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Laboratory Test Assessment of the Effectiveness of Treatments Applied on Brick-Wall Masonry: the Case of Torre Alberaria in Venice

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Abstract

In the framework of the European Project ASSET EVK4-2000-00572 “Assessment of suitable products for the conservative treatments of sea-salt decay” some laboratory tests were carried out in order to evaluate the effectiveness of some products intended to be used as water repellent and consolidant for brick-masonry located in a coastal environment and damaged by sea salt crystallization due to different salt-sources. This paper reports the results obtained for some traditional treatments and new generation products applied on brick samples, by the measurements of the bricks physical properties changes. Laboratory test were performed on untreated, treated and salt contaminated samples to verify the products behavior in different situations and mainly when salts are present in the substrate.

Keywords: sea salts, water repellent, laboratory test, salt crystallization

1 Introduction

In coastal environment building masonries are strongly decayed due to several salt sources: sea-flooding, rising damp from groundwater and marine spray. The aim of the project was to develop a conservation treatment with suitable products able to minimize both the decay processes ascribed to marine salts and to prevent additional factors responsible for the enhancement of deterioration processes.

It is therefore of primary importance to evaluate the behaviour of the traditional solvent and/or aqueous-based siloxane compounds with that one of creamy impregnating system. Traditional products are generally applied as liquids and for practical application two steps are required to reach the required amount of active substance inside the substrate. Generally with liquid impregnants a major concern is to know the quantity of the material which has finally been applied especially for vertical exposed surfaces. To overcome this situation a creamy impregnating system can be applied with the advantage that, contrarily to the conventional low viscosity impregnants, they can be applied even on vertical surfaces or ceilings without the materials trickling or dripping off in an uncontrolled way. While the contact time of common liquid products is in the range of 10-20 seconds this can be extended with creams to a range of 30 minutes and more. The reaction is the same as normally known for liquid or micro-emulsion solutions and silanoles can either polymerize and/or react on the capillaries' walls forming a water-repellent silicon-resin network. A creamy product can be applied by brush, lambskin roller or spatula to small areas, but generally it is preferable sprayed by an airless process onto the substrate. Depending on the absorbency of the substrate, usually 200 g/m^2 are adequate, applied in a single operation with no waste. After it has penetrated, the milky white cream layer disappears completely. The thixotropic consistency of the product ensures a long contact time of the silane/siloxane active ingredients with the surface thus improving penetration depth. Of course penetration depth depends on the absorption properties of the mineral substrate as well as the concentration of the active ingredient. Silane/siloxane creamy products have the same performance of the most common impregnating agents at least by only a one step application.

The present paper was developed in the framework of the EU project ASSET EVK4-2000-00572 "Assessment of suitable products for the conservative treatments of sea-salt decay".

2 Experimental part

According to results obtained from a screening on the performance of traditional and creamy products, some water repellents and a consolidant have been selected to be tested on brick samples. In order to take into consideration the different sources of moisture and salts, that can affect building materials, the experimental research was carried out evaluating the effect of water repellent treatment on uncontaminated and contaminated with sodium chloride brick samples respectively.

The effectiveness to prevent capillary water absorption and to minimize the water vapour permeability reduction as well as the colour changes were assessed.

2.1 Selection of substrates and treatments

Torre Alberaria, located at the Venice's Arsenale, was one of the building selected for the study because it is representative of building materials exposed to marine environment in Venetian coastal areas. It is affected by different prevailing mechanisms according to the different part of the wall-brick masonry considered. In the lower part rising groundwater and occasionally high tide were prevailing phenomena, on the contrary in the upper part marine aerosols deposition and strong ventilation are taking place more frequently with respect to the lower part. Decay phenomena are still in progress and give rise to partial disintegrations of the bricks such as spalling, crumbling and powdering [1] in the area of salt crystallization. On the basis of the macroscopic features (structures and colour) and microscopic observations of thin sections, four types of bricks were identified on the masonry of the building [2].

In order to obtain suitable samples for laboratory measurements, one brick of each type (table 1) was collected at different heights from the Northern side of the building. Bricks were successively immersed in tap-water for one week, to eliminate the salt content, and each of them was then cut into specimens of 5x5x1 and 5x5x2 cm in size. Some of these samples were contaminated with a 10% NaCl solution in order to simulate the real condition of the substrate. All samples were then stored at 20°C and 50% RH. The selected chemical products to be tested are silicon-based organic compounds that, according to their physical and chemical properties, can be used for different purposes in the treatment of materials. Details on these treatments are given in table 2. Rhoximat HD RC 80 was dilute 1:1 in white spirit. Each product was applied by capillary absorption by soaking the sample surface to be treated for 30 minutes. The same laboratory tests were repeated four weeks after treatments.

