Hydrophobe III -
3^{rd} International Conference on Surface Technology with Water Repellent Agents,
Aedificatio Publishers, 287 – 298 (2001)

Protecting Concrete with Cream – Practical Aspects

H. Geich
Wacker-Chemie GmbH, Silicones Division, Burghausen, Germany

Abstract

Silicones have been used very successfully over decades to protect concrete, especially reinforced concrete, against moisture, since water plays a key role in damaging processes such as reinforcement corrosion. Impregnating agents are normally based on silanes and siloxanes. Very often significant amounts of these low viscous fluids are lost due to evaporation of volatile ingredients and running off of excess material, particularly when working over head. To avoid this, Wacker-Chemie GmbH has developed a very new type of water cram. This material ca be applied very easily in only one application step in very high coverage rates without loss of any active ingredients. It penetrates even high grade concrete gigantically and leaves no visible residues on the surface.

1 Introduction

Concrete offers attractive properties, particularly economy, durability and freedom of design, that have made it the most widely used construction material. Concrete is essential for modern industrial and public buildings, roads, tunnels and bridges.

Until a few years ago, concrete was thought to be resistant to all harmful effects. The many examples of damage demonstrate the contrary: concrete is vulnerable. Concrete structures are in peril [1].

Damage to concrete involves water. While water can cause purely physical damage, for example in the case of freeze/thaw stressing, it is also a medium for the transport of aggressive substances, such as chlorides from road salts, and forms a reaction medium for harmful chemical processes, particularly corrosion of the reinforcing steel [2].

The most efficient type of protection for concrete – and this naturally also applies to other construction materials – is thus protection against moisture [3]. In recent years, silicones have emerged as the class of materials most suitable for this purpose [4]. Silicones are pe-eminent among masonry protection agents, thanks mainly to their outstanding water repellency and durability. Practically no other substance is so inert to physical, chemical and microbiological attack. Assuming that the material has been chosen correctly, silicone impregnation can contribute significantly to the long-term preservation of a structure.

The impregnants used for concrete protection usually consist of low-molecular silanes or mixtures of silanes and siloxanes, applied either undiluted, diluted with organic solvents or a as aqueous formulations. All of these preparations take the form of low viscosity liquids. During application, this results in the loss of significant amounts of the active substances as the liquid runs off vertical surfaces. This applies particularly to overhead work. This drawback could be remedied by a new system: impregnation cream.

Before considering the properties and advantages of this new product grade, however, a brief look at the fundamental principles of concrete construction materials, at the concrete damage most commonly found, and at concrete protection shall be taken.

2 Concrete as construction material

2.1 Introduction

Concrete and reinforced concrete have drastically changed the course of building construction in the last few decades. When these materials were developed about 120 years ago, architects, civil engineers and builders were suddenly presented with materials that not only had outstanding mechanical and physical properties, such as compressive strength and tensile strength in bending, but which could be moulded like no other material before. It was possible to build either delicate and intricate structures or massive civil engineering works, such as bridges, towers and skyscrapers. Concrete´s economy and durability made it indispensable.

Concrete and reinforced concrete consist essentially of Portland cement as binder, sand and gravel aggregates as well as, in the case of reinforced concrete, steel reinforcement to improve tensile strength. Water is also required, to harden the concrete and adjust ist consistency for processing. One of the factors critical to the quality of concrete is its water/cement ratio: the ratio of the mass of mixing water to the mass of cement. Too high a water/cement ratio increases the formation of capillary pores in the cement matrix, leading to a loss in strength.

Assuming good workmanship and the correct ratio of ingredients, the resulting construction material has outstanding resistance to weathering and ageing.

