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On the necessity of new hydrophobic treatment after repointing of water repellent masonry

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ABSTRACT

The impregnation of the exterior surface of a masonry wall with a water repellent is a common intervention in (historic) building renovation and maintenance. Such treatments, whilst degrading at the surface with time under influence of ultra violet light, remain effective below the surface several decades after their application. During renovation works of masonry previously treated with a water repellent, the question arises whether it is necessary to repeat the hydrophobic treatment of the entire masonry after repointing. Opposing opinions exist with this regard, but no research clearly supporting one or the other. This research investigates for the first time the effect of hydrophobic treatment when applied on previously treated and repointed masonry walls. Small masonry walls were subjected to rain periods in the laboratory and their water uptake and drying behaviour were studied. Moreover, this laboratory research was followed by 30 months of outdoor exposition of the masonry specimens. The following cases were considered: (1) wall treated with water repellent, (2) wall treated with water repellent, followed by repointing but without new water repellent treatment, (3) wall treated with water repellent, followed by repointing and retreatment. This was done for three different types of pointing mortar: ordinary Portland cement and natural hydraulic lime with standard sand, and natural hydraulic lime with sand with one grain size. The results show that, after prolonged rain periods, the water uptake by repointed but not retreated masonry is comparable to that of untreated, non-hydrophobic masonry, whereas drying is considerably slower. This leads to a high saturation degree in repointed but not retreated masonry, which, in turn, increases the risk of damage to the masonry by e.g. frost. Therefore, retreating repointed hydrophobic masonry should definitively be considered.

1. Introduction

The impregnation of the exterior surface of a masonry walls with a water repellent is a common intervention in (historic) building renovation and maintenance. It is, however, not undisputed and often undesirable in case of built heritage. Water repellent treatments are meant to protect the masonry from water ingress, mainly from rain. These treatments increase the contact angle between water and the building material, inhibiting thereby capillary transport of liquid water in the treated layer. As a consequence, in a masonry wall treated with a water repellent, liquid water transport to the surface of the wall is not possible and drying can only take place by water vapour transport; being vapour transport much slower than liquid transport, a material treated with water repellent will dry slower than an untreated one. This may have negative effects on frost and salt decay [1,2]. Water repellent treatments, including the most common categories of silane and siloxane products, are generally irreversible; therefore, current interventions often have to deal with the effects of past treatments. Such treatments, whilst degrading at the surface with time under influence of UV, remain effective below the surface several decades after their application [e.g. 2–5]. For example, Van Hees et al. documented this after a period of 10–15 years for projects from the 1970′s and 1980′s in several European countries in 1996 [2,3]. An unpublished survey by the current authors and colleagues of some of the same objects in 2018 still showed part of the masonry to be water repellent. These observations are in line with practical experience of restorers and contractors who, when repointing is needed, have to deal with the effect of past hydrophobic treatments. Besides potential problems of adhesion of the new pointing mortar to the

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hydrophobic bedding mortar and bricks/stones, the question arises whether it is necessary to repeat the water repellent treatment of the entire masonry after repointing. Opposing opinions exist with this regard. If the masonry is not retreated, water will penetrate through the non-hydrophobic joints, whereas it will have difficulties to escape because the bricks only allow drying by vapour transport, which is notoriously slow. As a consequence, the masonry will remain longer and more wet, enhancing the risk of freeze-thaw and/or salt damage. From this point of view, retreatment is advised. However, others advocate that, because the bricks make up the majority of the surface area of the masonry by far, the amount of absorbed water will be small, whilst the masonry can still dry through the non-hydrophobic joints. If this is true, retreatment will not be necessary, with clear advantages in terms of intervention costs.

Whilst there is a significant body of literature covering the role of mortar joints on the hygric behaviour of brick masonry, especially considering capillary suction, interface resistance and composition [e.g. 6–9], the role of pointing is rarely considered; the same holds for the combination of water repellent treated brick and (un)treated joints. Therefore, the current study aims to evaluate both forementioned scenarios. In order to do so, the wetting and drying behaviour of small masonry walls was studied in the laboratory. The following cases were considered: (1) wall treated with water repellent, (2) wall treated with water repellent, followed by repointing but without new water repellent treatment, (3) wall treated with water repellent, followed by repointing and retreatment. This was done for three different types of pointing mortar, viz. ordinary Portland cement and natural hydraulic lime with standard sand, and natural hydraulic lime with sand with one grain size (gap-graded sand). Moreover, the laboratory research was followed by 30 months of outdoor exposition of the masonry specimens.

2. Approach, materials & methods

The study involved 1) characterization of the materials used, 2) preparation of small masonry walls, 3) evaluation of the wetting and drying behaviour of these walls, 4) evaluation of their behaviour in rain-drying cycles and 5) assessment of durability of treatments and of occurrence of decay after 2,5 years of outdoor exposition.

2.1. Materials and test specimen

Test specimens are composed by two bricks with a bedding and pointing mortar in between (Fig. 1). The size of the specimens is about 215 × 112×102 mm (l x h x b).

All specimens have been made with the same type of brick and bedding mortar, and treated with the same type of water repellent agent. The selected brick is a type widely used in the Netherlands: Waalrood, hand-mould shaped, Waal size (215 ×102×50 mm), produced by Wienerberger Beerse.

