Hydrophobe V
5th International Conference on Water Repellent Treatment of Building Materials
Aedificatio Publishers, 155-168 (2008)

Water Repellent Treatment of Porous Materials. A New Edition of the WTA Leaflet

E. Wendler[1] and E. von Plehwe-Leisen[2]
[1]Munich Conservation Laboratories, Munich, Germany
[2]Laboratory for Stone Conservation, Cologne, Germany

Abstract

The application of silicon based water repellents on stone and brick during the past decades often was of limited success. Insufficient knowledge of material properties, weathering state and product properties frequently lead to wrong applications, partly followed by subsequent damage. Moreover, the durability of the treatment is restricted to only ten to fifteen years in most cases. The new edition of the WTA leaflet which will be ready in 2008 enables the user to decide if a hydrophobising measure is really necessary, a useful completion of a restoration intervention or eventually even harmful. In cases of proved necessity, guide values for intrusion depth, application time and consumption rates can be easily determined by a nomogram assuming that the porosity and capillary water uptake coefficient of the building materials are known.

Keywords: stone, brick, water repellents, application, efficiency, durability

1 Introduction

The impregnation of stone and brick facades with water repellents based on silicone resins or precursors thereof has been a common practice for almost 40 years. The basic consideration was to slow down the weathering process by keeping out of the building material rain water and any acidic compounds dissolved in it. Additionally, it was expected that soiling should be reduced by such a treatment. Only a few years after the first applications it became clear that the cause and effect relation “preservation of historical monuments = shelter from (acidic) rain water” is an inadequate simplification since there are other deterioration factors involved in this process. Furthermore, subsequent damage has been observed in many cases that may have resulted from misapplied or ineffective treatments.

By systematic research projects addressing the effectiveness and durability of water repellent treatments and by evaluation of a great number of case studies, the state of knowledge could be remarkably improved over the past two decades. Thus, the time was right to replace the 20 year-old leaflet “Hydrophobic Treatment of Building Facades” [1] by an improved version. This is being completely revised and edited by an ad-hoc working group of specialists. The document provides decision criteria to help the owners of the building in question to understand the need for a treatment and the possible risks involved with it. The leaflet will be finished in 2008.

2 Functional principles and products

Since the early 1950s water repellents based on silicon compounds have been in use for the treatment of porous building materials. The common final product in all cases is a silicone resin that covers the pore walls. The adhesion of water to this film is almost zero, thus water is not sucked into the stone and tends to stay outside in discrete drops, because of the predominating cohesion forces between the water molecules (Fig.1), and will run down vertical walls. The water transport into the stone is normally still inhibited even if the beading effect on the surface is decreased by weathering. Mostly a transport of water vapour remains possible after the treatment.

Figure 1: Water drop on a stone treated with a water repellent agent. (Photo: H. Leisen).

Highly crosslinked silicone polymers in organic solvents, as used some 15 to 20 years ago, have no significance to date, as they show poor penetration because of their relative high viscosity. On the other hand, alkylsilanes developed for concrete do not perform well on stone, as their chemical reactivity is low at a neutral pH and their volatility is rather high.

Currently mixtures of alkylsilanes and oligomeric siloxanes are in use, either as solutions in organic solvents, as aqueous emulsions or microemulsions, or as creams, as shown in Table 1. To achieve an optimal result, the advantages of each of these systems need to be considered with reference to the material to which it is to be applied, its state of weathering, the main deterioration problem and in the context of the specific conditions of the building.

Table 1: Advantages and disadvantages of available systems based on silicone compounds.

System	Solution	Microemulsion concentrates	Aqueous emulsions	Creams
Advantages	good penetration, high stability	free of solvents, good penetration in wet materials	free of solvents, high stability	high concentration precise application long time of contact defined applied quantity of hydrophobic agent
Disadvantages	hazardous organic solvents	not ready for use (must be diluted in situ)	low penetration	Possible change in colour lack of efficiency on high absorbing materials

3 Durability

It has been observed that treated facades show a remarkable reduction in effectiveness within a period of some 10 to 15 years [2, 3]. In most cases, the decrease is restricted to the outer surface zone, while the interior still shows the water repellent effect. As a consequence, those facades show a slower drying after having been wetted by rain or dew as compared to their original performance, because some water can be absorbed in the outer surface zone. Therefore, an enhancement of microbial attack and soiling is frequently observed.