2.2 Concrete Damage

Despite its high resistance to the effects mentioned above, serious damage to concrete occurs time and again, threatening the stability of building structures. The main cause of concrete damage is corrosion of the reinforcing steel resulting from environmental effects. While fresh concrete has a high alkalinity that passivates the steel, acidic gases in the atmosphere, particularly carbon dioxide, will over time neutralize the alkalinity of the surface. In the case of carbon dioxide, this process is called carbonation. Eventually, this non-alkaline carbonated zone reaches the reinforcing steel and destroys its passivating protective layer. Atmospheric oxygen and moisture can then begin to rust the steel. Since ferrous metals greatly increase in volume when they rust, the concrete layer above the reinforcement spalls, resulting in serious damage to the concrete. Similar patterns of damage are also caused by salts dissolved in water, particularly chlorides. Irrespective of the alkalinity of the concrete, chloride ions can cause catastrophic corrosion within an extremely short time. Since concrete chiefly absorbs chlorides via deicing salts, roads and bridges are particularly prone to the damage.

2.3 Concrete Protection

Once the fundamental mechanisms of damage were known, researchers could work on achieving extremely durable and economical concrete protection. Investigations have concentrated on two main surface protection processes: water-repellent impregnation and film-forming coatings (Figure 1).

Both processes focus on keeping out moisture, since water plays a key role in the absorption of harmful substances, eg. from deicing salts, as well as in corrosion processes.

In water-repellent impregnation, the pores of the concrete remain open. There is little or no effect on gas and water-vapour diffusion. Film-forming coatings, on

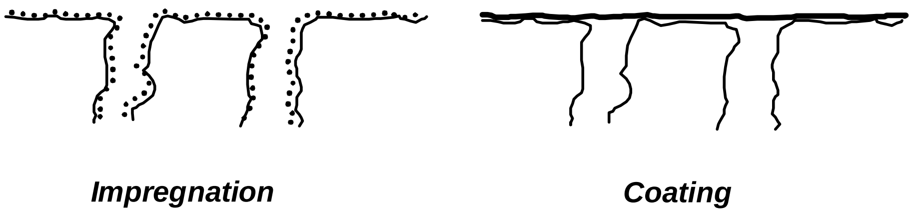

Figure 1: Schematic view of water-repellent and coated capillaries

the other hand, aim at preventing gas diffusion and thereby also the migration of carbon dioxide; the agent of carbonation. The two processes are often combined, ie, water-repellent impregnation is applied as primer for a subsequent coating.

Organosilicon compounds have a proven track record as impregnants. They are characterized by outstanding water-repellency, with no significant impairment of water-vapour permeability. They also show outstanding durability. The latter property results from the fact that silicones are extremely resistant to environmental effects (such as UV radiation, heat, chemically aggressive substances and microbes), and that silicone resin forms a stable, covalent bond with the construction material – concrete – on account of its chemical similarity (Figure 2).

Silicones must have two main properties in particular for concrete impregnation. They must be able to penetrate the relatively dense concrete matrix, and they must not degrade under the highly alkaline conditions in fresh concrete.

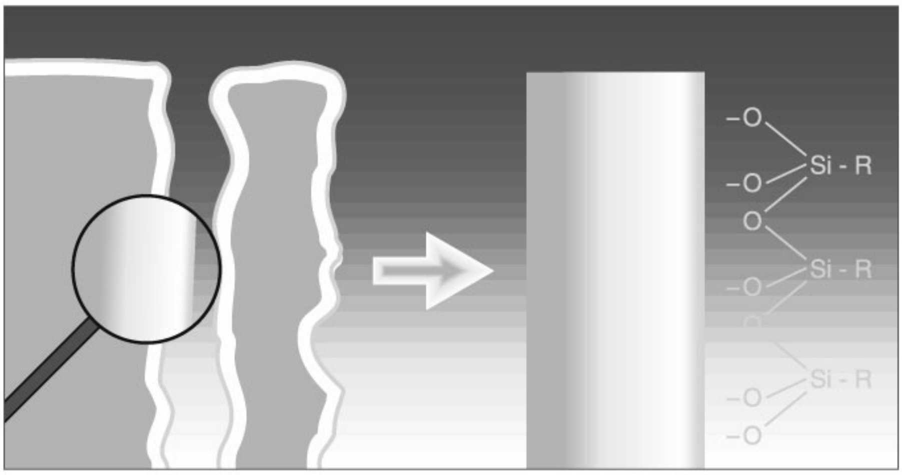

Figure 2: Physiochemical bonding of the silicone-resin network to the pore surface