Table 1: Different bricks grouped according to texture-structure and colour

Structure	color	Grains	grain size (µm)	firing phases	firing T (°C)
isotropic porphiric	brownish-red (blackish in the external parts)	quartz, plagioclase feldspars, volcanic rocks, chert, chamotte	40-125	hematite, anorthite Ca-piroxene	> 900
	brownish	quartz, plagioclase, chert, feldspars, volcanic rocks, chamotte, limestones	50-100	hematite Ca-piroxene	800-850
isotropic aphanitic	reddish-yellow	quartz, limestones, chert, feldspars, plagioclase, chamotte, dolostones	150-250	-	~ 750
	reddish-yellow	quartz, plagioclase, feldspars, limestones, dolostones, chamotte	80-100	-	
	pink	quartz, plagioclase, feldspars, limestones, dolostones, volcanic rocks, chamotte	~ 100	hematite	
anisotropic aphanitic	pink with pale yellow bands	quartz, plagioclase, volcanic rocks, feldspars, chert, chamotte	50-250	hematite, Ca-piroxene, gehelenite	850-900
anisotropic porphiric	pale yellow	quartz, limestones, chert, dolostones, plagioclase, feldspars, volcanic rocks, chamotte	150-300	Ca-piroxene	800-850
	brownish red-light brown	quartz, plagioclase, feldspars, limestones, dolostones	~100	hematite Ca-piroxene	

Table 2: Chemical products applied on brick samples

commercial name	water repellent	Composition
Funcosil IC	Cream	Alkyl alkoxy silane+siloxane in water emulsion
Funcosil SNL	liquid solvent based	Alkyl polysiloxane in aliphatic hydrocarbon solvent
Wacker VP 5035	liquid solvent based (consolidant)	Alkyl alkoxy silane in organic solvent
Rhoximat HD RC 80	liquid solvent based	Ethyl-silicate+poly-methyl-siloxane in organic solvent
Dynasylan BSM 40 SKI	liquid solvent based	Monomolecular alkyl alkoxy silane in anhydrous alcohol solvent

3 Results and discussion

In order to verify the effectiveness of the chemical products the four types of bricks selected in the brick-wall masonry on the Northern façade were subjected to the following measurements before and after the treatment:

- determination of water absorption by capillarity (EN 15801) [3],
- determination of water vapor permeability (EN 15803) [4],
- colour measurement on surfaces (EN 15886) [5],
- determination of drying properties (WI 346022) [6].

Colour changes were determined by a Chroma meter (Minolta CR 200) and expressed in the CIE-Lab system.

3.1 Treatment evaluation on uncontaminated samples

The shape of the curves obtained by water capillary absorption measurements show the same behaviour, but the water absorption coefficient (AC) calculated showed different values probably according to the porosity:

- type 1, isotropic-porphiric structure, AC=1.39; ($Kg /m^2 \bullet s^{-½}$)
- type 2, isotropic-aphanitic structure, AC=1.18; ($Kg /m^2 \bullet s^{-½}$)
- type 3, anisotropic-porphiric structure, AC=0.79; ($Kg /m^2 \bullet s^{-½}$)
- type 4, anisotropic-porphiric structure, AC=1.38 ($Kg /m^2 \bullet s^{-½}$)
- The AC values were obtained by the following equation

$AC = (Q_{30}-Q_0)/t_{30}^{½}$ ($Kg /m^2 \bullet s^{-½}$)

Q30 amount of water absorbed after 30 minutes

Q0 amount of water absorbed at time zero

After treatment curves show a strong decrease of water absorption for liquid products: VP 5035, SNL and BSM 40 SKI, RC 80, while IC do not show a relevant decrease (Figure 1). The assessment of the effectiveness of the treatment regarding water absorption can be obtained by considering the Protection Degree, PD_C %, which is the percentage ratio between the difference of the water amount absorbed by the sample before (Q_{bt}) and after treatment (Q_{at}) and the amount of water absorbed at before (Q_{bt}):

$$PD_C\ (\%) = \frac{Q_{bt}-Q_{at}}{Q_{bt}} \bullet 100$$

Data obtained show that PD_C % (Figure 2) is above to 90% at least up to 24 hours of absorption time for VP 5035, BSM 40 SKI, RC 80 and SNL, while for Funcosil IC the value is sudden decreasing to 60% after 4 hours and it is stabilizing at 35% after 24 hours.