The bedding mortar is a lime-cement mortar with 3 lime: 1 cement: 10 aggregate by volume, the lime being Supercalco 90 from Carmeuse, the cement ordinary Portland cement (OPC), CEM I 42.5 N from ENCI (HeidelbergCement), the aggregate standard graded siliceous river sand with grain size 0–2 mm.

The thickness of the bedding and pointing mortar is about 12 mm.

Three compositions of the pointing mortar have been used: NHL - a mortar with a binder: aggregate ratio of 1: 3 in volume and natural hydraulic lime (NHL 3.5 from St. Astier) as a binder and standard sand with D_{max} 2 mm; OPC sg – similar to the NHL mortar but with OPC as binder; OPC gg a 1:3 mortar with ordinary Portland cement and gap-graded sand with a diameter between 0.8 and 1.2 mm obtained by sieving.

The latter was chosen as the use of gap-graded sand, leading to coarse porosity, may enhance the durability of pointings in frost sensitive situations [10]. Pointing was executed smooth and full, with a designed thickness of 12 mm.

Fig. 1. Example of sealed and pointed test specimens.

For all three pointing mortars, three types of specimens have been prepared:

- pointed and untreated (coded O);
- treated with a water repellent, subsequent removal of the pointing and repointing (coded HH)
- treated with a water repellent, subsequent removal of the pointing, repointing and renewed water repellent treatment (coded HHH).

The overall procedure for preparation of the test specimens consisted of the following steps: 1) assemblage of the bricks by application of the bedding mortar; 2) removal of the outermost (up to 2 cm depth) bedding mortar on one side, as preparation for pointing; 3) application of pointing mortar; 4) hardening and curing; 5) sealing of the lateral sides of the specimens with epoxy resin (Fig. 1); 6) application of water repellent on the surface by spraying; in order to apply similar amounts of water repellent, test specimens have been placed on a balance during application; 7) assessment of the penetration depth of the water repellent (Fig. 2); this was done in order to establish the depth of removal of

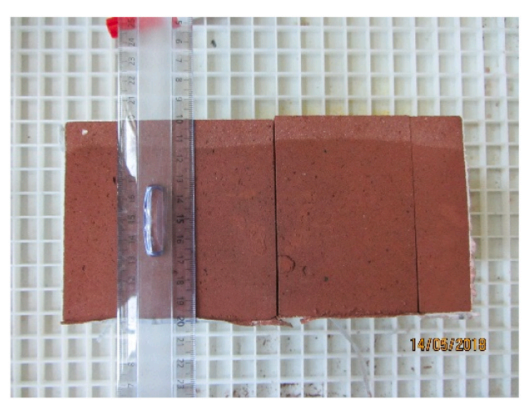

Fig. 2. Penetration depth of water repellent on a cross section of the brick; the light area (dry) in the upper part of the brick indicates the penetration depth of the water repellent (about 15 mm).

the old pointing and bedding mortar; 8) application of the new pointing mortar (HH and HHH series) and, if necessary, repair of the sealing, 9) hardening and curing of the repointing, 10) new application of water repellent treatment (HHH series). An overview of the specimens and their purpose is given in Table 1.

During preparation of the specimens, care has been taken to allow for sufficient curing time, for both bedding and pointing mortar as well as for the applied water repellent treatments. Specimens were cured for one week before application of the pointing; after pointing, the specimens were then cured for at least 28 days before the first application of the water repellent (specimens coded HH and HHH). After 21 days from the application of the treatment, the pointing was removed and applied again. After 28 days from re-pointing, HHH specimens were treated a second time with a water repellent; the water repellent was then allow to cure for at least 21 days, before the start of the tests.

During removal of the pointing, care has been taken to remove the entire treated part.

Table 1 provides an overview of the specimens made with each pointing mortar (NHL, OPC sg, OPC gg).

The selected water repellent agent is a solution of ca. 7 wt. oligomer alkyl-alkoxysilane (triethoxy(2,4,4-trimethylpentyl)silane) in an alifatic solvent, Funcosil SNL produced by Remmers.

When relevant for the tests, a waterproofing membrane (Mapegum WPS by Mapei) has been applied in two layers for sealing the sides of the test specimens. This product was chosen after evaluation of the effect of several candidates on both water absorption and drying of the sealed surface [11].

2.2. Methods

2.2.1. Characterization of individual materials

For the individual materials (i.e. brick, bedding and pointing mortars), water absorption by capillarity, drying, total porosity and pore size distribution have been determined. Water absorption by capillarity and drying have been determined in sixfold on specimens of 50 × 50×20 mm. For the mortars, specimens have been made on a brick substrate placed in a styrofoam mold, brick and mortar being separated by paper. Specimens have been demolded after a day and subsequently allowed to harden for 14 days. Subsequently, specimens have been dried at 50 °C til constant mass before sealing. Water absorption (including calculation of Water Absorption Coefficient, WAC) and drying have been determined following NEN-EN 15801:2009 [12] and NEN-EN 772–11:2011 [13]. Open porosity and pore size distribution were determined in twofold by mercury intrusion porosimetry (MIP), using specimens of ca. 1 cm^3. Total porosity was also determined from the dry mass and mass below water according to RILEM CPC 11.3 [14].

