Hydrophobe VI
6th International Conference on Water Repellent Treatment of Building Materials
Aedificatio Publishers, 125 - 136 (2011)

Evaluation of the Effect of Nano-Coatings with Water Repellent Properties on the Absorption and Drying Behaviour of Brick

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Abstract

Surface treatment of porous building materials with water repellent products is often used to avoid the ingress of rain water and to reduce biological growth. Water repellent treatments, even when they do not reduce water vapour transport, hinder liquid water transport and significantly delay the drying of porous materials. This may lead to an increased risk of both salt and frost damage in treated materials, in case water ingress from behind is still possible, for example due to rising damp. Recently, water repellent products based on nanotechnology, claiming to have an improved performance in comparison to traditional ones, have been introduced to the market.

In this research the effect of two nano-coatings with water repellent properties (one based on silane and the other on silicate) on the water absorption and drying behavior of fired-clay brick has been evaluated.
The tested nano-coatings show to significantly reduce water absorption, while they do have a limited effect on the drying behavior, much lower than traditional water repellents. This might have a positive effect on the occurrence of both salt and frost damage. The impregnation depth reached by the tested nano-coatings is much lower than that of traditional products.

Keywords: nano-coatings, water repellent, water absorption, drying behaviour

1 Introduction

The moisture content in a material is an important factor for the occurrence of several decay processes, like frost action, salt crystallization and biological growth. A water repellent treatment can hinder rainwater penetration thereby reducing, if other moisture sources are absent, the moisture load in a material. The working principle of a water repellent consists in modifying the contact angle between the material and water, by covering the pore wall with a hydrophobic layer. The contact angle, that is equal to 0° in most stone-like materials, becomes, after the application of a water repellent, larger than 90°; as a consequence, capillary water absorption stops. A water repellent treatment modifies not only the water absorption, but also the drying of a material, by hindering liquid water transport to the surface. It is known that the drying process of an untreated, water saturated material occurs in different phases: initially, at high moisture content, there is a continuous network of water filled pores in the material and capillary transport of liquid water to the surface occurs; the drying front is at the surface and the drying speed is high and constant. Then, when the moisture content drops below the Critical Moisture Content (CMC), the drying front enters the material; from this point on, there is no capillary transport of liquid water to the surface while water vapour transport to the surface can still occur. As a consequence the speed of drying will drastically decrease [1, 2].

Water repellent treatments, even in case they do not reduce water vapour transport, inhibit liquid moisture transport. The drying of a treated material will therefore occur by water vapour transport. A dramatic decrease of the drying rate may be the overall result [2]. This implies that a material treated with a water repellent, in case a moisture source like e.g. rising damp is present, will keep a high moisture content for a longer period, increasing the risk of the occurrence of frost damage. The risk of salt crystallization damage can be increased too by the presence of a water repellent: salts can not be transported by water vapour and will therefore accumulate behind the treated layer, leading eventually to spalling of the treated part. The advantages and risks of traditional silicon based water repellent treatment on the absorption and drying behavior of building materials are known [among others 2-4]. Recently, nano-coatings with water repellent properties have appeared on the market. Before these new products are going to be applied on large scale also on cultural heritage objects, it is of major importance to study not only the effectiveness in terms of water repellency of these products, but also their effect on the drying behavior and their possible risks related to processes like frost and salt crystallization.

This paper reports the results of a study of the absorption and drying behavior of brick substrate treated with two different nano-coatings with water repellent properties. As comparison, traditional water based, silane-siloxane water repellents have been tested too.

2 Experimental

The effect of two nano-coatings (NCOAT Stone en NCOAT Stone A) with water–repellent properties on the absorption and drying behavior of fired-clay brick was measured and evaluated by comparison with untreated bricks and bricks treated with traditional water repellent products.

2.1 Products

Two nano-coatings with water repellent properties have been tested:

- NCOAT Stone is an organofunctional silane system in water
- NCOAT Stone A is an organofunctional silicate system in water

The properties of the products are to be found in [5-6].

As comparison two traditional water repellent products have been tested too:

- Products A: silane and –siloxane, emulsion in water (Funcosil WS)
- Product B: silane and –siloxane, emulsion in water (Aquasil RS8)

2.2 Substrates

All products have been tested on the same substrate: a red fired-clay brick with a total open porosity of 29 vol. % and a majority of pores with diameter size between 4 and 10 μm. The water absorption coefficient of the brick is 334 $g/m^2\sqrt{sec}$.