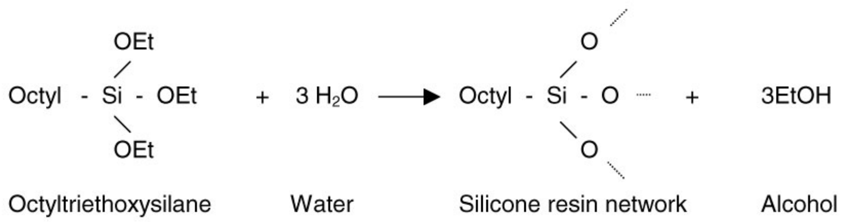

Figure 3: Chemical reaction of silane in concrete

Alkylalkoxysilanes, such as Octyltriethoxysilane, best meet these requirements. They are colourless, highly mobile liquids, which are usually applied undiluted to the concrete by flooding. There they react with moisture, eliminating alcohol, to form a three dimensionally crosslinked silicone resin chemically anchored to the concrete.

Years of experience have clearly demonstrated that silanes are highly efficient and durable concrete waterproofing agents. However, they also have some disadvantages that should be eliminated where possible:

- On very dry concrete surfaces (exposed to sun or wind), the silane lacks the necessary moisture for the crosslinking reaction, and considerable amounts of the active ingredient evaporate to the atmosphere
- On vertical surfaces and particularly overhead surfaces, there is the risk of the material running off before it has penetrated into the concrete
- Several application stages are usually necessary to apply effective amounts and obtain the required depth of penetration.

To prevent evaporation of the active ingredient, there are two alternative countermeasures. Instead of pure long-chain alkylalkoxysilanes, either catalysed mixtures of silanes and oligomeric siloxanes are used, or aqueous products. Both methods have a good track record. To prevent loss of the active ingredient by uncontrolled flowing off of the impregnant, the aggregate state of the product must be changed. Low viscosity liquids must be replaced by thixotropic, non-sag systems. This was the idea that formed the germ for the development of impregnation cream.

3 Impregnation cream

3.1 Characteristics

Impregnation cream is doubtless one of the most revolutionary of recent innovations in the water-repellent treatment of concrete. The outstanding characteristics of this novel system can be summarized as follows:

- High protection against attack by frost/de-icing salt
- Drastic reduction in capillary water absorption
- No impairment of water vapour permeability
- Outstanding penetration
- High content of active ingredient
- Optimum resistance to alkalis
- Low volatility
- Solvent-free, aqueous preparation, therefore environmentally compatible
- Thixotropic consistency, therefore application without loss
- Good adhesion of coatings

3.2 Active Ingredients

The impregnation cream contains essentially Octyltriethoxysilane as active ingredient in an amount of 80 %. The remaining 20 % is predominantly water and minor amounts of auxiliaries, such as emulsifiers. For an aqueous product, an active ingredient content of 80 % is unique. The emulsions used for concrete impregnation usually contain from 20 to 40 % active ingredient. The high content of active ingredient in the impregnation cream guarantees deep penetration, even when comparatively small amounts are applied.

The active ingredient and mechanism of the impregnation cream are the same as for conventional liquid silane impregnants. The silane reacts with water, eliminating alcohol, to form a polymeric silicone resin network, which forms a thin film on the surfaces of pores and capillaries. Its effect on the concrete´s diffusion rate and water-vapour permeability is also no greater than that of liquid silanes.

Unlike conventional silane impregnants, the impregnation cream already contains the required amount of water for the crosslinking reaction. This prevents significant quantities of silane from evaporating when the preparation is applied to dry concrete surfaces.

