

Studies of hydrophobed plastered autoclaved aerated concrete

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Abstract

The service life of external building materials largely depends on the severity of the micro climate and the properties of the material itself. The rainwater is the most effective environmental agent, particularly on porous building materials, either as a harmful agent itself or as a means of several degradation mechanisms resulting from the combined attack with other weathering agents. Thus the moisture characteristics of the material play an important role in determining its durability.

As most of the damages are related to water, measures must be taken against the ingress of water into the structure. The use of surface treatments for the protection of porous building materials against rainwater extends the service life of the component. The silicon-based water repellants are increasingly used due to their hydrophobic properties.

In order to evaluate the performance of the hydrophobed porous building materials, some laboratory tests have been carried out on autoclaved aerated concrete (AAC) specimens, rendered with different combinations of plasters and hydrophobed with silicon compounds. Common properties, such as capillary water absorption and vapour permeability were tested. This paper reviews degradation mechanisms related to rainwater and the general properties of surface treatments. Brief results on moisture characteristics of plastered AAC with and without water repellants are presented.

Keywords: Autoclaved aerated concrete, surface treatments, water repellants, degradation, moisture properties

1 Introduction

A large number of buildings have various problems due to exposure to wind-driven rain and water vapour from the inside. Failures of facades can be seen both on existing old and new buildings. Agents originating from the atmosphere are most relevant for the ageing process of the materials used in the exterior envelope of the buildings. External walls are deteriorated by the atmospheric agents in scale of components and materials, especially on facades exposed to wind-driven rain. The severity of damage is increased by the combined attack of the weathering elements like solar radiation, rain, air constituents and contaminants and freeze-thaw cycles.

When porous building materials are subjected to rain, an inward transport of water occurs. Water penetrates through the capillaries, cracks and joints by wind and capillary suction forces directed into the building enclosure. The absorption rate depends on the pore structure of the substrate and the hydraulic properties of the surface. The rate of drying after wetting is also dependent on the porosity of the material and the ambient temperature, relative humidity and wind velocity.

In fact, the wetting of the walls is due not only to rain but also to condensation phenomena. Vapour permeable waterproofs should be applied to vapour permeable substrates in order to allow vapour to pass through the coating to the outside of the building. Otherwise, vapour condenses at the interface of the nonpermeable layer, causing deterioration. Therefore, the continuity of the moisture transport through the different layers of the wall, that is, the vapour permeability of the whole wall system, plays an important role in proper material selection.

The use of surface treatments for the protection of porous building materials against water ingress is expected to extend the service life of the walls by raising their performance. However, surface treatments should not affect the vapour transmission as not to cause condensation in the wall structure.

2 Degradation mechanisms related to rainwater

Rainwater is the major destructive atmospheric agent for most external building materials. The amount of water hitting a wall depends on the intensity of driving rain, which in turn is directly proportional to the amount of rainfall and the wind velocity during rain.

Volume changes, as expansion on exposure to moisture and contraction during drying out, result in cracking or surface crazing of porous building materials. The flow of water over surfaces or splashing back of water against surfaces from rainfall causes change in appearance of facades, such as staining.

Water transports salts within the wall structure and deposits them on the surface of the porous material by evaporation. This phenomenon is known as efflorescence. The crystallisation of soluble salts within the pores beneath the exposed surface within the structure is referred to as 'cryptoflorescence'. The white deposits of soluble salts on surfaces can lead to change of appearance as well as give rise to deleterious effects by the reversible uptake of water. Cryptoflorescence may cause loss of adhesion of external wall finishings such as renderings and surface coatings

and leads to embrittlement and crumbling of the surface material as a result of crystallisation pressure [1]. Formation of these crystals can trap moisture in masonry pores, which cause spalling during freeze-thaw cycles. Additionally, if cryptofluorescence is severe enough, it prevents the natural moisture transport properties of the masonry wall.

When porous building materials are exposed to low temperatures, the water in the capillary pores freezes and stresses produced lead to deterioration. The frost resistance of the material is mainly influenced by the water content and the pore structure of the material. For the deterioration mechanism the influence of water content is related to a value known as 'critical water content', below which materials are resistant to frost action. Therefore the permeability of a material plays an important role in frost action. The most common frost damage, such as cracking and spalling, is caused by progressive expansion from repeated freeze-thaw cycles. By preventing water penetration, substrates will also be protected from the damaging effects of freeze-thaw cycles.

Ultraviolet radiation received on the surfaces of buildings causes degradation particularly when it acts in conjunction with oxygen, water, heat or a combination of these agents. Loss of appearance, fading, yellowing, and erosion are common UV failure modes. UV also contributes to the loss of protection properties such as water repellency.

