Hydrophobe IV
4th International Conference on Water Repellent Treatment of Building Materials
Aedificatio Publishers, 133–144 (2005)

Internal Impregnation of Concrete: Experimental Results and Application Experiences

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Abstract

Internal impregnation of cement based materials is accounted a suitable measure to improve the durability of concrete structures exposed to chlorides. Anyway, yet only few reliable research has been performed and even less application experiences have been gained regarding internally impregnated concrete. Based on laboratory results and practical experiences it is explained in which way a reinforced concrete structure can be protected against chloride impact by an internally impregnated cementitous overlay. In addition to this it is outlined how internally impregnated cementitous materials can be designed and how the internal impregnation influences capillary suction as well as resistance against frost and chlorides. A railway underpass which was severely contaminated by chlorides was refurbished in winter 2001/2002. At this occasion an internally impregnated and fiber reinforced repair concrete was used to replace the deteriorated covercrete. The condition of the concrete structure and its repair measure is described as it is three years after the refurbishment. It is shown in which way the internal impregnation could significantly improve the durability of the concrete structure.

1 Introduction

1.1 Overview

An internal impregnation is made by adding a water repellent agent to the fresh cementitous material. The agent is dispersed homogeneously in the mix. Hence, the capillary suction of water and dissolved harmful substances such as chlorides is remarkably reduced within the whole material. This increases the durability of the concrete and the protection of the steel reinforcement.

Justnes et al. [1] successfully used vegetable oils for internally impregnated mortars. Anyway, in the majority of cases silanes, siloxanes, water repellent calcium stearates and resins are utilized [2, 3]. To assure a good dispersion of silanes and siloxanes aqueous emulsions are used rather than the pure agents [4].

Water repellent agents influence both, fresh and hardened properties of a cementitous material [5, 6, 7]. They slightly plasticize and retard the fresh material [4] and may also entrain some air [8]. Strength and fracture energy are slightly reduced whereas final shrinkage and carbonation resistance are somewhat improved. Nevertheless systematic investigations are yet missing.

1.2 Advantages and disadvantages

Compared to superficial water repellent treatments and coatings internal impregnations feature the following advantages:

- Simplified application procedure
- Reduced risk of application errors
- Less quality control necessary
- Trouble-free regarding adherence and penetration depth
- Independent on weathering and moisture content
- Protection almost independent on external deterioration mechanisms such as UV-radiation, abrasion, dust-sedimentation, cracks and carbonation

Disadvantages:

- Additional chemical additive to be added during concrete production
- Possible influence on other material properties require preliminary testing

1.3 Applications

Generally speaking the application of an internal impregnation is suitable for any structure or part of it that requires additional protection against harmful impacts (e.g.: chlorides, frost, etc.) in order to accomplish the required durability.

The higher the surface volume ratio is the more efficient an internal impregnation is compared to superficial water repellent treatments and coatings. Considering new constructions the following elements are suited for internal impregnations:

- Walls and slabs (e.g. facades, tunnel-claddings, tunnel-walls, partial tunnels)
- Columns (e.g. parking lots, partial tunnels, etc.)
- Concrete roads and pavements (e.g.: parking lots [4], bridge decks, solid railway basements, etc.)
- Protection walls (e.g. New-Jersey-elements, bridge guide walls, etc.)
- Shotcrete
- Precast elements (e.g. tunnel tube segments, pipes, cladding elements for facades, etc.)

Regarding refurbishments the following applications are suited for internal impregnation:

- concrete overlays, covercrete replacement
- repair mortars, sprayed mortars

A promising concept to achieve highly durable concrete structures is the separation of assignments [9]. This concept strictly separates the load bearing and the protective function of a structural member. The load bearing function is taken by reinforced concrete whose main property is strength and stiffness. This concrete is covered by a protective overlay which features specific qualities regarding its durability rather than mechanical strength. A very low value of capillary suction and a high resistance against frost and chlorides are the most important properties. The following chapters outline that an internal impregnation is the ideal technology to achieve this performance.