2.2.2. Assessment of treatment and pointing quality

Quality (i.e. water repellent effect) of the water repellent treatment and pointing have been determined using Karsten pipes measurements and pointing hardness test according to CUR Recommendation 61:2013 [15], respectively. In the latter case, in order to obtain reliable results, specimens were supported. Normally, the pointing hardness is determined by nine measurements on the horizontal joints with one square metre of masonry, and expressed as the median [15]. This is evidently not possible for the current specimens. Therefore, pointing hardness has been determined in threefold for each small wall and is reported as the median of all measurements of walls of the same type.

Table 1
Number of specimens for each of the test.

Purpose op specimens	Untreated	Treated Repointed	Treated Repointed Retreated	Treated
	O	HH	HHH	H
Penetration water repellent				5
Drying, moderate	3	3	3	
Drying, high	3	3	3	
Rain test, trial	2			
Rain test & outdoor exposure	3	3	3	
Spare	8			

2.2.3. Drying rate of O, HH and HHH specimens

In order to establish the effect of retreatment after repointing, the drying rate of the treated and untreated masonry walls has been determined. Prior to drying, test specimens were saturated at two levels, viz. the moderate and high conditions of the old Dutch freeze-thaw test for masonry bricks, NEN 2872:1989 [16]. Moderate saturation was obtained by drying the specimens til constant mass and subsequently allowed to absorb water during 4 days by immersion under atmospheric pressure and room temperature. High saturation was obtained by placing the specimens in a thermostat water basin in which water temperature was increased to 80 °C and maintained for 72 h. After cooling during two hours, the specimens were kept in the water basin for an additional 22 h. After saturation, all specimens were sealed on all except one side and drying was allowed at 20 °C, 50%RH, whilst their mass was periodically determined.

2.2.4. Rain test on HH and HHH specimens

A rain test has been performed to determine the different saturation degree of HH (treated, pointed and not retreated) and HHH (treated, pointed and retreated). A purpose made test setup has been built (Fig. 3): the specimens were laid on a metal grid, positioned at an angle of approximately 30º, to obtain an even thin water film on the surface; 10 water sprinklers were positioned in two rows, at a distance of 150–200 cm from the specimens top surface, depending on the position of the specimen (Fig. 3). The test involved continuous raining for 8 h a day for four days; this period was enough for the untreated specimens (O) to reach the saturation degree corresponding to moderate saturation as pre-conditioning for the freeze-thaw test (see above). The test was performed under laboratory conditions, i.e. about 20 °C, no (artificial) sunning nor wind. To prevent evaporation from the test specimens in periods without rain, the surface of the specimens was covered with a plastic foil. The specimens were weighted after the first, second and fourth 8 h rain period. At the fourth day, the moisture distribution in brick and mortar was determined gravimetrically, on powder samples collected at different depths from the surface.

2.2.5. Outdoor exposure of O, HH and HHH specimens

After the end of the rain test, specimens were exposed outdoors at the premises of the TNO laboratory in Delft, the Netherlands, from October 11, 2018 til April 8, 2021 (Fig. 4). Relevant climate data are given in Fig. 5. The masonry walls faced east and were placed under angle to enhance exposure to precipitation. The masonry walls were periodically inspected visually; after 2.5 years exposure, the state of the pointing, the hydrophobicity (including penetration depth of the treatment) and moisture contents of brick and mortar were determined.

3. Results

3.1. Materials properties

Fig. 6 shows the open porosity and pore size distribution of the brick, bedding and pointing mortars, as determined by MIP. The brick has an open porosity of 21.99 ± 1.87 vol% and pores in the range of 5–7 µm. The open porosity of the bedding mortar is 25.51 ± 0.14 vol%, composed by pores smaller than 1 µm. A very limited amount of pores in the range of 1–400 µm is observed. These properties are in agreement with what expected for a 1:2,5 binder/aggregate ratio of this mortar. The porosity and pore size of the pointing mortars vary considerably:

Fig. 3. Rain test.

Fig. 4. Test specimens in outdoors exposition. Left October 11, 2018, right January 21, 2019.

NHL and OPC sg mortars show very different open porosity and pore size distribution, despite their identical binder to aggregate ratio (1:3 in volume) and sand grain size. NHL mortar has much higher volume of small pores, leading to a high open porosity, and misses coarser pores in the 100–400 μm range, which are present in the OPC sg mortar. The reason of this difference is unclear. Differently, the effect of the sand grain on pore size is clear: pointing mortar OPC gg with gap graded sand shows a large volume of pores in the 100–400 μm range, pores which are absent in the OPC sg with standard graded sand: in OPC sg the porosity in between coarser sand grain is filled by small grains and binder. MIP can only measure pores with radius between about 0.01 and 400 μm; therefore finer and coarser pores are not contributing to the open porosity measured by MIP.

The capillary water absorption of the materials was measured and the WAC calculated. Results are reported in Table 2. Among pointing mortars, NHL-based pointing and OPC-based pointing with gap graded sand show the highest WAC; OPC mortar with standard sand has the lowest WAC. Table 2 also gives the total porosity of the materials as determined by MIP and immersion; results fit reasonably well for brick, bedding mortar and NHL pointing. OPC pointing mortars show a higher porosity when measured by immersion, suggesting the presence of pores/voids coarser than 400 μm. Pore size distribution and total porosity are reflected by the drying behaviour (Fig. 7), the NHL pointing mortar with small pores showing the slowest drying, the brick and pointing mortar OPC gg fastest drying. The OPC sg pointing maintains the highest moisture content over time: after more than 50 day of drying, its weight is stable and less than 70% of the absorbed water has evaporated.