Sulphates and nitrates in the air form sulphuric and nitric acids by reacting with rainwater (acid rain), which acids are transported deep into the porous material via wet deposition and capillary suction. They attack the calcium compounds of the substrate, causing deterioration.

Fine particles of atmospheric dirt settle at building surfaces and the contaminated rain falls at and runs off the same surfaces. The flow of water may wash the particles out but usually redeposit them, the outcome depending on direction and rate of the flow. Porous materials trap the particles in their pores [2].

In addition to the deterioration effects of water, the high moisture content declines the thermal performance of the wall, bringing significant energy losses.

3 Surface Treatments

Surface treatments are used as a preventive measure for improving the performance of porous building materials against external degradation agents. As most of the damages are related to water, the protection is usually intended to reduce the absorption of water in the material.

Surface treatments can be classified in four main groups according to their protective action [3]:

- penetrant / pore liners
- penetrant / pore blockers
- sealers and coatings
- cementitious coatings

3.1 Pore-liners

These treatments line the pore surfaces of the substrate by a chemically bonded water-repellent hydrocarbon molecule [4]. As they do not block the pores, the effect on the vapour permeability of the wall is negligible. As the surface treatment is colourless, it makes very little change on the appearance of the facade.

By penetrating the substrate, the material itself is shaded and thus highly protected from the UV radiation. Accordingly, a long term durability is achieved. The performance of the pore-liners largely depends on properties of the substrate, such as porosity and moisture content and on the amount of material applied.

Silanes, siloxanes and silicon compounds are examples of this type.

3.2 Pore-blockers

These treatments penetrate into the substrate and clog the pores. In this way water is repelled along with any dissolved salts, acids and other aggressive agents. This treatment is also known as the crystal growth method. The crystalline reaction products bind to the water molecules and increase in volume.

The vapour transmission is greatly restricted by the blockage of the pores. Improper application can cause water uptake by capillary action. Pore-blockers have no effect on the appearance of the surface. They are usually used for hardening of the surface and as a primer before the main coating.

The most common examples are silicates, silicofluorids and some kinds of epoxy and acrylic resins.

3.3 Sealers and coatings

By forming a pinhole-free, continuous film layer on the surface, sealers and coatings prevent the water ingress but obstruct also the vapour diffusion. Owing to their penetration into the substrate to some degree, sealers have a good adhesion to the substrate and are often used as primers. Film forming surface coatings can be pigmented when colour is desired.

Epoxy resins, polyurethanes, acrylics, linseed oil, alkyds, vinyls, chlorinated rubber, styrene-butadiene, cement based stone paints and bitumens are the typical examples of sealers and coatings.

3.4 Cementitious coatings

These are cement-based products containing finely graded siliceous aggregates. Chemical additives impart integral water repellency and improve the adhesion of the coatings to the substrate. Since cementitious coatings are water-repellent, they are highly resistant to freeze-thaw cycles. The performance against weathering is excellent, while the resistance to acid rain and other contaminants is poor.

These products are also vapour permeable, allowing transmission of vapour. Cementitious coatings adhere well to the substrate and are considered as an integral part of the substrate. But they do not function if cracking or substrate movement occurs.

The coatings completely change the original appearance of the facade. Pigments are added to colour and various textures are available, either by coarseness of aggregate or by application methods [5].

4 Silicon-based water repellants

Silicon-based water repellants are considered as the best protective agents against aforementioned facade failures. They are colourless, low viscous, capillary active liquids which act by forming a hydrophobic zone against water. The effect of water repellants is based on their low surface tension. They are claimed to satisfy requirements as [6]:

- excellent water repellency
- high vapour permeability
- good adhesion
- excellent durability (resistance to weathering, e.g. UV)
- solvent-free (environmentally friendly)
- no change in appearance.

Silanes and siloxanes have the best performance characteristics and long-term durability among the silicon compounds. They have t-structured molecules containing three silicon functional groups and one organofunctional group. While siliconates also belong to this group, they are no longer used for protecting facades. The reason is that a white layer is formed on oversaturated areas, which is hard to remove [7].

The hydrophobicity is provided by the organofunctional (alkyl) groups of the compound. The penetration depth into the substrate is determined by silicon functional (alkoxy) groups and affects the long-term durability of the repellant. By penetrating the substrate, the alkyl group is protected against UV radiation. Factors influencing depth of penetration include the porosity (particularly on the surface), moisture content of the substrate, molecular size and amount of water repellant agent applied [4]. The molecular size of silanes (10-15 Å) and siloxanes (25-75 Å) is small enough to permit the compounds to enter the pore structure of concrete (20-200 Å).

