions with positive and negative electrical charges attract water molecules, since these have both positive and negative poles. At temperatures above absolute zero, molecules vibrate because of thermal excitation. Vibration intensity varies between molecules. Overactive water molecules can jump from ion to ion along the capillary walls, pulling other water molecules, in so forming water layers and volumes, that are held together by hydrogen bonds. The ionic capillary walls becomes hydrophilic and their surfaces become wet, Fig. 2a. If the capillary walls have no electrical charges (as after being impregnated and covered by silanes), the surfaces become hydrophobic and water is repelled, Fig. 2b. The water is not attracted by the capillary walls devoid of ionic electric charges, and the internal hydrogen bonds hold together the water molecules, by forming droplets or layers outside the capillaries. To have water in a hydrophobic capillary, it has to be pressed in.



(a) (b)

Figure 2 - Water intrusion (a) in a hydrophilic capillary with electrically-charged ionic structure and (b) in hydrophobic capillary, where water intrusion requires some pressure, since the capillary is electrically uncharged.

The wind pressure acting on a water film covering a concrete surface can deform this film and push it into the capillaries.

Thermally vibrating water molecules can penetrate among thermo-vibrating ions in ionic materials, where water molecules force the structure of the material to swell, see Fig. 3. On the contrary, when the concentration of the water molecules in the environment decreases, the same molecules are expelled and the structure of the material shrinks. It is a reversible process.

Should enough water molecules be around an ion, this ion may move away from the ionic structure, to become a part of the solution, see Fig. 4. In this way, calcium ions are dissolved out of the cement binder and follow the water flow. When the water comes out of a crack in a structural member and evaporates, carbonated calcium remains in the form of white calcareous coating.

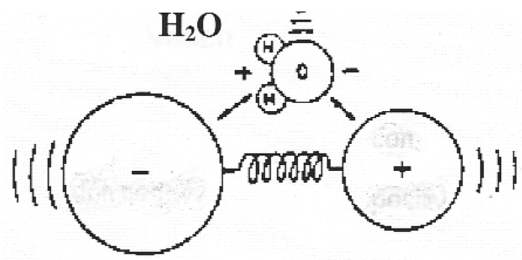


Figure 3. - Thermal vibrations allow the water molecules to penetrate into the ionic structure.

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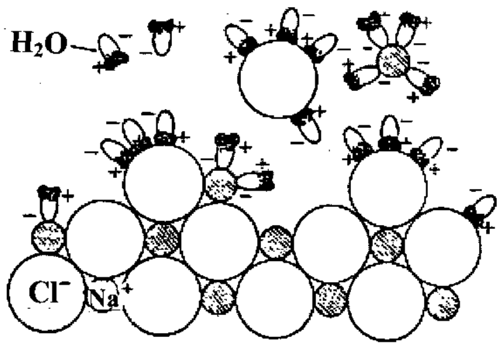

Figure 4 - Several water molecules around an ion can expel the ion from the ionic structure, forcing it to join the solution.

3. HYDRATION PRODUCTS (CEMENT GEL) AND WATER

The structure of the cement gel is ionic, as shown in Fig. 5 (electron microscope), where the capillaries are not visible in the form usually adopted in modelling, even if their aim is clear: "sucking" water. The structure has ions with electric charges and is attracting polar water molecules.

In a polar structure the water molecules are able to climb by taking advantage of the temperature-induced vibrations of the molecules, that create layers and layers of water molecules. As a result, menisci are formed and further water molecules are drawn ("capillary suction"). Depending on the direction of the sucking process, gravity counteracts, is neutral or favours water intrusion – "suction".

Figure 5 - Enlarged cement-gel particle, as observed by means of an electron microscope.

4. THE IMPREGNATING EFFECTS OF SILANES

Silanes come as solutions, emulsions or gels. When applied to concrete surfaces, silanes react rapidly with the silicates of the cement gel and cover concrete surface with a hydrophobic layer. If for some reasons the reaction is delayed, the silanes can be progressively and partially sucked into the capillary system, before the reaction takes place. There are different opinions about the depth required by the impregnating layer to guarantee an effective

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protection (between ~ 0.1 mm and 20mm). According to current knowledge, the impregnation can last for as many as 10 years, tough with decreasing efficacy.

The aim of concrete impregnation with silanes is to prevent the water from entering into the concrete. As a matter of fact, a correctly performed impregnation with silanes breaks water continuity into the capillary system, prevents water intrusion and hinders the migration of chlorides or other ions into the concrete (Wittman, 2007). However, silane impregnation does not hinder concrete carbonation, since carbon dioxide - CO_2 can penetrate the open capillaries. The requirements for the carbonation to start the corrosion in steel reinforcement (Ljungkranz et al., 1994) are as follows:

(a) the temperature should exceed 4^o C;
(b) the moisture content in the concrete should be in the range 0.7-1.5%, which corresponds to RH = 50-75% (i.e. ordinary conditions);
(c) the amount of carbon dioxide in the environment should be adequate (this condition is always met).