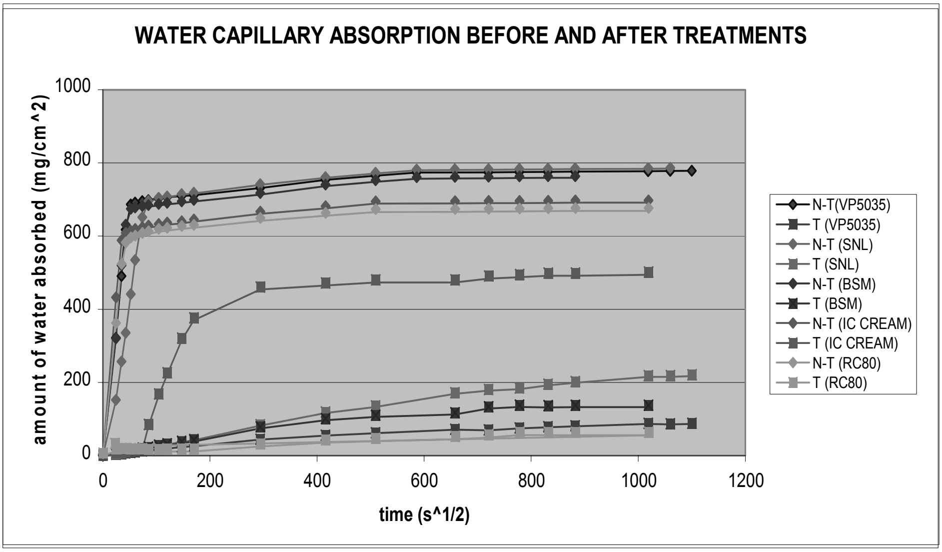

Figure 1: Water capillary absorption before (♦) and after (■) treatments. NT=not treated; T=treated. VP5035=Wacker VP5035; SNL=Funcosil SNL; BSM=Dynasylan BSM 40 SKI; IC Cream=Funcosil IC; RC80=Rhoximat HD RC 80

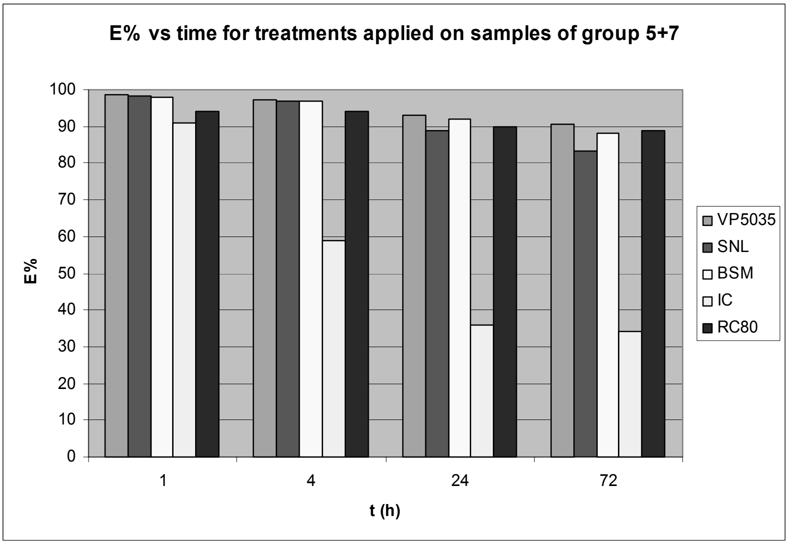

Figure 2: PD_C % vs. time for treated samples. VP5035=Wacker VP5035; SNL=Funcosil SNL; BSM=Dynasylan BSM 40 SKI; IC Cream=Funcosil IC; RC80=Rhoximat HD RC 80

As regards drying behaviour, treated samples absorb a lower quantity of water and they maintain high amount of water after drying (Figure 3). Funcosil SNL, Funcosil IC, Rhoximat HD RC 80 and Dynasylan BSM 40 SKI show the best behavior because they allow almost the entire evaporation of the water absorbed (residual water content 1-2%). Wacker VP 5035 do not give satisfying results (residual water content 5%).