1.4 Overview of investigations

The experimental investigations presented herein were performed at three different levels:

1. Laboratory measurements on an internally impregnated standard concrete

2. Investigations on an internally impregnated repair mortar in a big scale test facility (tunnel model)
3. Investigations on an internally impregnated self compacting repair concrete applied on a real concrete structure (railway underpass in Staefa, Switzerland)

2 Experimental investigations

2.1 Internally impregnated standard concrete

A 50 % alcyltrialkoxysilane-emulsion was added to a standard concrete with a water cement ratio of 0.5 and a cement content of 350 kg/m^3. Five different dosages of the water repellent agent were used: 0 % (reference), 0.1 %, 0.5 %, 1.0 % and 2.5 % by cement weight. The following measurements were performed at an age of 28 days:

- Capillary suction (A-value) on drilled cores (according to [10])
  Three cores each are dried at 50 °C for 48 hours and their superficies surfaces are sealed. The face surfaces of the cores are then immersed into a water quench with a depth of 5 mm for one hour. The capillary suction is measured on the face surface and in a depth of 10 mm.
- Resistance against chloride penetration (according to [10])
  Three cores each are dried at 50 °C for 48 hours and their superficies surfaces are sealed. The face surfaces of the cores are then immersed into an aqueous 3 % sodium chloride solution for three times. Each Immersion lasts for 24 hours. After each immersion the cores are dried at 50 °C for 24 hours and the chloride content is determined at different distances from the exposed face surfaces.

2.2 Investigations on an internally impregnated repair mortar

In a big scale test facility [11] certain areas of a tunnel wall were exposed to cyclic impacts of an aqueous 3 % sodium chloride solution (twelve hours per week).

Among other protective coatings an internally impregnated repair mortar was investigated. The capillary suction and the chloride content of the 20 mm mortar layer and the substrate concrete have been determined. The water cement ratio and the cement content of the mortar are 0.43 and 450 kg/m^3 respectively. 1.0 % by cement weight of an aqueous 50 % alcyltrialkoxysilane-emulsion was used for internal impregnation.

2.3 Investigations on an internally impregnated SCC

A railway underpass which was severely contaminated by chlorides was refurbished in winter 2001/2002 (Staefa, Switzerland, see figure 1). The deteriorated covercrete was removed down to the first layer of reinforcement. A fiber reinforced self compacting concrete was used to replace the removed covercrete [12, 13].

This concrete was internally impregnated by 1.0 % by cement weight of an aqueous 50 % alcyltrialkoxysilane-emulsion. The depth of carbonation and the chloride content at three different distances from the exposed surface has been measured at an age of three years. The capillary suction and the resistance against combined impact of frost and deicing salts have been determined at an age of 28 days and three years respectively. For the measurement of the resistance against combined impact of frost and deicing salts (according to [14]), the cores each are stored under water for seven days before they are exposed to 28 freezing-thawing-cycles. One cycle consists of two times six hours at +15 °C and -15 °C respectively. The observed face surfaces of the cores are covered with an aqueous 3 % sodium chloride solution during the test. After 28 cycles the mass of spalled material (m_{28}) is determined. The results are rated according to [14]:

m_{28} < 600 g/m^2:	high resistance
600 g/m^2 < m_{28} < 3800 g/m^2:	medium resistance
m_{28} > 3800 g/m^2:	low resistance

Figure 1: Railway underpass in Staefa (Switzerland)

Table 1: Internally impregnated standard concrete (mean values)

property/parameters	unit	value				
age	days	28	28	28	28	28
content of silane-emulsion	by cement weight	0.0% = ref.	0.1%	0.5%	1.0 %	2.5%
capillary suction (A-value) on the surface	kg/($m^2 \cdot h^{0.5}$)	0.48 100%	0.32 67%	0.26 54%	0.26 54%	0.07 15%
capillary suction (A-value) in a depth of 10 mm	kg/($m^2 \cdot h^{0.5}$)	0.44 100%	0.32 73%	0.19 43%	0.15 34%	0.07 16%
chloride content in a depth of 0 - 2 mm	$mg_{Cl}/g_{concrete}$ % of ref.	3.04 100%	2.38 79%	1.47 48%	0.93 31%	0.55 18%
chloride content in a depth of 5 - 6 mm	$mg_{Cl}/g_{concrete}$ % of ref.	0.65 100%	0.53 81%	0.38 59%	0.17 27%	0.06 10%
chloride content in a depth of 10 - 11 mm	$mg_{Cl}/g_{concrete}$ % of ref.	0.19 100%	0.11 56%	0.07 35%	0.06 32%	0.03 18%