The pointing hardness at an age of three weeks, expressed as median, is comparable for all three types of pointing mortars. The median of all samples is 13 (109 measurements), 16 (112 measurements), 16 (106 measurements), respectively for the NHL, OPC sg and OPC gg mortars.

The pointing hardness measured on the specimens is reported in Fig. 8. According to CUR-Recommendation 61:2023 [15], the pointing hardness is defined as the median of 9 measurements on the horizontal joints within one square metre of masonry. This is not possible for the small laboratory samples. Therefore, the median has been taken of 18 measurements, being 3 measurements on each of 6 replicate specimens. Based on these results, it can be concluded that NHL pointing shows, as expected, a lower hardness than OPC-based pointing mortars. The latter is, however, also low compared to modern cement based pointing. The gap graded sand (OPC gg) leads to a lower hardness than in the case of standard graded sand. The specimens regularly show a lower hardness after treatment of the walls (compare O walls with HH and HHH walls). The reason for this is unclear.

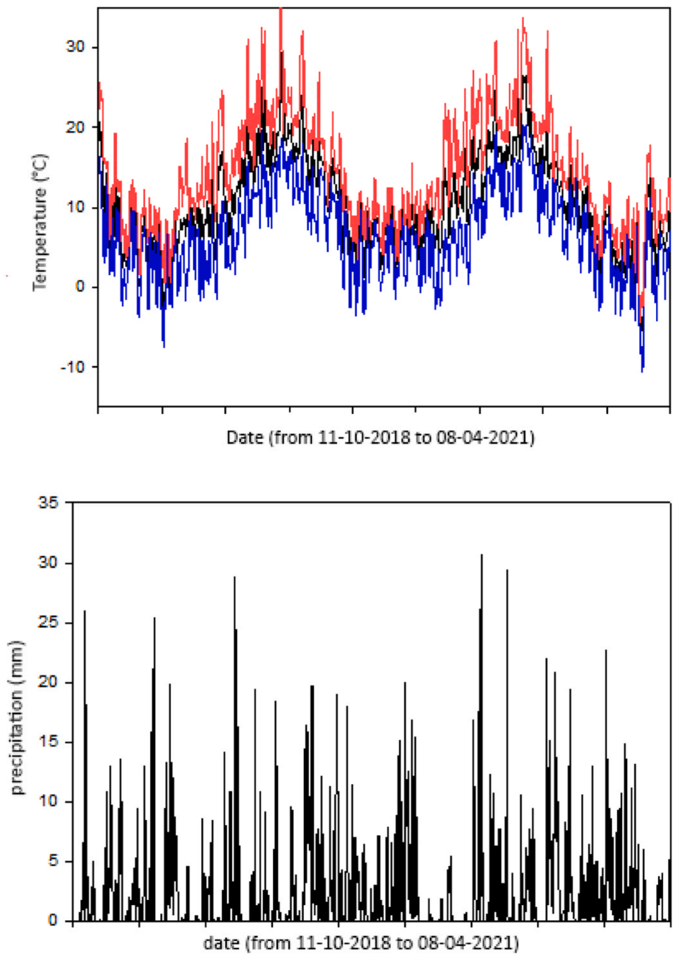

Fig. 5. Climate date for weather station Rotterdam, close to Delft, over the period October 11, 2018 til April 8, 2021. Upper graph: maximum (red), mean (black) and minimum (blue) day temperature. Lower graph: amount of daily precipitation.

3.2. *Effect water repellent*

Fig. 9 shows the amount of water repellent absorbed by the test specimens in the first (before repointing) and second application (after repointing), as function of the type of pointing mortar. There is no significant effect of the type of pointing; absorption is ca. 0.35 kg m^{-2}. As can be seen from Fig. 8, the second application after repointing involves in a higher absorption of water repellent. The reason is unclear. The presence of (micro)cracks at the interface between brick and pointing mortars could be a possible explanation. This would imply an increased risk of not perfect working of the water repellent. The impregnation depth measured in the brick is 10–15 mm for the first application (Fig. 2). After the second application a slightly deeper impregnation (16–19 mm) was measured. The depth of impregnation in the mortar after the first application is similar to that of the brick and equal or occasionally a few mm deeper than the thickness of the pointing, which is 12–13 mm. This is the same for the second application.

3.3. *Drying of masonry walls*

Fig. 10 shows the drying of untreated masonry walls with the three different pointing mortars, starting from moderate and high saturation levels. In both cases, the moisture content of the masonry walls is similar at onset of drying, i.e. there is no or little effect of the type of pointing on the amount of water absorbed. In case of moderate saturation, the walls dry almost completely within 65 days, without significant differences between the three types of pointing. In case of high saturation level, the masonry walls with the NHL based pointing dry slightly faster than those with a cement based pointing.

Fig. 11 shows the same curves, but for the masonry walls that have first been treated with the water repellent and subsequently been repointed. Again, the total amount of absorbed water at onset of drying is about the same for all pointing types. However, for the specimens with moderate saturation, an effect of the type of pointing on the drying rate is present. The drying rate decreases in the order NHL > cement with gap graded sand > cement. In these walls, as no liquid water transport can take place through the brick, the effect of the pointing mortar becomes more important. Curiously enough, this effect is not observed for the specimens with high saturation, though the walls with NHL based pointing mortar dry slightly faster during the latest stage of drying. The explanation for this is not clear. It can be speculated that the method of saturation, involving water of 80 °C, affected the performance of the water repellent treatment. For example, intrusion of liquid water into the pores of the treated layer could have occurred, due to the higher pressure during saturation at 80 °C. This hypothesis seems to be supported by the fact that the first part of the drying curves is steep suggesting that initially some liquid water transport to the surface has occurred, despite the presence of the water repellent.