The reason for the decrease in effectiveness is believed to be caused by the deposition of hydrophilic dust particles on the outermost grain layers rather than UV radiation (the latter seems to be unlikely due to the large thermodynamic stability of the Si-C-bond). The polar dust particles can be moistened, and micro-organisms find favourable conditions due to the prolonged time of wetness. Once a bio-film is formed, it is able to survive without dew or rain, because the polysaccharide compounds that are part of the film, absorb and retain humidity from the ambient air.

4 Misapplications

It is to be remembered that the function of water repellents is limited to reducing the absorption of liquid water of the treated material. Thus, other deterioration factors that may play a significant role in the deterioration of stone, i.e., hygric swelling in humid air or thermal dilatation effects will not be reduced by a water repellent treatment. In fact, in some of these cases, the presence of the water repellent may even increase the deterioration rate of the treated materials [4]. This fact has to be considered in the decision pro or contra a water repellent treatment.

In the course of around 55 years of water repellent treatments by impregnation with silicone compounds numerous misapplications led to considerable damages. Often building materials with low capillarity were treated and the hydrophobic agent could not penetrate deep enough into the stone to provide protection. The same applies to materials with dense surfaces that will result in a low impregnation depth of the water repellent leading to a poorly or non performing treatment.

In many cases, poor design, defects in building construction and insufficient maintenance are the reasons for failure. For example, the presence of a leak in the building will allow water to penetrate into the masonry behind the treated zone. Thus, the hydrophobised surface may delaminate, spall, flake or scale, particularly if soluble salts are present in the masonry (Fig. 2). In most cases, damage appears only after a few years. This is particularly the case for masonry with a high salt content where hygroscopic sorption of the material is enhanced leading, eventually, to the same scenario described above.

Finally, the long list of misapplications and provoked damages to be seen today leads to the conclusion that the application of water repellent treatments on stone or brick facades needs a competent preparation and control of the intervention.

Figure 2: The example shows a detail of the heavily salt laden wall of the Kaiserpfalz in Gelnhausen (Hesse, Germany) only a few years after a water repellent treatment. Note the white salt efflorescence that contributed significantly to the delamination of the hydrophobised surface. Insufficient pre-investigations resulted in the application of a water repellent treatment to a salt laden masonry where it should not have been applied.

5 Decision criteria

Every treatment with water repellent agents based on silicone network formers is generally irreversible. The Si-C-bond responsible for the hydrophobic effect does not exist in natural silicon compounds, and it is so stable that it can not be cleaved by chemical or biochemical reactions induced by the environmental nor by natural UV radiation. The life span of silicone resins will exceed by far the service life expected for buildings and even monuments. If eventually a removal of these materials will be necessary in the future, the elimination of these compounds in the pore space will be a challenge since it will require intensive physical or chemical processes. Thus the decision to treat a building with water repellents should be carefully considered and demands a high degree of responsibility.

Basic deciding factors are the understanding of the capillary water uptake of the building material, its weathering state, and its physical, chemical and biological reactivity in the presence of liquid water. In summary, detailed knowledge of the following parameters is pre-condition:

- Presence of expanding or swelling components, i.e. clay minerals;
- Frost susceptibility;
- Chemical reactivity of mineral components, such as carbonates, argillaceous minerals; and,
- Solubility characteristics of the various components.

Moreover, information concerning specific parameters of the building must be taken into consideration:

- Geometry of the building;
- Environment and exposure conditions;
- Moisture and/or soluble salt content;
- Climate and micro-climate;
- History of previous interventions (anamnesis); and,
- State of repair/conservation.

In any case, the central point of the decision is the capillary water uptake coefficient w of the material. Knowing this parameter, i.e., the amount of water taken up per area and time, it is not only possible to judge the need for a treatment, but also to estimate the consumption rate of the required liquid agent.

