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# Hygric properties of hydrophobized building materials

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**Abstract.** Moisture loads due to wind-driven rain can lead to accelerated decay of exposed building facades. Hydrophobic impregnation reduces water absorption of facade materials and is thus presumed to decrease moisture related damages. Hydrophobic impregnation however also lowers the drying speed of the exposed facade, leaving mainly water vapour transfer to take place. This study examines the open porosity and capillary absorption coefficient of impregnated brick samples as well as the effect of hydrophobic impregnation on the vapour permeability of brick and mortar samples. The open porosity was measured with vacuum saturation test, the absorption coefficient was determined by water uptake tests, both done after one month of curing of the impregnated brick samples. The vapour permeability was derived from cup tests and from drying tests. The resulting open porosity from brick samples indicates that the changes in the overall pore structure are minimal after impregnation. In addition, the absorption coefficient of brick was found to be fairly close to zero, even with low concentrations of active ingredient, and regardless the percentage of silane/siloxane. Our findings support the claim that the hydrophobic impregnation does not influence significantly the water vapour permeability of brick and mortar.

## 1 Introduction

Masonry walls exposed to wind-driven rain exhibit elevated moisture contents [1], which can induce a higher potential risk of moisture related damage [2]. Hydrophobic impregnation is considered to counteract this, by significantly reducing the absorption of liquid water in exposed facades. Hydrophobization is though also known to slow down the drying speed of impregnated materials [3]. The final net impact of hydrophobization on the moisture response of masonry walls is hence undetermined still.

The objective of this study is to investigate the influence of hydrophobic impregnation on the moisture storage and transport properties of building materials. First, the paper presents results from vacuum saturation tests to determine the change in vacuum saturation moisture content between untreated and impregnated brick. Subsequently, it is investigated how a low concentration of active ingredients affects the impregnation strength, quantified

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by the water absorption coefficient. The paper continues by studying the vapour transport with cup tests and alternatively with drying tests, a methodology developed to determine the impact of any remaining liquid transport in hydrophobic materials.

2 Laboratory test setup

Table 1 summarizes the test methods, building materials and water-repellent agents (liquid and cream products) used to investigate the impact of hydrophobic impregnation on open porosity ( $\Phi$ ), water absorption coefficient ( $A_{cap}$ ) and vapour diffusion resistance factor ( $\mu$ ).

Table 1. Test plan.

| Vacuum saturation test ( $\Phi$ ) acc. to [4] (0.4x4x4 cm samples)  |                 |                 |        |         |               |
|---------------------------------------------------------------------|-----------------|-----------------|--------|---------|---------------|
| Identification of material<br>(No. of samples)                      | Product         | Type            | Form   | Diluent | Conc.         |
| R brick (5)                                                         | Wacker SMK 2100 | Silane/siloxane | Liquid | Water   | 5 %           |
| Capillary water uptake ( $A_{cap}$ ) acc. to [5] (8x4x4 cm samples) |                 |                 |        |         |               |
| R brick (5)                                                         | Untreated       |                 |        |         |               |
| R brick (9)                                                         | Wacker SMK 2101 | 90% silane      | Liquid | Water   | 1 / 2.5 / 5 % |
| R brick (9)                                                         | Wacker SMK 1311 | 90% siloxane    | Liquid | Water   | 1 / 2.5 / 5 % |
| R brick (9)                                                         | Wacker SMK 2100 | Silane/siloxane | Liquid | Water   | 1 / 2.5 / 5 % |
| Cup test ( $\mu$ ) acc. to [6] (8 cm diameter, 3 cm height samples) |                 |                 |        |         |               |
| R brick, Y brick, H brick, L mortar (4)                             | Untreated       |                 |        |         |               |
| R brick, Y brick, H brick, L mortar (4)                             | Remmers FC      | Silane          | Cream  | Water   | 40 %          |
| Drying test ( $\mu_{eq}$ ) (1x4x4 cm samples)                       |                 |                 |        |         |               |
| R brick, Y brick, H brick, L mortar (3)                             | Wacker SMK 2100 | Silane/siloxane | Liquid | Water   | 6 %           |
| R brick, Y brick, H brick, L mortar (3)                             | Remmers FC      | Silane          | Cream  | Water   | 40 %          |

R brick: Robusta Vandersanden Belgian brick, Y brick: Yellow soft molded Danish brick, H brick: Historic Danish brick from an old building in Copenhagen (1944), L mortar: carbonated lime mortar.  $\mu_{eq}$ : equivalent  $\mu$  value derives from drying test.