3.3 Processing

The biggest advantage of the impregnation cream compared to conventional low-viscosity impregnants is that even vertical surfaces and ceilings can be treated without the material trickling or dripping off in an uncontrolled way. This ensures that the entire surface is uniformly impregnated and protected.

The product is preferably sprayed by an airless process onto the concrete. It can also be readily applied by brush, lambskin roller or spatula to small areas.

A single application is usually sufficient. Depending on the absorbency of the substrate, up to 400 g/m^2 can usually be applied in a single operation – even to vertical surfaces and ceilings – with no waste. Only very high quality concrete, which has low absorption, should not be treated with more than about 200 g/m^2 in a single operation. When large amounts are applied, there is an increased risk of the cream layer being fluidized and starting to flow under the effect of the alkalinity of the concrete. A second application of cream may be used if required. However, 200 g/m^2 is usually adequate for high-quality concrete. With liquid products, this rate of impregnant application can usually only be achieved with three or more applications. Impregnation with cream thus saves significant amounts of time and money.

After application, the white cream coat on impregnated surfaces clearly distinguishes them from untreated concrete, giving a good visual indication of the uniformity of application. The thickness of the impregnant layer can be easily controlled.

According to the concrete quality and application rate, the active ingredient penetrates into the concrete within 30 minutes to some hours, and the milky white cream layer disappears completely.Surfaces that have been treated with impregnation cream can subsequently be coated just as easily as those impregnated with conventional liquid impregnants.

3.4 Penetration Depth

The impregnation cream is formulated to provide the greatest penetration depth of the active ingredient into the concrete, and thus provide optimum protection against the absorption of water and harmful substances, as well as against frost/deicing salt.

The tremendous penetration depth is a function of the thixotropic consistency of the product, which ensures a long contact time of the silane active ingredient with the surface. It is also a function of the high concentration of active ingredient.

In addition to the active ingredient concentration, the penetration depth naturally also depends on the quality of the concrete. For different concrete grades (compression strength 15, 25, 35 and 45 MPa) the penetration depth is summarized in Table 1

3.5 Water Repellency and Alkali Resistance

The impregnation cream is tested for water repellency and alkali stability as part of the basic testing of surface protection systems according to Class OS-A of the Additional Technical Rules and Test Guidelines for Protecting and Renovating Concrete Structures (ZTV-SIB, published by the German Ministry of Transport [3]). Mortar slabs (water/cement ratio 0.5) were treated by brushing them all over with approximately 200 g/m^2 of the impregnation cream and aged for 14 days under standard climatic conditions (23 °C/50 % r.h.). After this treatment, the test specimens were immersed for 2 days in a 0.1 molar .KOH solution, dried again

Table 1: Penetration depth depending on application rate and concrete quality

Concrete compression strength	Penetration depth	
	100 g cream / m^2	200 g cream / m^2
15 MPa	6 mm	12 mm
25 MPa	5 mm	10 mm
35 MPa	5 mm	8 mm
45 MPa	3 mm	5 mm

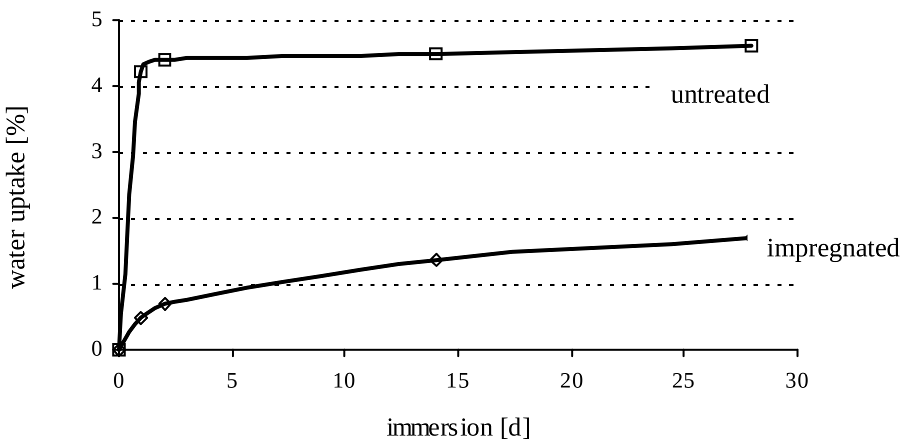

Figure 4: Water absorption of mortar slabs after alkaline exposure

and then immersed in water for 28 days. The water absorption characteristics shown in Figure 4 were obtained [4].