In general, a coefficient of $w = 1.0\ kg/m^2h^{0.5}$ is the minimum threshold value above which a water repellent treatment is justified. However, from three decades of experience it can be claimed that a treatment applied to materials with coefficients below $w = 2.0\ kg/m^2h^{0.5}$ is not particularly useful. The coefficients can be easily determined directly on the building by non-destructive techniques (Fig. 3) or by laboratory measurements on material taken from the building facade.

Figure 3: Non-destructive measurement of the capillary water uptake with the Karsten tube. From the data (time / water amount) the water uptake coefficient w can be calculated.

Besides a limit rate for water uptake, a sufficient impregnation depth of the agent is necessary for a successful treatment as climatic changes induce dilatation (swelling and shrinking) to the masonry material by wet-dry cycling or even by relative humidity changes. The reactivity of a stone material to hygric loads is influenced by a water repellent treatment. The relative expansion or shrinkage between the hydrophobised layer and untreated zones can lead to shear forces and subsequent delamination. Defects in the building material or in the joints, i.e., cracks and voids, can cause water infiltration behind the treated area and lead to the same damaging effects. These processes are most prominent close to the surface but decrease with increasing depth. Therefore, it is necessary that the water repellent agent penetrates to a sufficient depth to reduce the risk of this type of deterioration.

Figure 4 shows the theoretical relationship between the water uptake coefficient w and the minimum impregnation depth of the water repellent agent required for a good performance. The (simplified) graph is the result of some 25 years of practical experience of the working group members [5, 6]. For w < 2 kg/m² $h^{0.5}$, a minimum impregnation depth of 10 mm is required. On the other hand, impregnation depths > 40 mm are not necessary even for materials with high capillary uptake rates. For example, a material having w = 3 kg/m² $h^{0.5}$ a minimum impregnation depth of 12 mm for the water repellent agent is necessary, while a highly absorbing stone with w = 15 kg/m² $h^{0.5}$ the impregnation depth should reach 23 mm.

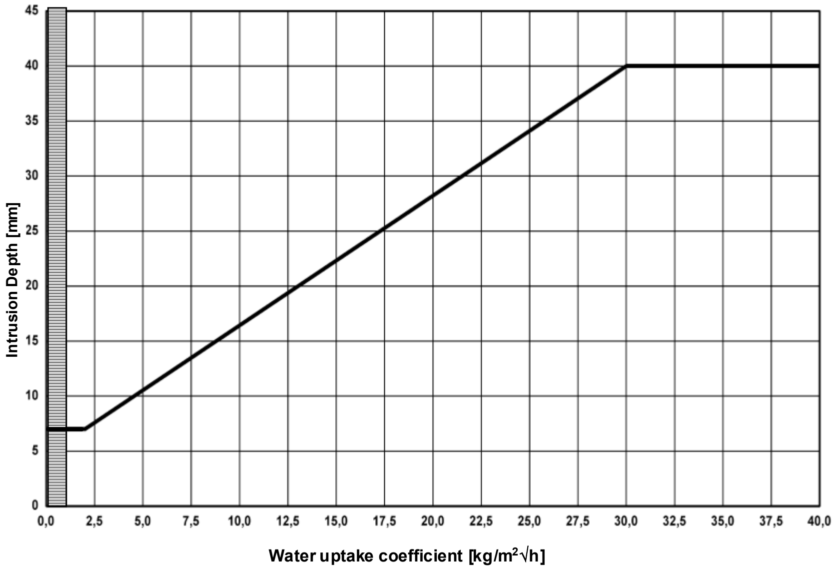

Figure 4: Impregnation depth of the water repellent product as function of the water absorption coefficient w of the porous material (M. Krus). The bar on the left hand side of the diagram indicates that a treatment is not useful when w < 1 kg/m² $h^{0.5}$.

The uptake rate for a liquid impregnation agent can be easily determined by the impregnation depth of the agent from Fig. 4 and the characteristic water saturation (M%) of the material under normal pressure. However, the application time necessary to reach this goal can only be estimated roughly since it depends on additional factors such as pore structure, mineralogical composition and properties of the liquid agent (i.e. viscosity).