Table 2: Internally impregnated mortar (mean values)

property / parameter	unit	value
age	years	3
content of silane-emulsion	rel. to cem.-weight	0.50 %
capillary suction (A-value) on the surface	kg/($m^2 \cdot h^{0.5}$)	0.09
chloride content in a depth of 0 - 2 mm	$mg_{Cl}/g_{concrete}$	1.32
chloride content in a depth of 5 - 6 mm	$mg_{Cl}/g_{concrete}$	0.51
chloride content in a depth of 10 - 11 mm	$mg_{Cl}/g_{concrete}$	0.08

3 Results and discussion

3.1 Internally impregnated standard concrete

The results show that increasing contents of silanes improve the durability of a standard concrete. The maximum dosage of 2.5 % by cement weight reduces the capillary suction by 85 % down to 0.07 kg/($m^2 \cdot h^{0.5}$). The same is true for the chloride content which was reduced by 82 to 90 % (table 1).

But even lower dosages show some improvements. A silane content of 0.5 % by cement weight for example reduces both the capillary suction and the chloride content by 50 %.

3.2 Investigations on an internally impregnated repair mortar

The effect of a weekly chloride impact is very strong. High amounts of chlorides are penetrating deeply into the unprotected concrete. The penetration depth exceeds 35 mm (figure 2). The outer layer of reinforcement is usually located at a depth of 25 to 40 mm. Hence, corrosion would be very likely.

In contrast to this the chloride penetration depth in case of the internally impregnated mortar overlay is only about 6 mm (figure 3). Its capillary suction is only 0.09 kg/($m^2 \cdot h^{0.5}$) (table 2), which is quite low compared to the substrate concrete (0.55 kg/($m^2 \cdot h^{0.5}$)) and a similar mortar without internal impregnation (0.30 kg/($m^2 \cdot h^{0.5}$)). Nevertheless the capillary suction is not entirely prevented. This would require values below 0.05 kg/($m^2 \cdot h^{0.5}$) according to experiences.

The overlay mortar showed two types of damages: Shrinkage cracks and partial debonding near the edges. These mechanisms are typical for overlay applications. By this the chlorides were penetrating through the cracks and into the interface between the mortar and the substrate concrete. As a consequence the concrete beneath the mortar shows very high chloride contents (figure 2). The protective effect of the overlay mortar got lost locally.

It becomes obvious that hygrally and thermally induced crack formation must be prevented. This has to be taken into account within the development of repair and overlay mortars. Martinola [9] and Bäuml [15] suggest different approaches and measures to control crack formation in cement based overlays and concretes.

3.3 Investigations on an internally impregnated SCC

Different from the mortar mentioned above the self compacting repair concrete in Staefa remained crack free. Among others a high performance fiber reinforcement and shrinkage reducing measures were realized successfully.