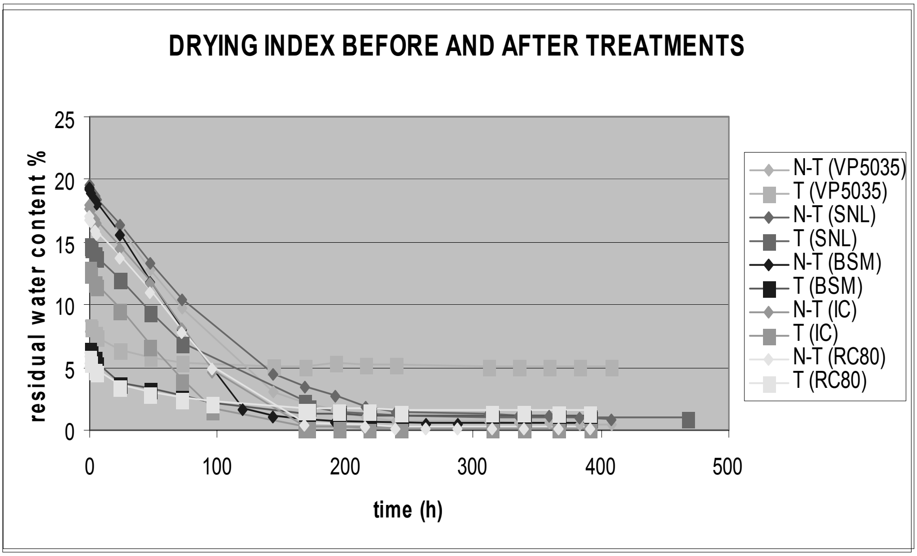

Figure 3: Drying behaviour before and after treatments. VP5035=Wacker VP5035; SNL=Funcosil SNL; BSM=Dynasylan BSM 40 SKI; IC Cream=Funcosil IC; RC80=Rhoximat HD RC 80

The test of water vapour permeability was carried out only on Funcosil IC cream and Dynasylan BSM 40 SKI on uncontaminated samples.

The reduction of water vapour permeability (WV_{Red} %) is obtained by the water vapour flux comparison of untreated (Φ_{nt}) and treated (Φ_t) sample. Low values of WV_{Red} % indicate that the applied product gives a minimum interference to water vapour flux.

$$WV_{Red}\ \% = (\Phi_{nt}-\Phi_t)/\Phi_{nt} \cdot 100$$

Analytical results show that the WV_{Red} is less than 20% for the three types of bricks treated with Funcosil IC (Figure 4), while the WV_{Red} is between 15% and 40% for the four types of bricks treated with BSM40SKI.

Only for the bricks of group 1 the reduction of WV_{Red} is comparable for the Funcosil IC and the Dynasylan BSM40SKI. Generally the application of BSM40SKI causes a greater decrease of the water vapour flow than the application of Funcosil IC.

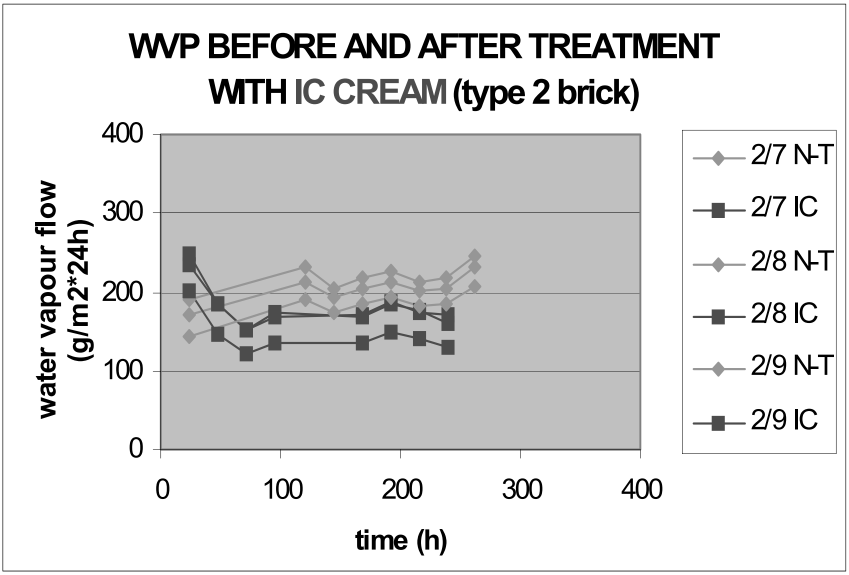

Figure 4: Water vapour permeability before (♦) and after treatment (■) for Funcosil IC cream applied on brick type 2