Still under preparation is a nomogram that will allow the determination of the minimum impregnation depth, the consumption rate of the agent (kg/m²) and the corresponding application time based on the knowledge of the water uptake coefficient w and the water saturation value. Thus, these two parameters will allow an estimation of the application requirements for a water repellent treatment.

Based on these calculations it is evident that, in the case of some building materials, the required impregnation depth cannot be reached by simple spraying of a liquid water repellent considering that usual application times are in the order of 2 to 4 minutes. The duration of the application can be prolonged by different techniques, i.e., poultices, or by the use of a different formulation, i.e., creams.

6 Decision (pros and cons)

The first questions to be asked in the planning process for a water-repellent treatment are:

- Is the material sensitive to moisture? Is the material remarkably water absorbing ($w > 1$ kg/m² $h^{0.5}$)?

Only positive answers to both questions justify a hydrophobic treatment.

During the decision for or against a water repellent treatment the next basic condition is the positive answer to the following questions concerning the building. Otherwise, existing defects have to be repaired in advance.

- Is the water run-off system, i.e., gutters, down pipes, etc., in working order?
- Can rising damp be eliminated?
- Can condensation water be eliminated inside the building?
- Is the draining system in working order?
- Are the joints in good condition?
- Can hollow spaces, cracks and fissures be eliminated?
- Can all other steps of the conservation/restoration intervention be completed before the treatment?

In general, all other possibilities of external moisture load reduction by constructional methods (roofing, covering with metal etc.) have to be considered first, and only then should a water repellent treatment be taken into account. For the specific case of historic buildings and monuments, the constructional methods have to fulfil special requirements such as respect for the aesthetics and the document value of the monument. It is also important that before the treatment is applied, especially when dealing with a complex conservation/restoration project, sufficient time is allowed to let the building materials dry out as a result of the previous steps, such as cleaning, repointing, etc.

Water repellent treatments are characterised by significantly reducing the capillary water uptake of the material. As a result of this, it may in certain cases improve the properties of building by:

- Decreasing thermal conductivity thus increasing its insulation;
- Shifting the dew point temperature to the interior of the wall; and,
- Decreasing moisture transport into the interior of the building.

A water repellent treatment should not be carried out, in the following situations:

- Presence of hygroscopic salts;
- Sealed surfaces (due to gypsum, lime sinter (calcin), dirty crusts, coating residues, etc.); and,
- Intensive biocolonisation (mosses, lichens, fungi).

It should be further mentioned that the soiling behaviour of facades may change remarkably due to a treatment with water repellent agents. Run-off water may release partial traces of dirt on the surface which may be disadvantageous from the aesthetic point of view.

Before a decision on whether to apply a water repellent agent, the advantages and risks of a treatment have to be carefully balanced. In the leaflet being prepared, a list sequential questions, will help to determine if a water repellent treatment is useful, unnecessary or even harmful. The user, i.e., the owner and/or the architect, and even the salesperson for the product, is led from one question to the next by different jump addresses depending on the answers “yes” or “no”, respectively. However, this does not exclude the input of professionals with experience in the field, since a basic precondition is the knowledge of the material parameters and the properties of the water repellent agents described above.

7 Quality management

After the decision for a water repellent treatment the intervention itself has to be prepared and accompanied by detailed tests and quality control. The applicability of water repellent agents for the building material in question has to be tested by laboratory treatments. Uptake, intrusion depth and efficiency of the agent have to be determined.

The next step is the application of the favourite agents on representative test areas on the facade. As sampling might become necessary the test area has to be planned in inferior areas of the facade. In the neighbourhood an untreated area has to be selected for reference. The complete intervention plan must be applied to the test area. Each step as well as the environmental conditions need a detailed documentation.

The results from laboratory investigation and those from test areas build a base to select the water repellent, to calculate the quantity of agent necessary for treatment and to identify the best application technique. The treatment of the whole object can only start after all results of the test areas are known and favourably assessed. The main treatment of the object has to follow the established plan. All interventions carried out, all parameters like real uptake of agent, impregnation procedures and observations have to be fixed in a report.