Drying curves of masonry walls treated with water repellent, then repointed and treated again with water repellent are given in Fig. 12. For the specimens with moderate saturation, differences in drying rate are minimal: NHL ~ cement with gap graded sand > cement. For specimens with high saturation, no significant differences are observed between the three pointing types, though the slope of the drying curve changes faster for NHL; during the latest stage of drying, NHL dries slightly faster than the other pointing mortars.

Fig. 13 compares the drying behaviour of treated and repointed (HH) and untreated walls (O), starting at moderate saturation. The water repellent treatment considerably delays the drying of the masonry walls. Also when present only on brick (specimens treated once, HH), the water repellent significantly reduces the drying rate. After 65 days, walls that have been treated once and moderately saturated still have a moisture content between 1.5 wt% (NHL) and 4.5 wt% (cement with standard sand). The difference between untreated (O) and treated walls (HH) is more evident for cement-based pointing: as the brick cannot dry fast (because of the water repellent) and the pointing does not dry fast (because of fine porosity within the cement paste), these walls dry very slowly.

Retreatment after repointing, involving application of the water repellent on the new pointing (specimens HHH) reduces further the drying rate. After 65 days, walls with moderate saturation that have been treated twice still have a moisture content of about 5 wt%. There are small differences between the three pointings. The effect is the largest for NHL pointing and the smallest for the pointing with cement and standard sand. This is due to the fact that, even when untreated, the cement-based pointing contributes less to the drying of the masonry. In the case of NHL pointing, which itself significantly contributes to drying the masonry, retreatment causes a relevant difference in drying. Fig. 14 compares the drying of untreated and treated walls, starting at high saturation conditions. For the masonry walls with high saturation, water repellent treatment has a very strong effect on drying. After 65 days, walls that have been treated once still have a moisture content between 5 and 6 wt%. There is only a small effect of pointing type, NHL being slightly faster. When treated twice, the drying is further delayed during the second part of the drying period, but the differences observed are small and not relevant to practice. The samples show a clear effect of saturation conditions. At a moderate degree of saturation, the moisture content at onset of drying is different for the treated and untreated samples, as water does not penetrate the hydrophobe part of the pores by capillarity. At a high saturation degree, treated and untreated have a similar initial moisture contents. In this case, water reaches also the treated pores. This is confirmed also by the fact that the drying curves of

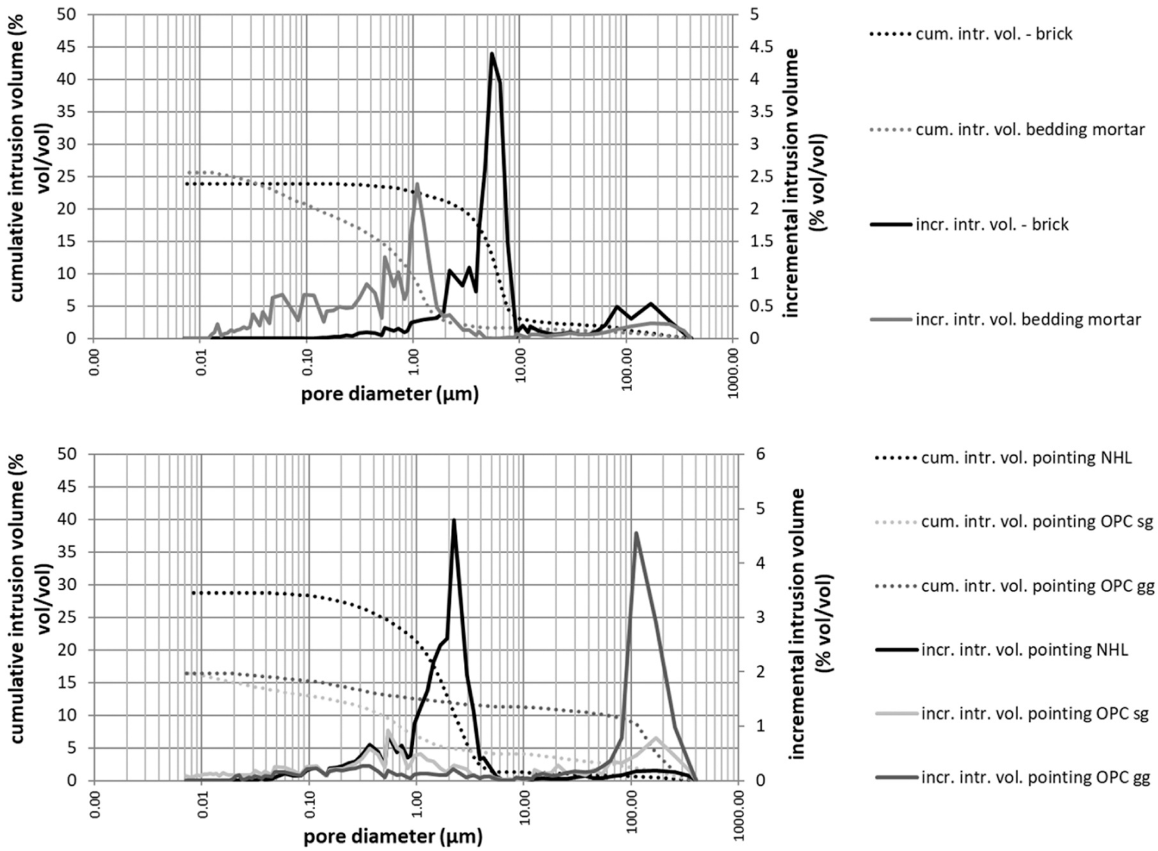

Fig. 6. Pore size distribution of the brick and bedding mortar (above) and of the different pointing mortars (below) as determined by MIP (because of readability reasons, only one of the two MIP measurements performed on each material is reported).