The water-repellent hydrocarbon molecule (alkyl group) chemically bonded to the substrate, reduces the surface tension of the substrate. Different alkyl groups reduce the water absorption to various levels. The water absorption rate is represented by the water absorption coefficient of the surface coating, A [$\text{kg/m}^2\text{h}^{0.5}$]. This coefficient describes the water absorption of a wall when a film of water occurs at the surface. The behaviour of water when in contact with the surface of the material is governed by its surface tension which is measured by the contact angle.

5 Experiments

In order to study the performance of porous building materials against weathering, the moisture characteristics of hydrophobed plastered autoclaved aerated concrete (AAC) were tested. The hydrophobic properties of the sample components, i.e. capillary water absorption and vapour permeability were taken as performance parameters.

5.1 Materials

Tests were carried out on ten AAC specimens, rendered with five different plaster systems with and without silicon. Two different water-repellent products were used; as an additive in the plaster and as a treatment at the surface of the AAC. The water repellent used as an additive is a powder consisting of a silicon resin on a carrier matrix and forms pores in the plaster. The plaster gets flexible and thus has a low tendency to crack. The water repellent used as surface treatment is an aqueous silane/siloxane emulsion. It is solvent-free and water thinnable.

The plaster systems used are (in general) as following:

- A1: Two layered thin plaster, (4 mm); primer and a sprayed topcoat
- A2: Two layered thin plaster, (4 mm); primer with silicon additive and a sprayed topcoat with silicon additive
- B1: Three layered plaster (17 mm); primer, lime-cement undercoat and a sprayed topcoat
- B2: Three layered plaster (17 mm); primer with silicon additive, lime-cement undercoat with silicon additive and a sprayed topcoat with silicon additive
- C1: Four layered coating (17 mm); primer, lime-cement undercoat, acrylic primer and a acrylic plaster as topcoat
- c 2: Four layered coating (17 mm); primer with silicon additive, lime-cement undercoat with silicon additive, acrylic primer and a acrylic plaster as topcoat
- D1: Monosystem plaster (18 mm)
- D2: Monosystem plaster (18 mm); (AAC surface treated with silicon)
- E1: Three layered coating (15 mm); hydraulic lime primer, hydraulic undercoat and a cement-dolomite paint
- E2: Three layered coating (15 mm); (AAC surface treated with silicon), hydraulic lime primer, hydraulic undercoat and a cement-dolomite paint.

5.2 Tests

Specimens in dimensions of $150 \times 150 \times 70 \text{ mm}^3$ were used in the capillary absorption test. The faces of the samples, except the surface to be immersed, were sealed water and vapour-tight. The samples were immersed in 1-3 mm of water (Figure 1). The samples were weighed at the start of the test before immersion and at various time intervals. The water level was kept constant during the experiment.

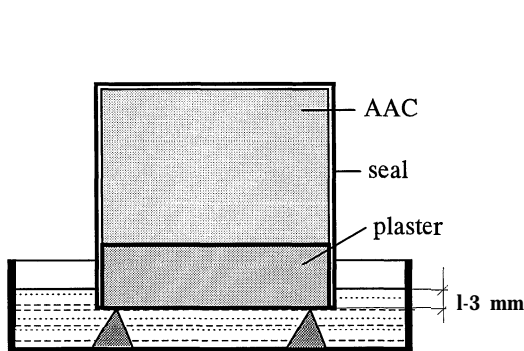


Figure 1 Capillarity test set-up

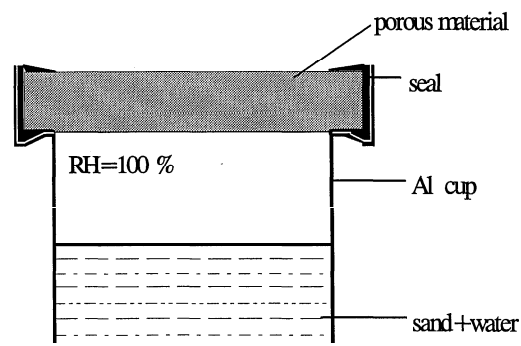


Figure 2 Wet cup method

The vapour permeability tests were carried out in accordance with the wet cup method. Cylindrical specimens with a diameter of 90 mm were placed in aluminium cups containing sand and water (Figure 2). The edges were then sealed so that only the upper and the lower surfaces were exposed. The cups were stored in the climate chamber at 20⁰C and 65 % relative humidity. Changes in the mass of water in the cups were determined by weighing at certain time intervals.