On treated and uncontaminated samples colorimetric measurements were carried out. Results are expressed in the CIE-Lab system as ΔE:

$$\Delta E = [(\Delta L^*)^2+(\Delta a^*)^2+(\Delta b^*)^2]^{½}$$

where: L* = color brightness;

a* = color value in the red-green axis;

b* = color value in the yellow-blue axis.

Data obtained (Figure 5) show that the colour change of samples is very low for Funcosil IC Cream, Funcosil SNL, BSM40SKI and RC80 (ΔE=4.2-4.8). The only exception is represented by VP5035 which application give rise to a colour variation mainly related to a lightness decrease of the surfaces (ΔE=8).

Table 3: ∆E values after treatments for different chemical products

Product	∆E
Funcosil IC	4.4
Funcosil SNL	4.2
Dynasylan BSM40SKI	4.3
Wacker VP5035	8
Rhoximat HD RC80	4.8

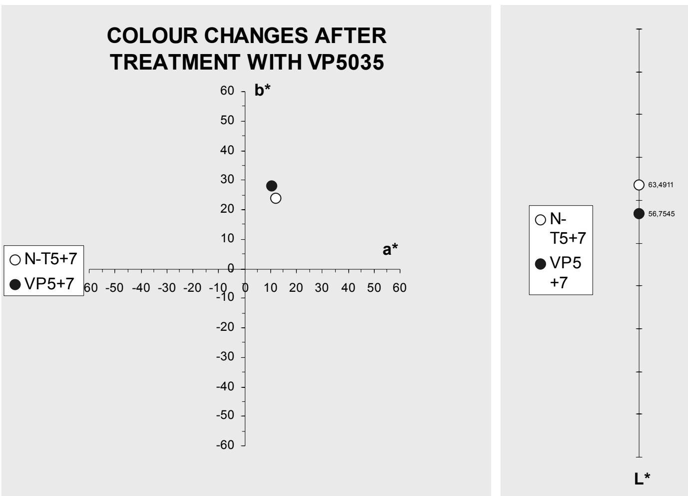

Figure 5: Colour change of VP 5035 treatment

3.2 Treatment evaluation in presence of sea-salts

For contaminated and treated samples, the capillary protection degree (PD_C) is slightly lower than the treated ones (Figure 6). Even if the PD_C % increase with salt-contamination, IC on contaminated and treated samples shows a not satisfying value, less than 70%.

The PD_C value is generally affected by the contamination, except for the BSM40SKI, which show a good PD_C value also in presence of salt-contamination.

As for drying behaviour, samples contaminated and treated with VP5035 and RC80 at the end of the test showed a greater water content than the untreated and the treated ones. Samples contaminated and treated with BSM40SKI, SNL, IC at the end of the test show almost the same water-content than the untreated and the treated ones. So finally it is possible to remark that salt-contamination is irrelevant for samples treated with BSM40SKI, IC and SNL, while it is quite negative for samples treated with VP5035 and RC80.