Table 2
Total porosity as determined by MIP (average of two samples, standard deviation in italics between brackets) and immersion (average of three samples, standard deviation in italics between brackets).

Material	WAC (g/cm^2 sec$^{0.5}$)	Porosity (vol%)	
		MIP	Immersion
Brick	0.038 *(0.01)*	21.9 *(1.87)*	21.2 *(0.23)*
Bedding mortar	0.038 *(0.00)*	25.4 *(0.23)*	24.6 *(0.15)*
Pointing, NHL	0.043 *(0.02)*	28.9 *(0.20)*	27.2 *(0.86)*
Pointing, OPC sg	0.029 *(0.02)*	16.4 *(0.03)*	20.2 *(0.90)*
Pointing, OPC gg	0.043 *(0.04)*	17.1 *(0.63)*	25.5 *(2.8)*

specimens with a high degree of saturation show an abrupt change in the slope, suggesting that, initially, some liquid water transport to the surface has occurred, despite the presence of the water repellent. This might be due to intrusion of liquid water into the pores of the treated layer during saturation at 80 °C. The presence of liquid water in the treated pores might have further affected moisture transport and smothered the effect of the type of pointing on the drying. In fact, as already observed, for walls which have been treated only once, there are no relevant differences in drying depending on type of pointing in the case of the high saturated walls, in contrast to the moderately saturated walls, where a clear effect is visible (Figs. 11, 12).

3.4. Rain test

The rain test involved 4 cycles of 8 h of continuous rain over 4 days without drying in between, i.e. 32 h of rain in total. As can be seen in Fig. 15, the moisture content in the untreated masonry walls (O) and the walls treated only once and then repointed (HH) has almost reached a plateau (i.e. saturation) within the first 8 h of rain, independently of pointing type. With no reapplication of water repellent after repointing, the total absorption is only slightly lower than for the untreated samples, probably due to the presence of a ~15 mm thick water repellent layer in the brick, which cannot be intruded by water. The masonry walls that have been treated, repointed and treated again (walls HHH) require a significantly longer time to saturation, those with NHL pointing being faster than those with cement based pointing. It is important to report that the walls repointed and treated a second time (HHH) show a large standard deviation (between 27% for OPC gg and 59% for NHL and OPC sg) in the amount of absorbed water, probably due to water ingress via microcracks along the interface between pointing and brick. The standard deviation in O and HH specimens was low and varied between 1% and 4.5%.

In Fig. 16, the moisture content of the walls is compared to the moisture contents of untreated walls obtained by applying the conditioning of moderate and high moisture loads according to the old Dutch freeze-thaw test for masonry bricks, NEN 2872:1989 [15]. For all pointing types, the untreated walls (O) as well as walls which have not been retreated after repointing (HH) (almost) reach the moderate saturation conditions already after 8 h of rain (or perhaps less, as 8 h was the first measurement point). This implies that a risk of frost damage is present for the non-retreated walls, comparable to the untreated ones. Retreatment after repointing results in significantly lower moisture contents. The effect of the type of repointing is limited.

In Fig. 17, the moisture contents of both brick and mortar at two different depths from the surface (0–2 cm and 2–4 cm) at the end of the rain test are shown. For all three pointing mortars, the moisture content is considerably lower for the retreated specimens (HHH) than for the untreated (O) and not retreated (HH) ones, indicating a smaller potential risk on frost damage. The moisture content of the brick is also lower in

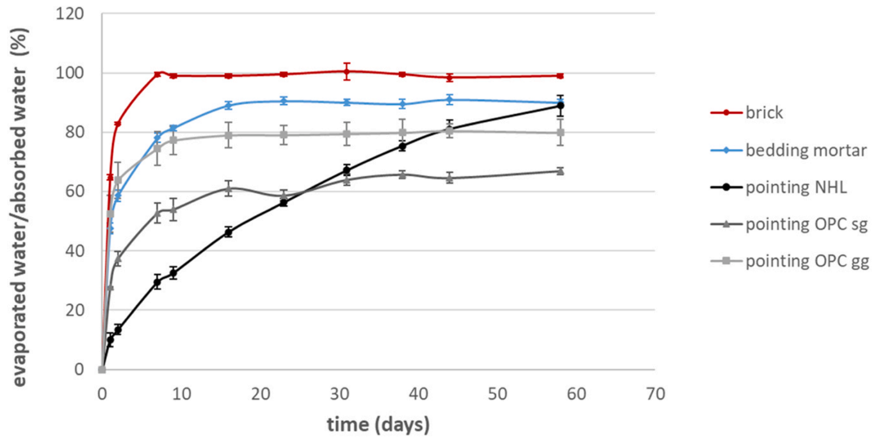

Fig. 7. Drying curves for the individual materials. Each line reports the average of measurements on 3 specimens; the bars at each measuring point report the standard deviation.