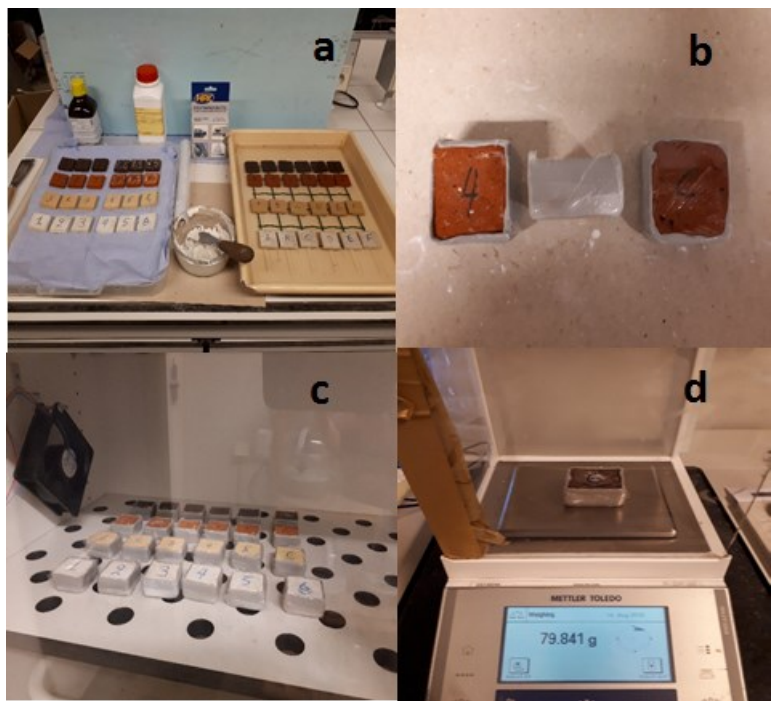
The impregnation process in the laboratory consisted of the following steps: the samples, prepared from regular bricks and casted mortar, were washed with deionized water to avoid absorption of extra salts and were carefully cleaned with a brush to remove dirt and dust. Afterwards, the samples were stored for drying in an oven (70 °C) for the absorbed moisture from the intense water exposure to evaporate. After reaching a stable mass (4-5 days), cooling in a desiccator took place, for the samples to reach room temperature and relative humidity. For impregnation with liquid products one surface of each sample was exposed to free agent uptake until the sample became fully impregnated (by visual observation of top surface becoming darker). The cream product was applied with a brush on the sample top surface with sufficient amount of agent for the sample to become fully impregnated. Finally, the samples were cured for one month in a climatic chamber (21 °C, 53.4% RH).

Vacuum saturation test was conducted according to [4], in order to determine open porosity ( $\Phi$ ), which is proportional to vacuum saturated moisture content  $w_{sat}$ .

A free water uptake test was conducted to obtain the water absorption coefficient ( $A_{cap}$ ) according to [5]. As impregnation significantly reduces the capillary water uptake, the test went on for three hours for impregnated samples compared to one hour for untreated samples. Measurement time intervals were: 10', 30', 1h, 1h 30', 2h, 3h. In addition, measurements were conducted after 18h and 30h but it was not possible to define a second stage in the water uptake curve [7]. Therefore, the absorption coefficient was calculated, taking into account all the points obtained from the water uptake test (3h), since it was assumed that all points belonged to the first stage of the water uptake test.

The cup test was conducted along [6], to calculate the water vapour diffusion resistance factor ( $\mu$ ). After pre-conditioning, each sample, enclosed in a lid, was attached to a cup containing a saturated salt solution ( $K_2SO_4$ , 97.3% RH) and placed in a climatic chamber (21 °C, 53.4% RH). The samples were weighed twice a week for four weeks. Further description of the procedures for the free water uptake, cup and vacuum saturation tests could be found in [8].