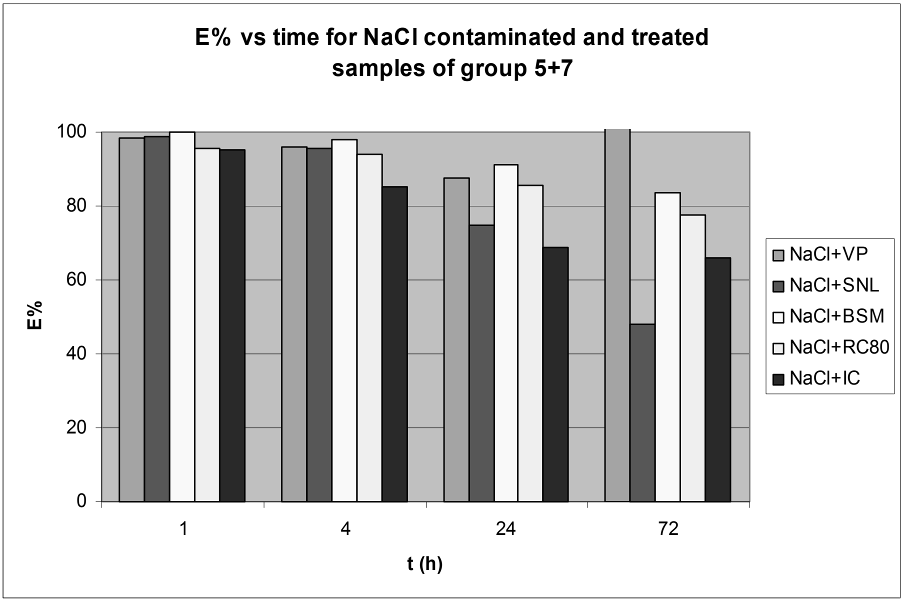

Figure 6: PD_C % vs. time for contaminated-treated samples. VP=Wacker VP5035; SNL=Funcosil SNL; BSM=Dynasylan BSM 40 SKI; IC Cream=Funcosil IC; RC80=Rhoximat HD RC 80

4 Conclusions

The behaviour of different water repellents applied on bricks samples, collected from the North side of Torre Alberaria in Venice, was evaluated by means of laboratory tests. The influence of uncontaminated and salt-contaminated (NaCl) substrate was also investigated on brick samples.

More precisely their capabilities to prevent liquid water transport and to minimize the water-vapour permeability reduction were studied. Measurements of the drying properties (drying behaviour) and of the colour changes after treatments were also performed.

Results of water capillary absorption tests show that capillary protection degree (PD_C %) values are good and decreasing (from 90% to 80%) for Wacker VP5035, Dynasylan BSM40 SKI, Rhoximat HD RC80 and Funcosil SNL, while Funcosil IC shows very low values.

As for contaminated and treated samples, generally the capillary protection degree (PD_C %) is slightly lower than the treated ones. The only exception is represented by Dynasylan BSM40 SKI which shows a good behaviour also in the presence of salts. Even if the PD_C % value for Funcosil IC increases with salt-contamination on contaminated and treated samples it shows a not satisfying value, less than 70%.

As for drying behaviour, treated samples absorb lower amount of water and they maintain a higher water quantity after drying. Salt-contamination is irrelevant for samples treated with Dynasylan BSM40 SKI, Funcosil IC and Funcosil SNL, while it is quite negative for samples treated with Wacker VP5035 and Rhoximat HD RC80.

Analytical results of the water vapour permeability tests show that the reduction of water vapour permeability (WV_{Red} %) is less than 20% for samples uncontaminated and treated with Funcosil IC, while it is between 15% and 40% for samples uncontaminated and treated with Dynasylan BSM40 SKI. Only in one case (bricks of group 1) the two products have been comparable behaviour, but generally BSM40 SKI causes a greater decrease of the water vapour flow than the Funcosil IC.

Finally it is possible to underline that:

- Funcosil IC cream (poly-methyl siloxane) has insufficient water-repellent properties (PD_C %= 20, PD_C $\%_{NaCl}$= 40); it allows the release of water vapour after water imbibition and it does not give rise to evident colour change;
- Funcosil SNL (solution of alkyl siloxane in decane as solvent) is a good water-repellent (PD_C %= 81, PD_C $\%_{NaCl}$= 61) and it allows the release of water vapour after water imbibition; any colour change is visible;
- Wacker VP5035 (solution of alkyl-alkoxy silane in isopropyl alcool) is a good water-repellent (PD_C %=90, PD_C $\%_{NaCl}$= 71); it does not allow the complete release of water vapour (residual water content 5%) and it causes a relevant colour change (ΔE=8);
- Dynasylan BSM40SKI (solution of alkyl-alkoxy silane in isopropyl alcool) is a good water-repellent (PD_C %= 86, PD_C $\%_{NaCl}$= 82); it allows the release of water vapour after water imbibition. Any colour change is visible;
- Rhoximat HD RC80 (solution of tetra-ethoxy-silane and poly-methyl siloxane in decane solvent) is a good water-repellent (PD_C %= 89, PD_C $\%_{NaCl}$= 77); it does not allow the release of water vapour after water imbibition and it does not give rise to any colour change.

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