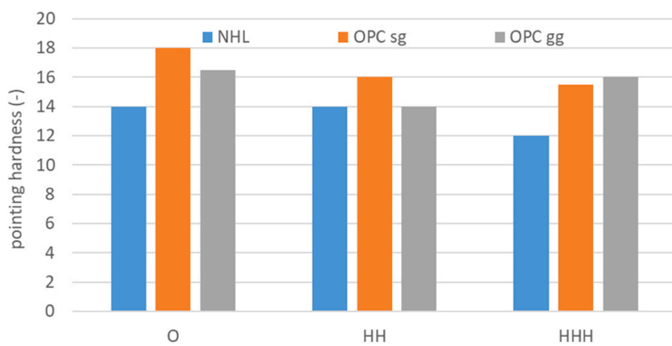

Fig. 8. Hardness of different pointing mortars (NHL, OPC sg, OPC gg), in untreated (O), repointed (HH) and repointed and re-treated (HHH) specimens. Each value is the median of 18 measurements.

the (re)treated walls, except for the OPC gg mortar that has not been retreated (i.e. the brick is hydrophobic, the mortar is not). This walls shows a high moisture content in the brick at 2–4 cm, which might be explained by limited penetration of the water repellent in this case.

3.5. Outdoor exposition

Fig. 18 gives an impression of the masonry walls after 2.5 years outdoor exposition. None of the test specimens shows damage. The surface of the brick is still hydrophobic; the hydrophobicity of the pointing could not be assessed, as this had already detached due to previous sampling during the exposition period.

4. Discussion

The discussion whether water repellent masonry should be retreated after repointing is widespread in practice. In case of NHL, when comparing the moisture content after wetting and drying of specimens that were only repointed (HH) with those that were repointed and retreated (HHH), it appears that the effect of water absorption on the moisture content in the masonry is faster than that of drying (Fig. 13). This implies that, when water is coming from the outside as rain, it would be beneficial to retreat the surface and prevent ingress; differently when water in the masonry is mainly coming from other sources (such as rising damp), it might be good to not retreat the surface. The walls pointed with OPC sg and gg pointing mortars dry slow anyway, and thus retreatment does not make a large difference on drying (Fig. 13). Therefore, retreatment should be preferred to avoid ingress of water. Retreatment results in significant reduction of water absorption (Figs. 15, 16), supporting such a retreatment.

From the rain test, it appears that the total water uptake of the repointed but not retreated masonry (HH) with OPC pointing mortars after 8 h of rain is comparable or a bit higher than that of untreated masonry (O) (Fig. 16). This total amount of water is comparable to the amount of water corresponding to moderate preconditioning conditions of the freeze-thaw test, though the specimens with the NHL pointing mortar lag behind (Fig. 16). This indicates that the often put forward argument that, when treated masonry is repointed but not retreated, the still water repellent brick makes up most of the masonry's surface and hence water absorption by the non-water repellent joints is of minor importance, is incorrect, at least for prolonged periods of rain. In contrast, retreatment after repointing reduces the water uptake significantly compared to untreated masonry (Fig. 16). The lower moisture

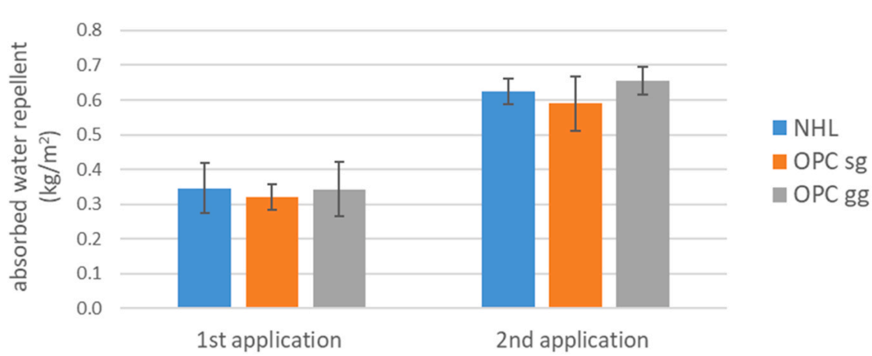

Fig. 9. Amount of water repellent absorbed by the wall specimens. Each bar reports the average of measurements performed on 6 (first application) or 3 (second application) specimens. The vertical lines report the standard deviation.