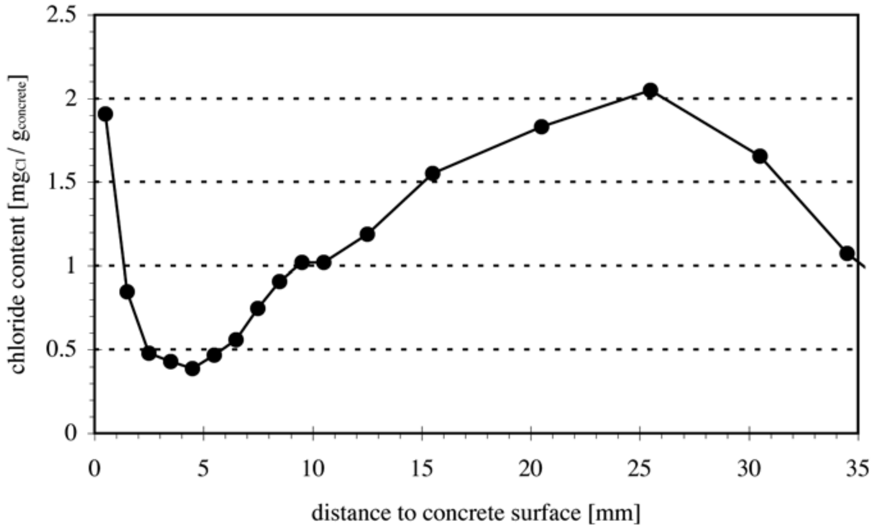

Figure 2: Chloride profile of unprotected concrete

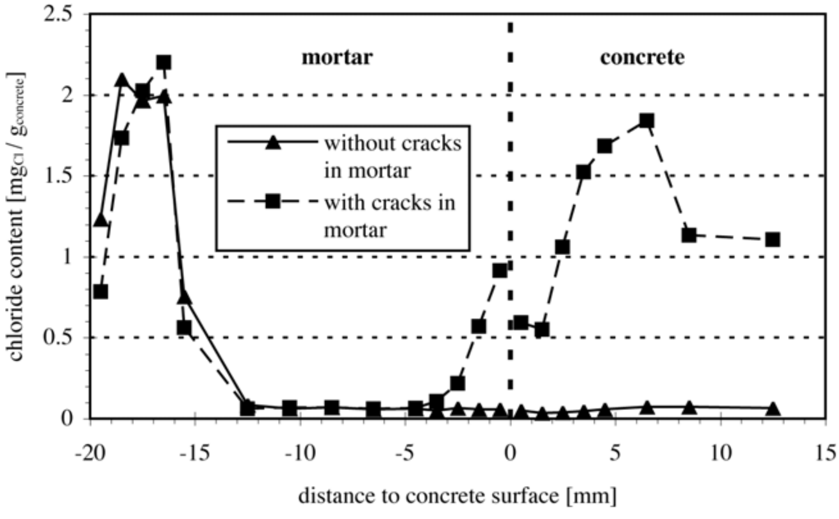

Figure 3: Chloride profile of coated concrete and overlay mortar (coating)

Table 3: Internally impregnated self compacting concrete (mean values)

property / parameter	unit	value	
age		28 days	3 years
content of silane-emulsion	rel. to cem.-weight	0.50%	
capillary suction (A-value) on the surface	$kg/(m^2 \cdot h^{0.5})$	0.04	0.26
capillary suction (A-value) in a depth of 10 mm	$kg/(m^2 \cdot h^{0.5})$	0.04	0.04
spalling due to freezing-thawing cycles m^{28}	g/m^2	4‘900 „low“	556 „high“
chloride content in a depth of 0 - 2 mm	$mg_{Cl}/g_{concrete}$	-	0.07
chloride content in a depth of 5 - 6 mm	$mg_{Cl}/g_{concrete}$	-	0.05
chloride content in a depth of 10 - 11 mm	$mg_{Cl}/g_{concrete}$	-	0.05

The capillary suction of the internally impregnated SCC is 0.04 $kg/(m^2 \cdot h^{0.5})$. By this low value any capillary transport mechanism is almost entirely prevented. The chloride contents measured three years after the repaired structure had been commissioned prove the outstanding protective effect of the concrete (table 3).

The capillary suction on the surface after three years is distinctly higher compared to the value at an age of 28 days. This may have the following reasons:

- carbonation (measured depth of carbonation: 5 to 7 mm)
- dust-sedimentation in capillary pores

Further investigations are necessary to explain this phenomenon. The resistance against combined impact of frost and deicing salts was low at an age of 28 days. Three years later the resistance is distinctly improved and is rated „high“. The area of the concrete close to the surface could easily dry due to its internal impregnation. During frost resistance testing after three years the cores did only take up very small amounts of chloride solution. Hence, the spalling due to the freezing-thawing cycles is very low.

3.4 Durability rating of the underpass in Staefa

The repair measure at the underpass in Staefa lead to a very high durability of the concrete structure. The application of the internally impregnated repair concrete provides a protective layer with a thickness of 70 mm. This layer is crack free and prevents the penetration of harmful substances such as chlorides. Even combined impacts of frost and deicing salts are held of effectively by the highly resistant concrete.

4 Conclusions

- Alcyltrialkoxysilane-emulsions are suited for internal impregnations and do neither lose their performance under real conditions nor under much more severe experimental conditions during a period of three years.
- The effectiveness of an internal impregnation based on alkcyltrialkoxy-silane-emulsions depends linearly on the dosage of the active agent. The necessary content should be defined depending on the material and its intended performance and application.
- An internal impregnation reduces the capillary suction by up to 85 %. This is similar to the effect of a high performance superficial water repellent treatment.
- An internal impregnation improves the resistance against chloride penetration. Hence, this technology is capable to protect the reinforcement from corrosion reliably and in the long run.
- An internal impregnation increases the resistance against the combined impact of frost and deicing salts. The development of this resistance takes a certain period of time as the concrete needs to dry. Instant frost resistance requires additional measures such as entrained air or hollow micro-spheres.
- The concept of the separation of assignments utilizing an internally impregnated protective layer is a promising approach. Nevertheless the necessary performance can only be achieved when crack formation and delamination of the overlay mortar is prevented successfully.

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