One should remember that *wet concrete is unaffected by carbonation*, and that impregnated concrete is generally accompanied by internal conditions that favour carbonation. Furthermore, steel reinforcement in concrete corrodes, if the relative humidity exceeds 60%, pH is below 11.8 and adequate oxygen is available. In ordinary concrete, were pH is above 12 and there are few chloride ions, the reinforcement does not corrode.

5. QUESTIONS BEFORE DECIDING WHETHER TO IMPREGNATE

Concrete impregnation aimed to prevent water intrusion brings in a lot of questions that are well-known to end users from a qualitative point of view, but should be answered by the scientific community from a quantitative point of view:

(a) Does the impregnation have different effects - for the same penetration depth of the silanes - if applied to the underside surfaces, side surfaces or top surfaces of any given concrete structure? In the three above cases, gravitation is unfavourable, neutral or favourable with reference to penetration. More specifically, in the case of silnes applied to the top surfaces impregnation prevents the entrapped air from getting out of the concrete pore system. Consequently, the air can hinder the penetration of silanes into the capillaries. However, the same yields for water penetration into the pore system.

(b) Since water inside capillaries is known to have a negative influence on silane intrusion, how should the moisture content in the concrete mass be determined? What method is the best for measuring water content inside the concrete? What is the maximum moisture content, that may still guarantee a successful impregnation? Does it depend on the direction of the intrusion?

(c) Before surface impregnation, may active measures be used in order to reduce moisture content in the concrete? Can drying pistols be used or are there other tools? Since a sudden rain shower during the impregnation process increases concrete moisture and requires specific checks, are there any indications on when to resume work?

(d) How deep should the impregnating layer be? Does wind-carried rain (that creates a water film on vertical concrete surfaces) reduce impregnation effects, because of the wind pressure deforming the film and forcing it into the capillaries? As a matter of fact, gust-induced wind pressure is comparable to that of a water depth of several decimetres. Should

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the impregnating layer be thin, water bridges would form and water transport through these bridges would occur, making a deeper impregnation layer necessary in such cases.

(e) What is the durability of a silane-based impregnated layer covering a concrete surface? Do thicker impregnating layers last longer? After the fading in a number of years (say ten years) of the first emulsion-based silane impregnation, does re-impregnation with updated agents (for instance gel-type silanes) provide the same durability? (Re-impregnation may even last longer).

(f) To what extent any dirt on concrete surface and into the capillaries may be detrimental to the efficacy of silane impregnation? Dirt is usually hydrophilic and can favor water transport into concrete pores. To what extent cleaning concrete surface with pressurized water containing appropriate chemical products can restore the effects of silane impregnation? (Before waxing the body of a car, that is dirt because of pollution, the water-repellent properties of the “sealing” can be guarantied by using a high-pressure water jet containing some specific chemical products).

(g) What is the best way to impregnate a concrete surface? By spraying the emulsion, or by using a brush, or are there other methods to have the best results?

(h) Does the impregnation reduce water diffusion through the impregnated concrete layer and towards the external environment, as some scholars declare? When re-applying the impregnation (after the first impregnation has lost most of its efficacy), does the new impregnation reduce capillary size to such an extent that water diffusion out of the concrete may be markedly impaired?

(i) What should be done when the re-impregnation process fills the external capillaries and water diffusion out of the concrete may be hindered? It is not always possible to remove the old impregnated layers, because in this way the concrete cover around the reinforcing bars may become too thin. As an alternative to concrete removal, could a layer of sprayed concrete be applied on a previously-impregnated concrete surface, in order to allow the new layer to be impregnated at a later stage?

6. CONCLUDING REMARKS

There are still many open questions requiring an answer from the scientific community about whether or to what extent or with what technology a concrete structural member should be impregnated with silanes. What type of silanes should be used? How deep the impregnated layer should be? Answers are instrumental in decision making!

It seems appropriate to limit the impregnation to the surface, without any intrusion, when the surface is not exposed to the combination of rain and high wind-pressure. However, if wind-driven rain is expected, the impregnated layer should be deeper.

Surface orientation has also some relevance in terms of impregnation success. If the surface to be impregnated is vertical or horizontal (belonging to the extrados – top surface - or to the intrados – sub-surface of the given structure), the success of the impregnation process tends to be rather different. Gravity seems to influence the intrusion of the silanes, as well as water penetration, something that should be investigated more thoroughly. The amount of moisture in the pore system is an important factor to be evaluated prior to impregnation. Also the air entrapped by the film of the silanes during the impregnation process along concrete top surfaces should be looked at carefully, since air may endanger any adequate impregnation.

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Other questions: is it possible to renew the impregnating effect by cleaning the surface? How can be measured any in-time changes in the water-repellent silane-induced capability? Is it possible to restore the impregnation effects induced by the silanes without altering the water diffusion from the concrete to the environment? Answering these questions requires further research efforts indeed!

Summing up, science has still (a) to give many answers to end users on a number of properties related to the coupling of concrete and silanes, and (b) to clear the way from the many diverging opinions about the efficiency of concrete silane impregnation, something badly needed for concrete preservation against environmental attacks.

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