2.3 Application of the surface treatments

Half bricks of the size 50 x 100 x 100 mm were used. The lateral surfaces of the brick specimens were coated with epoxy resin in order to avoid drying through the sides. The surface treatments were applied by brush on the upper surface of the specimens in the quantity prescribed by the product information sheets provided by the producer. In the case of both nano-coatings the prescribed amounts resulted to be insufficient to get a full impregnation of the whole surface. It was therefore decided to treat some extra specimens with 3 times the suggested amount. According to the product information sheet of the nano-coatings, the product should be applied in two layers. However, the brick surface became water repellent immediately after the first application, and no significant amount of product could be absorbed during the second application. The amount of products applied for each of the specimens is reported in Table 1.

Table 1: Amount of product used to treat the specimens; * indicates that 3 times the amount prescribed by the information sheet was used

Specimen no.	Product	Amount product used (g)	Amount product used (l/m^2)	Amount of product to be used according to the information sheet (l/m^2)
2	NCOAT Stone	0.89	0.178	0.1-0.15
17	NCOAT Stone	0.95	0.190	0.1-0.15
10*	NCOAT Stone	2.26	0.452	0.1-0.15
13*	NCOAT Stone	2.26	0.452	0.1-0.15
6	NCOAT Stone A	0.81	0.162	0.1-0.15
15	NCOAT Stone A	0.77	0.154	0.1-0.15
14*	NCOAT Stone A	2.30	0.460	0.1-0.15
16*	NCOAT Stone A	2.29	0.458	0.1-0.15
8	Treatment A	7.5	1.500	0.8-1.5
9	Treatment A	7.59	1.518	0.8-1.5
11	Treatment A	7.57	1.514	0.8-1.5
3	Treatment B	4.92	0.984	0.25 -1
12	Treatment B	5.04	1.008	0.25 -1
18	Treatment B	5.04	1.008	0.25 -1
19	Not treated	-	-	-
21	Not treated	-	-	-
22	Not treated	-	-	-

Four specimens were treated with NCOAT Stone and four with NCOAT Stone A (two specimens with the amount of product prescribed in the information sheet and two specimens with three times this amount); three specimens were treated with product A and three with product B, all with the amount prescribed by the producer. Additionally, three not treated specimens were used as reference.

After the application of the treatment, the specimens were stored for three weeks in a climatic room at 20 ºC / 50% RH in order to allow the complete reaction of the products.

2.4 Test procedure

The following measurements were carried out:

- Evaluation of the beading effect: this test is simpler than the measurement of the contact angle while still giving an indication of the water repellent effect. The shape of the water drop can vary from flat to elliptical and to spherical, indicating respectively no, little or very good water repellent effect.
- Absorption measurements by means of Karsten pipe (Figure 1) : this test has been carried out according to the procedure described in [7]. The test consists in filling the pipe stepwise and measuring the absorption at regular time intervals. The results of the measurements can be expressed as WA-K (= water absorption by Karsten pipe).

$$WA\text{-}K_{15\,min} = V(15min) - V(5min) \quad (1)$$

Where:

$WA\text{-}K_{15\,min}$ = water absorption by Karsten pipe measured after 15 minutes

V(15 min) = absorbed amount of water after 15 minutes

V(5 min) = absorbed amount of water after 15 minutes

In order to better evaluate differences between the surface treatments, some of the tests were carried out for a longer period than prescribed by the procedure and the absorption was also measured at 1, 2, 4 and 8 and 24 hours from the application of the water column. The WA-K at 24 hours ($WA\text{-}K_{24h}$) was calculated too, according to the following formula:

$$WA\text{-}K_{24h} = V(24\,h) - V(5\,min) \quad (2)$$

Where:

V(24h) = absorbed amount of water after 24 hours

- Measurements of the drying behaviour: the specimens, both treated and untreated, were saturated with water by capillary rise from the bottom surface. Then the bottom surface was sealed with tape in such a way that drying could occur only through the upper surface. The specimens were stored at 20 °C / 50% RH and their weight recorded at regular intervals for a period of about three months.
- Measurement of the impregnation depth: at the end of the drying test, the bricks were split and the impregnation depth of the treatment was evaluated by wetting the broken section.

3 Results

3.1 Water absorption as measured by means of the Karsten pipe test

The results of the absorption test by means of the Karsten pipe are summarized in the bar chart of Figure 2. Each bar represents the average of at least 2 measurements. The lower the absorption is, the better the water repellent effect. The maximum absorption is 4 ml, which corresponds to the maximum water column of the Karsten pipe.

The measured WA-K $_{15min}$ varies between 0 and 0.8 (average 0.28) and between 0 and 2 (average 0.73) for brick treated with NCOAT Stone and NCOAT Stone A respectively. For both products better results, which are comparable to those obtained for traditional products, are achieved when the product is applied in a higher amount (0.45 l/m^2). After 24 hours the absorption increases noticeably for NCOAT Stone and NCOAT Stone applied in the amount suggested by the information sheet. Again, the absorption of specimens treated with 3 times the prescribed amount of product, is very low and comparable to that of traditional products.