As it can be seen in Figure 4, the impregnation cream reduces water absorption by 64 % on average, and thus more than meets the requirements (water absorption of less than 50 % compared with untreated test specimens).

The penetration depth into the mortar slabs was up to 9.6 mm, a value that has never been achieved with liquid impregnants.

3.6 Weight Loss After Frost/Deicing Salt Loading

This test was also carried out as part of the basic testing of impregnation cream as a surface protection system according to Class OS-A of the Additional Technical Rules and Test Guidelines for Protecting and Renovating Concrete Structures (ZTV-SIB) [3]. Concrete cubes (10 cm edge length, average compressive strength 38.7 N/mm^2, water/cement ratio 0.6) were treated with approx. 200 g/cm^2 impreg-

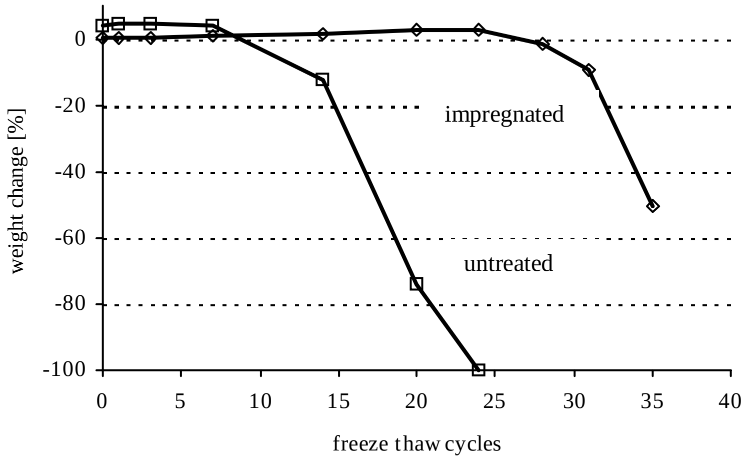

Figure 5: Weight change under frost/deicing salt cycles

nation cream and, after 14 days, immersed in a 3 % NaCl solution. Then the frost/ thaw cycles were started (16 hours –15 °C, 8 hours +20 °C). Figure 4 shows the weight change of untreated and treated test specimens.

As can be seen in the diagram, because of the protective effect of the impregnation cream, the treated samples last 20 cycles longer than the untreated cubes. The requirement is for only 15 cycles more than untreated cubes.

3.7 Test results according to prEN 104

The impregnation cream has also been tested for water repellency and alkali stability according to prEN 104 [7]. Concrete cubes (w/c ratio 0,45 compression strength 53 N/mm²) with a max. aggregate size of 20 mm and 360 kg/m² cement content were treated with 200 g/m² of the impregnation cream and conditioned per prEN 1766. The tests started 14 days after treatment of the cubes. The following results have been achieved.

3.8 Impregnation Cream In Practice

One of the first examples of concrete repair using the new cream technology was the Fürstenland Bridge in St Gallen, Switzerland, built in the thirties. It is made of reinforced concrete that has suffered heavily from carbonation and the effect of road deicing salts.After detailed preliminary tests by the laboratory of testing and material technology (LPM AG, Beinwill am See, Switzerland) [8], it was decided to use cream technology to render the concrete water repellent. This was not only because of the clear advantages for application, but also because cream technology