5.3 Results

In Table 1, the samples are identified according to the existence and type of the water-repellent material. The water absorption rates at 24 hours and the reduction gained by water repellants are given in Table 2.

Table 1 Summary of specimens

	samples without repellant	samples with repellant
repellant	A1	A2
as	B1	B2
additive	C1	c2
repellant	D1	D2
as surface	E1	E2
treatment		

Table 2 Summary of best performance

samples	Water Absorption Rate [kg/m ² h ^{0,5}]		Reduction %
	without repellant	with repellant	
A	2,12	1,18	44
B	1,67	0,25	85
C	0,99	0,22	78
D	1,90	0,67	65
E	2,15	0,55	74

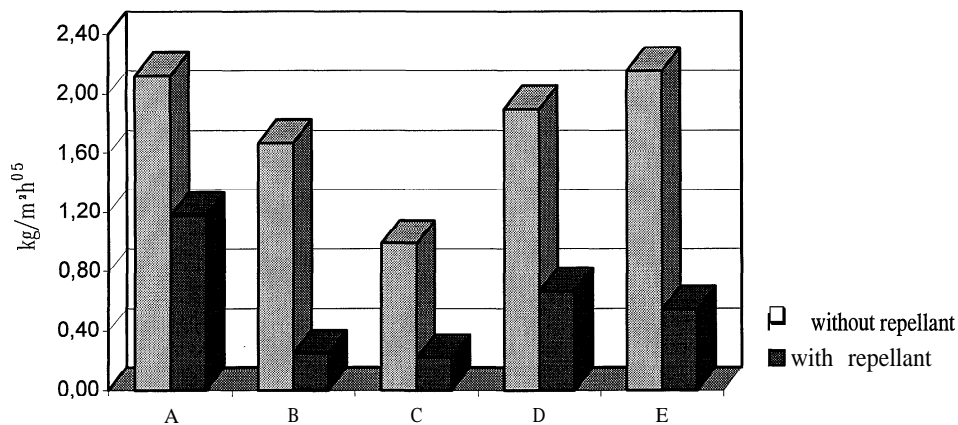


Figure 3 The water absorption rates for 24 hours

Samples B2 and C2 have the best performance among the plaster systems as can be seen from the diagram in Figure 3. The capillary water absorption curves are given in Figure 4 for both short and long periods. Unlike the hydrophobed plaster systems B2 and C2 (though, the same water-repellent additive was used), the water absorption of the specimen A2 is significantly higher in the long period. The most likely explanation to this is the specific pore structure of the plaster and also its thickness.