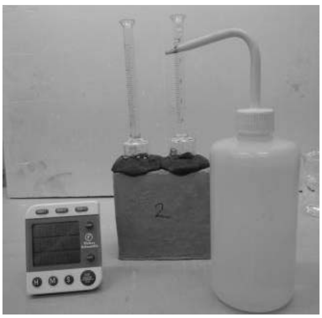

Figure 1: Karsten pipes applied on the surface of the brick specimen

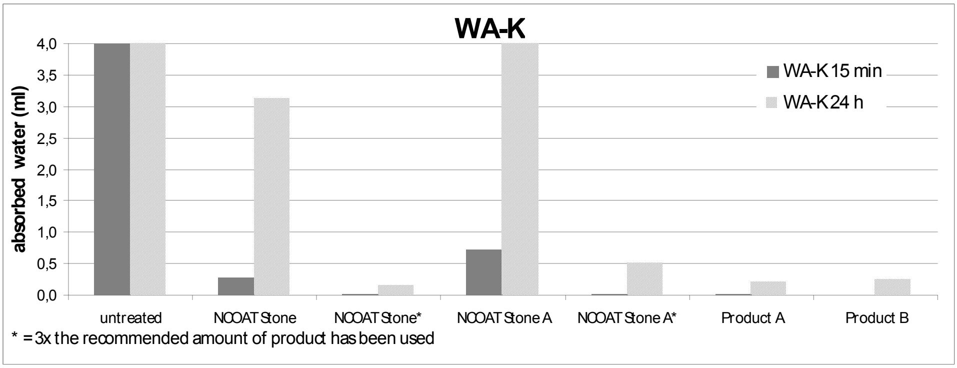

Figure 2: Average WA-K at 15 min and 24h for untreated and treated bricks

3.2 Effect of the treatments on the drying behavior

The drying curves of the bricks, both treated and untreated, are reported in Figure 3. Each curve represents the average of measurements carried out on at least two specimens.

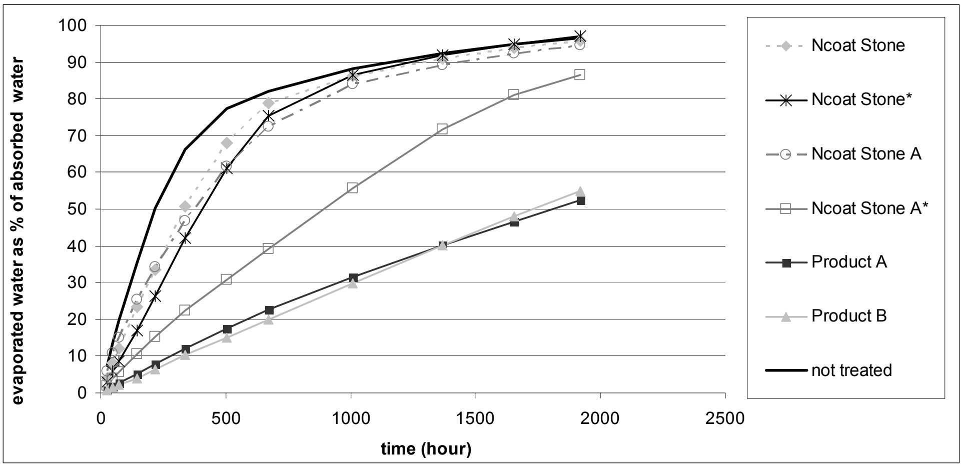

Figure 3: Drying curves of treated and untreated brick (each curve represent the average of at least two specimens)

3.3 Impregnation depth

At the end of the drying test the brick specimens were split and the impregnation depth of the treatments was measured by wetting the broken section (Figure 4). The measured impregnation depths are reported in Table 2.

The impregnation depth of NCOAT Stone varies between 0.2 mm, in specimens impregnated with the amount of product recommended in the information sheet, and 1.5 mm, in specimens treated with 3 times the amount prescribed in the information sheet.

NCOAT Stone A shows a maximum impregnation depth of 4 mm; also in this case the impregnation depth is proportional to the amount of used product.

The used traditional products, A and B, show very different impregnation depths: product A can impregnate the brick up to a depth of 50 mm, while product B shows a maximum impregnation depth of 5 mm.

It is remarkable to notice that the impregnation depth of NCOAT Stone A (specimens 14 and 16) is comparable to that of product B, while the amount of used product is much less.