Table 2: Test results according to prEN 104

Test	Test Procedure	Pass Criteria	Concrete treated with impregn. cream [200g/m^2]
Water absorption test	Immersion in demineralized water for 1 hr (untreated samples) and 1 day (treated samples)	AC < 7,5 %	AC = 3,1 % **PASS**
Resistance to alkali test	Immersion for 21 days in 0,1 M KOH, drying for 30 days and a repeat water absorption test is carried out	AC (alk) < 10 %	AC (alk) = 2,8 % **PASS**
Drying rate test	-	DRC > 30 %	DRC = 48,8 % **PASS**

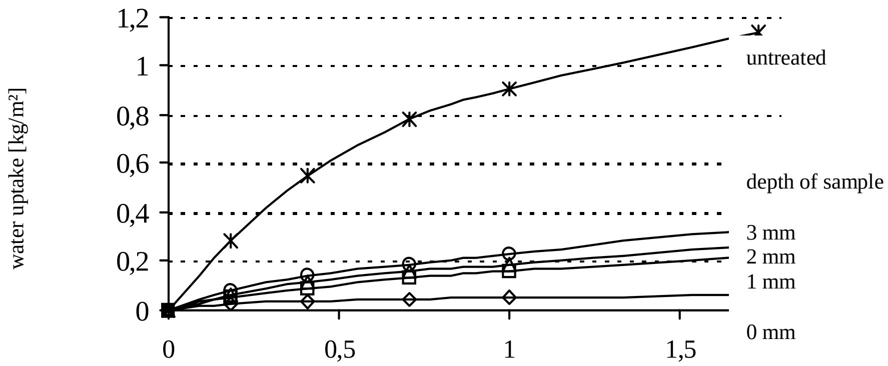

Figure 6: Capillary water absorption of drill cores from the Fürstenland Bridge in St Gallen, taken at different depths

obtains the best results for penetration depth and water repellency compared with liquid impregnants. At an application rate of 200 g/m^2 the active ingredient had penetrated to such a depth that the capillary water absorption was reduced by more than 80 %, even at a depth of 3 mm. Figure 6 shows the depth profile of capillary water ab.

4 Summary and outlook

Many experts are already agreed that cream technology, thanks to its intriguing properties, will change, even revolutionize, concrete technology, over the next few years. The results of extensive independent tests and practical experience demonstrate the outstanding properties of the impregnation cream. Its advantages include:

- High active-ingredient content
- Water-based preparation, and therefore solvent-free
- Outstanding, easily controlled penetration behaviour
- Easily processed by spraying, brushing or rolling
- Time-saving, single-step application
- Loss-free application
- Problem-free “overhead” application

Cream technology is a good example of how, even after decades of successful use of silicone-based masonry protection agents, truly innovative developments can still be made, and indeed are necessary. The Creme-technology will very likely become an essential part of any successful conservation and repair concept. This concept is not only limited to concrete but will be extended to all kinds of mineral substrates.

5 References

1. Weber, H. Reinforced concrete – Its afflictions and how to cure them. Bausubstanz, 1986, No. 1 and 2.
2. Klopfer, H. Bautenschutz und Bausanierung, Vol, 1, No. 3, 1978, pp 86 – 97.
3. Weber, H. and Wenderoth, G. Reinforces concrete – Damages and repair. Expert Publisher, 1987, Sindelfingen.
4. Hager, R. Silicones for concrete protection. Proceedings of the International Conference held at the University of Dundee, Scotland, 1996, pp 361 – 367.
5. ZTV-SIB 90, published by the German Ministry of Transport. Guidlines for protection and repair of concrete surfaces. Verkehrsblatt-Verlag, Dortmund, document no. B 5230, 1990.
6. Test report no. A 3299 from ibac, Aachen. Basic test on a surface protection system of class OS-A according to ZTV-SIB 90, 30th April 1998.
7. Test report no. BRE TCR 63/99 from BRE, Glasgow. Testing of Wacker Chemicals Impregnation products Creme C to pr EN 104, March 1999.
8. LPM report No. 17´160-2 (28.05.97).