After reaction time, a quality control of the intervention has to be carried out following the same procedures as described for the test areas [5]. Consistent effect of the treatment on the whole facade has to be proved by water uptake measurements by Karsten tube. The determination of the intrusion depth on a few drill cores is desirable and helpful in the case of later customer complaints.

8 Conclusions

As not everybody is aware of the many problems of water repellent treatments applied to stone and brick facades, the new edition of the WTA leaflet serves to give basic guidelines that will allow a more informed decision with regards to whether a water repellent treatment will prove useful or not, or even prove deleterious. However, the leaflet alone can not replace the required expertise of professionals in the field.

The application of water repellent agents based on silicone resins to porous building materials can be considered irreversible. Especially in the field of cultural heritage, misapplications may have severe consequences. Therefore, a careful study of physical, mineralogical and chemical properties of all materials as well as of their weathering state (especially salt and moisture content) is required before a decision can be taken. Furthermore, an understanding of the nature and properties of the available products is fundamental. But the basic minimum condition is the knowledge of water uptake coefficients and the water saturation values of the materials. Without these data, a decision is impossible.

References

[1] WTA-Merkblatt 3-2-84: Natursteinhydrophobierung (1984).

[2] Wendler, E., Sattler, L.: Untersuchungen zur Dauerhaftigkeit von Steinkonservierungen mit siliziumorganischen Stoffen.- Bautenschutz & Bausanierung, Sonderausgabe 1989, Bausubstanzerhaltung in d. Denkmalpflege, 2. Statusseminar des BMFT, Dez. 1988, Wuppertal, 70-75.

[3] Wendler, E., Rückert-Thümling, R., Klemm, D.D., Snethlage, R.: Zur Dauerhaftigkeit von Hydrophobierungsmaßnahmen auf Naturstein. Vergleichende Fallbeispiele am Kölner Dom und am Ulmer Münster. In: R. Snethlage (ed.): Jahresberichte aus dem Forschungsprogramm Steinzerfall - Steinkonservierung, Band 4 (1992), Ernst & Sohn, Berlin, 197 - 204.

[4] Möller, U., Schuh, H., Wendler, E.: Thermisches und hygrisches Längenänderungsverhalten hydrophobierter Sandsteine. 3. Int. Koll. "Werkstoffwissenschaften und Bausanierung", 15.-17.12.1992, Technische Akademie Esslingen, 1796-1806 (1992).

[5] Snethlage, R.: Leitfaden Steinkonservierung. Planung von Untersuchungen und Maßnahmen zur Erhaltung von Denkmälern aus Naturstein: 289 S., 2. überarbeitete und erweiterte Aufl., Stuttgart (IRB).

[6] Tenside im Gesteinsschutz – bisherige Resultate mit einem neuen Konzept zur Erhaltung von Denkmälern aus Naturstein. In: R. Snethlage (ed.): Denkmalpflege und Naturwissenschaft – Natursteinkonservierung I (1995), Ernst & Sohn, Berlin, 127 - 146.

WTA- Leaflet: Water-repellent Treatment of Porous Materials.

Members of the Working Group:

Ulrich Bauer-Bornemann, Steinrestaurierung, Bamberg
Dr. Stefan Brüggerhoff, Dt. Bergbau-Museum, Bochum
Jens Engel, Remmers Baustofftechnik, Löningen
Dr. Lothar Goretzki, Universität Weimar
Dr. Heinz Geich, Wacker-Chemie GmbH, Burghausen
Dr. Leo Gollwitzer, Wacker-Chemie GmbH, München
Dr. Martin Krus, Institut für Bauphysik der FhG, Holzkirchen
Dr. Esther von Plehwe-Leisen, LPL Natursteinerhaltung, Köln
Hendrik Romstedt, Steinrestaurierung, Kirchheim
Dr. Ludwig Sattler, Labor Dr. Ettl/Dr. Schuh, München
Dr. Thomas Warscheid, Labor Bode-Warscheid, Wiefelstede
Dr. Eberhard Wendler, Fachlabor f. Konservierungsfragen, München