On the basis of these results the following conclusions can be drawn:

- Both nano-coatings have a much lower influence on the drying than traditional water repellent products.
- NCOAT Stone has a limited influence on the drying of the brick, even when used in an amount 3 times higher than recommended in the information data sheet.
- NCOAT Stone A slightly delays the drying when applied in the amount recommended in the information sheet. If a higher amount is used (0.45 l/m^2) the effect becomes larger, but is still less than for traditional products A and B.

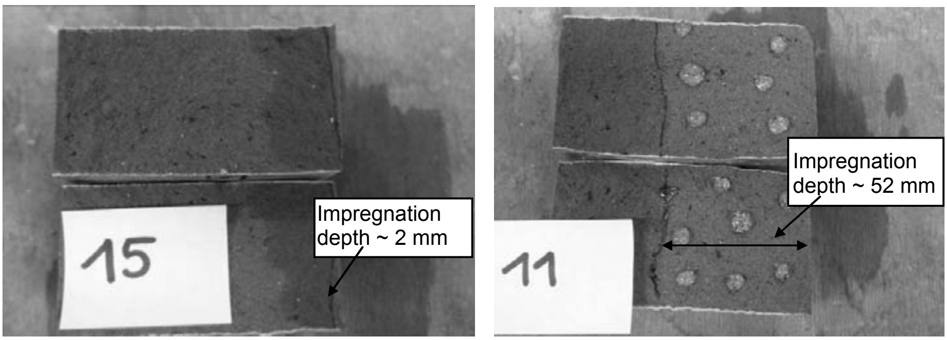

Figure 4: Impregnation depth of NCOAT Stone A (left) and product A (right)

Table 2: Impregnation depth obtained by the different products

Specimen no.	Product	Impregnation depth (mm)	Amount used product (g)
2	NCOAT Stone	0.2	0.89
17	NCOAT Stone	0.2	0.95
10*	NCOAT Stone	1.5	2.26
13*	NCOAT Stone	1	2.26
6	NCOAT Stone A	Not visible	0.81
15	NCOAT Stone A	2	0.77
14*	NCOAT Stone A	3.5	2.30
16*	NCOAT Stone A	4	2.29
8	Product A	25	7.5
9	Product A	30	7.59
11	Product A	52	7.57
3	Product B	4	4.92
12	Product B	3	5.04
18	Product B	5	5.04
19	Not treated	-	-
21	Not treated	-	-
22	Not treated	-	-

4 Discussion and conclusions

On the basis of the obtained results, it is possible to draw the following conclusions on the tested nano-coating products:

- The amount of nano-coating product to be used needs to be determined on the basis of the properties (porosity and pore size distribution) of the substrate. The amount of product reported in the information data sheet was not sufficient to fully impregnate the fired-clay brick surface; at least 3 times the amount had to be used.

- If a sufficient amount of product is used (in the case of fired-clay brick about 0.45 l/m^2), the tested nano-coatings are effective in hindering the absorption of water. Their effectiveness in limiting the ingress of water is comparable to that of traditional water based silane-siloxane water repellent products.
- Both nano-coatings delay the drying much less than the tested traditional water repellent products. NCOAT Stone has a limited effect on the drying of the brick. NCOAT Stone A slows down the drying slightly more than NCOAT Stone, but still much less than the tested traditional water repellent products. This can both be due to the properties of the nano-coating products as well as to their limited impregnation depth.

It can therefore be concluded that both tested nano-coatings are effective in hindering the ingress of water and, at the same time, have a limited influence on the drying of water saturated material. This suggests that these new nano-coatings might have the advantages of the traditional water repellent products, without suffering of their limits. Nevertheless, there are some questions left which should be answered before a complete evaluation of advantages and risks of these products can be performed and their application on valuable objects can be proposed:

- What is the suitable amount of product which should be applied, depending on the properties of the material to be treated?
- What is the durability of these products? It is known that UV light can damage traditional water repellents: the treatment becomes not effective anymore at the surface, but, due to the deep impregnation reached by the traditional product, remains effective in depth, even several years after the application [8]. In the case of nano-coatings, which have a very limited impregnation depth, UV light might significantly reduce the service life of these products.
- Is it possible to repeat the treatment? Re-treatability is an important requirement for surface treatments and it is relevant to know if, when needed, a new application of the treatment would be possible.
- Is the limited effect of nano-coatings on the drying, due to the different properties of the nano-coating with respect to the traditional products, or would traditional products, if applied in limited amount, show the same behavior as the nano-coatings?
- What is the effect of nano-coatings on salt crystallization and frost damage? Accelerated tests in the laboratory should be performed before these treatments could be applied in the practice of conservation on valuable and irreplaceable materials.

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