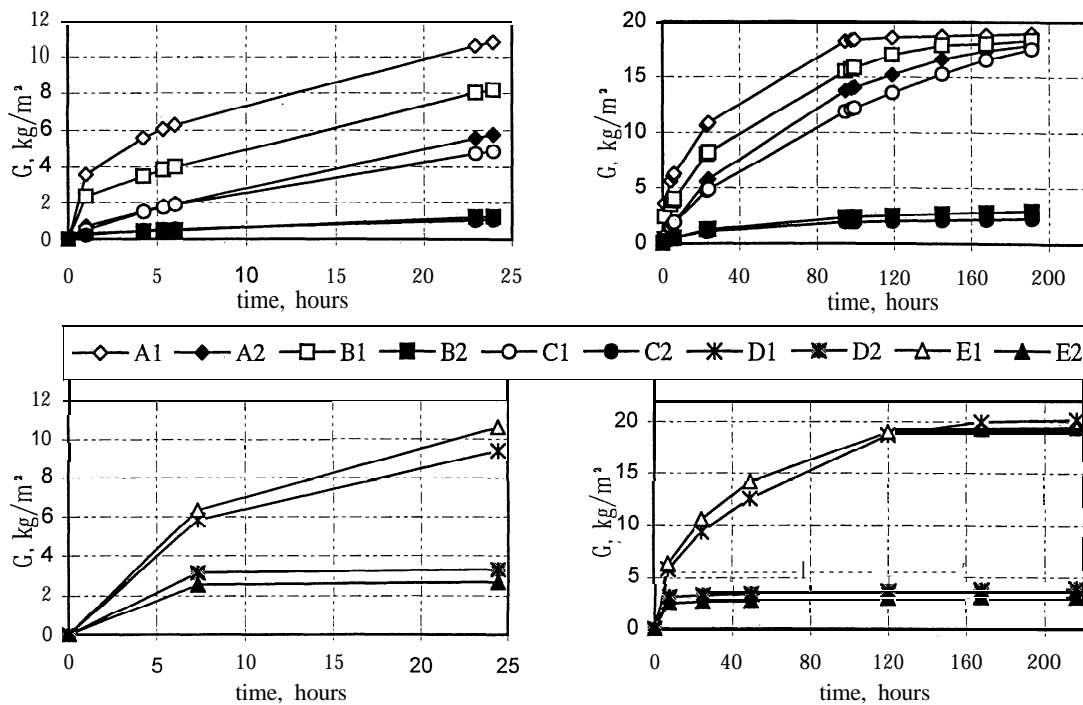


Figure 4 The capillary water absorption of the specimens

Diffusion resistances (the vapour diffusion resistance-equivalent air layer thickness, s_d), of the sample coatings are summarised in Table 3 and given as a diagram in Figure 6. The results indicate that the water-repellent products used do not have a considerable effect on the vapour permeability of the sample components.

Table 3 The water vapour diffusion resistance-equivalent air layer thickness, s_d [m] values of the specimens

samples	without repellent	with repellent
A	0,141	0,122
B	0,307	0,334
C	0,439	0,357
D	0,151	0,215
E	0,175	0,198

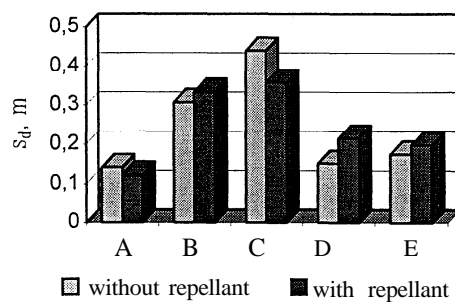


Figure 6 The s_d values of the specimens

6 Concluding Remarks

The test results indicate that the application of a water repellent on the surface of AAC, under the plaster, is not as effective as the water repellent applied as additive in the plaster. Hence, repellent as a surface treatment between the layers, may act as a barrier and cause accumulation of water at the interface, leading to deterioration. The application of repellent at the top surface of the plaster would perform better

only if the surface remains free of later cracks or spallings. This is even verified by the outcomes of the experiments which are still going on to investigate the performance of water repellants as surface treatment on the plaster.

According to Künzel [8]; an exterior rendering can be termed 'water-repellent' (managing heavy driving rain conditions) only if it meets the requirements:

$A < 0,5 \text{ kg/m}^2\text{h}^{0,5}$ and $s_d < 2 \text{ m}$;

and 'water-retarding' (managing medium driving rain conditions) if:

$A < 2 \text{ kg/m}^2\text{h}^{0,5}$ and $s_d < 2 \text{ m}$.

The comparison of the test results indicate that:

- Only hydrophobed plaster systems B and C meet above requirements to be termed water-repellent
- All the plaster systems, hydrophobed or not, meet the requirements to be termed water-retarding
- All the plaster systems, hydrophobed or not, fulfil the above requirements for water vapour transmission.

The results obtained from the tests confirm the hydrophobic effect of water repellants on porous building materials. However, (in this case) the performance of repellants depends on the properties of the plaster system, its layers and its thickness. They also perform different depending on their application as additive or surface treatment. In order to make broader assessments, tests are continued with the samples treated with silicon on the top surface. Moreover, additional tests are planned to investigate the long-term performance of the water repellants on porous materials.

7 References

1. Addleson L., Rice C. (1991) *Performance of Materials in Buildings*, Butterworth Heinemann, Oxford.
2. Mays G. (1992) *Durability of Concrete Structures*, E & FN Spon, London.
3. CIRIA TN 130 (1987) *Protection of Reinforced Concrete by Surface Treatments*, CIRIA, London.
4. McGettigan E. (June 1992) Silicon-based Weatherproofing Materials. AC. 'Concrete Int.', USA.
5. Kubal M. T. (1993) *Waterproofing the Building Envelope*, McGraw-Hill Inc., USA.
6. Sandin K. (1995) Surface Treatment With Water Repellent Agents. *Proceedings of the First Int. Symposium on Surface Treatment of Building Materials with Water Repellant Agents*, Delft, Netherlands.
7. Mayer H., Roth M. (January 1995) *Silicon Microemulsion Concentrates*, Wacker SMK 'A New Way of Obtaining Aqueous Masonry Water Repellants Based on Organo-silicon Compounds', Munich.
8. Kunzel H. (1977) Evaluation of Renderings and Paintings with Respect to the Rain Protection. *RILEM/ASTM/CIB Symposium on Evaluation of the External Vertical Surfaces of Buildings*, Espoo, Finland.