In a drying test developed at KU Leuven, impregnated samples were attached with kaolin clay (50% hydrated aluminum silicate – 50% water) on top of water saturated samples, sealed and left to dry in a climatic chamber (21 °C, 53.4% RH) for 17 days with daily measurements of mass reduction (see Fig. 1).



**Fig. 1.** Drying set up of impregnated samples a) Fully impregnated samples (left) and water saturated samples (right), b) Impregnated and saturated sample attached with kaolin clay to ensure hydraulic contact, seen from the top (impregnated), side and bottom surface (saturated). c) Left to dry out only from top surface in a climatic chamber (21°C, 53.4 % RH). d) Weighing of samples.

The current drying set up can provide the drying curve of the impregnated samples, and this can be translated into an equivalent vapour permeability, from the section of the test with a constant drying rate:

$$vapor\ permeability = (slope * thickness) / (pressure\ difference * surface\ area) \quad (1)$$

3 Results and Discussion

Open porosity ( $\Phi$ ) and vacuum saturation moisture content  $w_{sat}$  do not seem to be significantly influenced by hydrophobic impregnation (see Table 2). This is an indication that there is almost the same available pore volume space in the hydrophobized material that can be filled after submerging the sample and induce hydrostatic overpressure difference with the vacuum saturation test. The small reduction of the open porosity could be due to a limited extent of clogging in the finer pores of the brick [9].

Table 2. Results of vacuum saturation test. Open porosity and moisture content.

| R brick                                                           | Untreated* | Impregnated |
|-------------------------------------------------------------------|------------|-------------|
| Open porosity $\Phi$ [%]                                          | 32.6 (0.4) | 30.8 (0.01) |
| Vacuum saturation moisture content $w_{sat}$ [kg/m <sup>3</sup> ] | 326 (3.5)  | 307.9 (8.6) |

\*Values of untreated obtained from [10], where the same brick type is used.

The current study checks whether lower than recommended concentrations for brick samples, being 6 to 10% for SMK products [11], still have a good water repellency performance, as expressed by a low  $A_{cap}$ . According to Table 3, even with concentrations between 1 and 5 %,  $A_{cap}$  is very low compared with the untreated material. Further, the effect of the different water-repellent agents is the same for a specific type of brick. Combining the results in Table 2 and 3, the reduction in  $A_{cap}$  is therefore not due to a reduction of the pore space but due to changes in the adhesion between water atoms and pore walls.

Table 3. Water absorption coefficient of type R brick.

| Agent                                                | Untreated       | SMK 2101      |               |               | SMK 1311      |               |              | SMK 2100      |              |               |
|------------------------------------------------------|-----------------|---------------|---------------|---------------|---------------|---------------|--------------|---------------|--------------|---------------|
| Conc.                                                |                 | 1%            | 2.5%          | 5%            | 1%            | 2.5%          | 5%           | 1%            | 2.5%         | 5%            |
| $A_{cap}$<br>[10 <sup>-3</sup> kg/m <sup>2</sup> √s] | 607.3<br>(20.4) | 0.63<br>(0.3) | 0.43<br>(0.2) | 0.15<br>(0.1) | 0.47<br>(0.2) | 0.53<br>(0.2) | 0.3<br>(0.2) | 0.77<br>(0.3) | 0.5<br>(0.2) | 0.27<br>(0.1) |

The values in brackets corresponds to the standard deviation of the measurements.

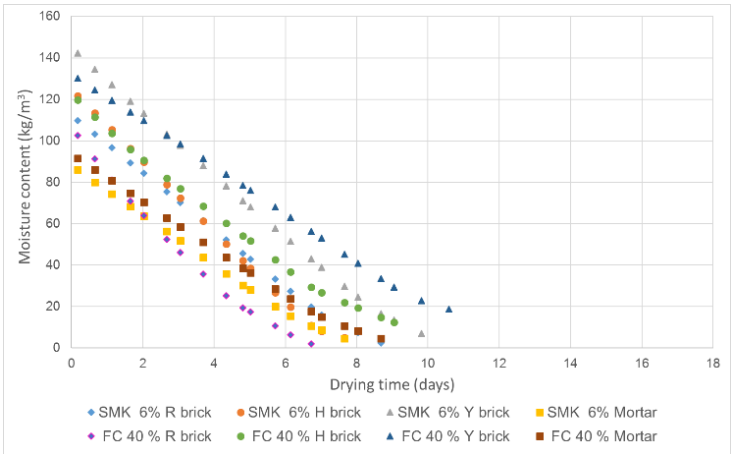


Fig. 2. Drying curves, average of three tested samples for each water-repellent agent (SMK 2100 6% and FC 40%) and building material (brick and mortar types according to Table 1).

Figure 2 shows the drying curves of impregnated samples, indicating that “trapped” moisture behind the hydrophobic layer is able to dry out, with the vapour diffusion resistance of the impregnated sample as the dominant resistance.

The vapour diffusion resistance factor ( $\mu$ ) of the tested types of brick and mortar do not seem to be significantly influenced by hydrophobic impregnation (Table 4). Opposed to the cup test, in the drying test, liquid transfer between the water saturated and the impregnated sample could take place as  $A_{cap}$  of impregnated samples is not completely zero. This explains why the drying test results in lower  $\mu$ -values. A small percentage of clogging in the fine pores of the impregnated materials [9] could possibly explain the increase in  $\mu$ -value in impregnated samples using cup test where there is solely vapour transfer. Although, drying test can provide an estimation of the  $\mu$ -value, by having solely vapour transfer cup test should be considered more reliable. Moreover, the comparison of the resulting  $\mu$ -values between cup test and drying test indicates limited liquid transport in the hydrophobic layer in the drying test that can accelerate the drying speed.

**Table 4.** Vapor permeability ( $\delta_v$ ) and vapor diffusion resistance factor ( $\mu$ ) of untreated and impregnated samples. Cup test and drying test for three types of brick and one type of mortar.

|                     |                                    | R brick    | H brick   | Y brick    | L mortar  |
|---------------------|------------------------------------|------------|-----------|------------|-----------|
| Cup test, untreated | $\delta_v$ [ $10^{-11}$ kg/(msPa)] | 1.8 (0.2)  | 2.3 (0.2) | 1.7 (0.2)  | 2.5 (0.1) |
|                     | $\mu$ (53-97%)                     | 11.3 (1.2) | 8.7 (0.9) | 11.9 (1.4) | 8.0 (0.4) |
| Cup test, FC 40%    | $\delta_v$ [ $10^{-11}$ kg/(msPa)] | 1 (0.8)    | 2 (0.2)   | 1 (0.2)    | 2 (0.1)   |
|                     | $\mu$ (53-97%)                     | 15.1 (0.9) | 9.7 (1)   | 13.7 (2)   | 9.7 (0.7) |
| Drying test, SMK 6% | $\delta_v$ [ $10^{-11}$ kg/(msPa)] | 3 (0.4)    | 3.4 (0.3) | 3.5 (0.5)  | 2.9 (0.8) |
|                     | $\mu-eq$ (53≈100%)                 | 6.7 (0.9)  | 5.8 (0.6) | 5.8 (0.8)  | 7.1 (1.8) |
| Drying test, FC 40% | $\delta_v$ [ $10^{-11}$ kg/(msPa)] | 5.1 (2)    | 3.6 (2)   | 2.3 (0.8)  | 2.5 (0.5) |
|                     | $\mu-eq$ (53≈100%)                 | 4.1 (1.1)  | 6.4 (3.1) | 9.4 (3.1)  | 8.0 (1.5) |

The values in brackets correspond to the standard deviations of the measurements.

4 Conclusions

The slightly reduced open porosity between untreated and hydrophobic impregnated brick indicates only a minimal change in the pore structure of impregnated brick.

According to the transport properties of the hydrophobic impregnated brick tested, the absorption coefficient is significantly reduced compared to the untreated regardless of the percentage of silane/siloxane, even with lower concentrations than recommended. On the other hand, the vapour diffusion resistance factor ( $\mu$ -value) does not seem to significantly change after hydrophobic impregnation, neither in bricks or mortar.

Drying set up can provide an estimation of the vapour diffusion resistance factor ( $\mu$ -value) of the impregnated materials, but cup test could be considered as a more accurate method as the samples are not in contact and there is no liquid transfer. However, the slightly lower  $\mu$ -value derived from drying tests indicate limited liquid transport in the hydrophobic layer that accelerates the drying speed.

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