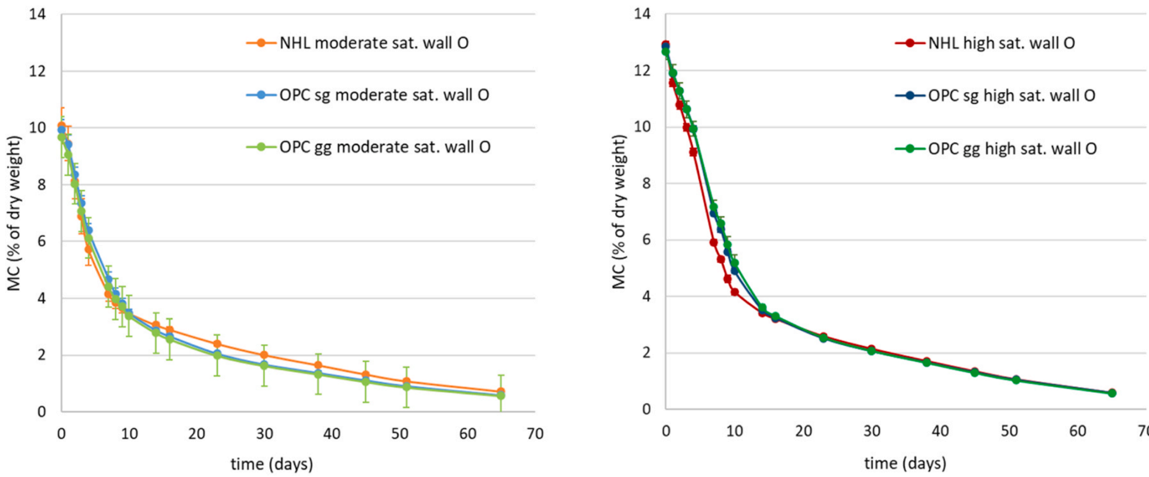

Fig. 10. Drying curves of untreated masonry walls (O) starting at moderate (left) and high (right) saturation. Each line is the average of measurements on 3 specimens, the vertical bars report the standard variation.

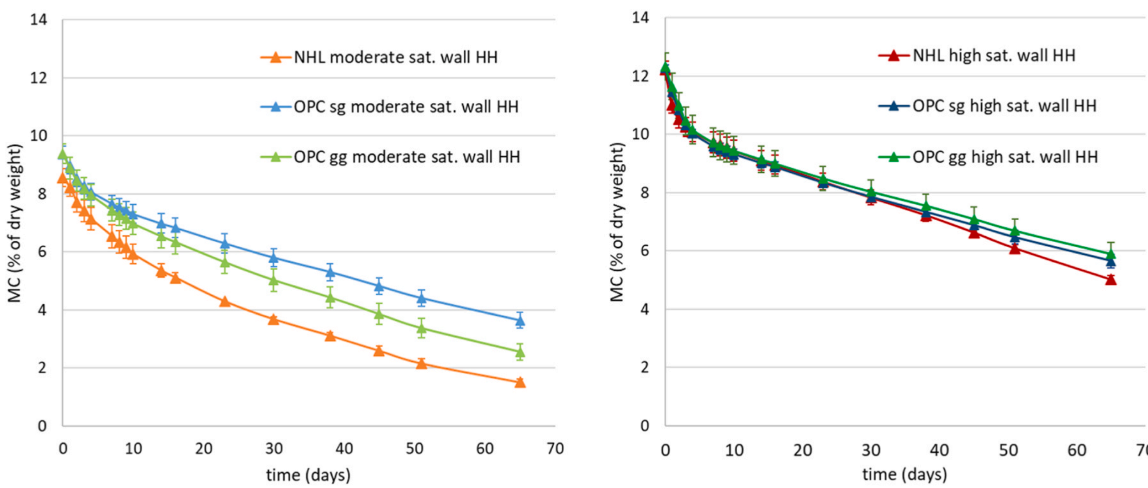

Fig. 11. Drying curves of masonry walls treated with water repellent and subsequently repointed (HH), starting at moderate (left) and high (right) saturation. Each line is the average of measurements on 3 specimens, the vertical bars report the standard variation.

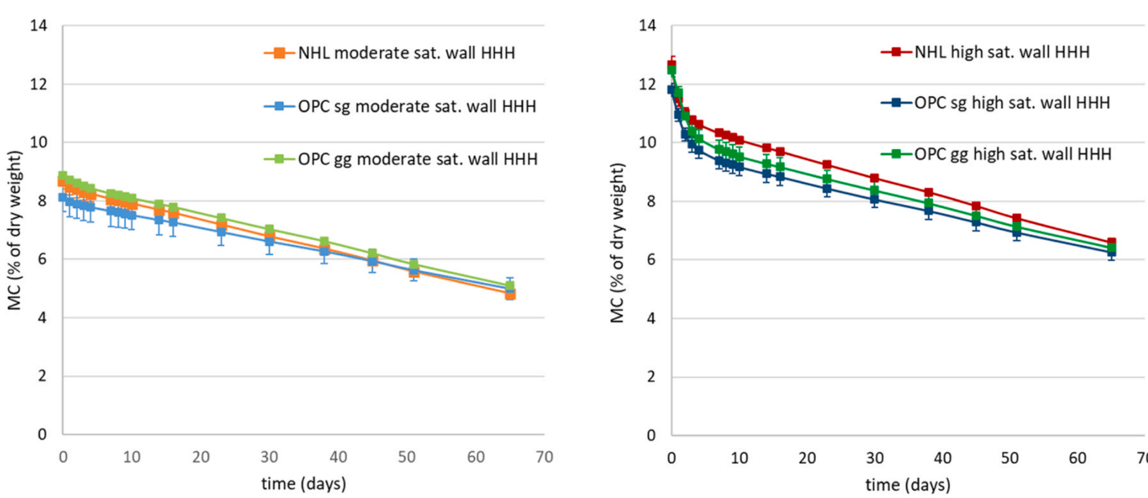

Fig. 12. Drying curves of masonry walls treated with water repellent, then repointed and treated again with water repellent (HHH), starting at moderate (left) and high (right) saturation. Each line is the average of measurements on 3 specimens, the vertical bars report the standard variation.

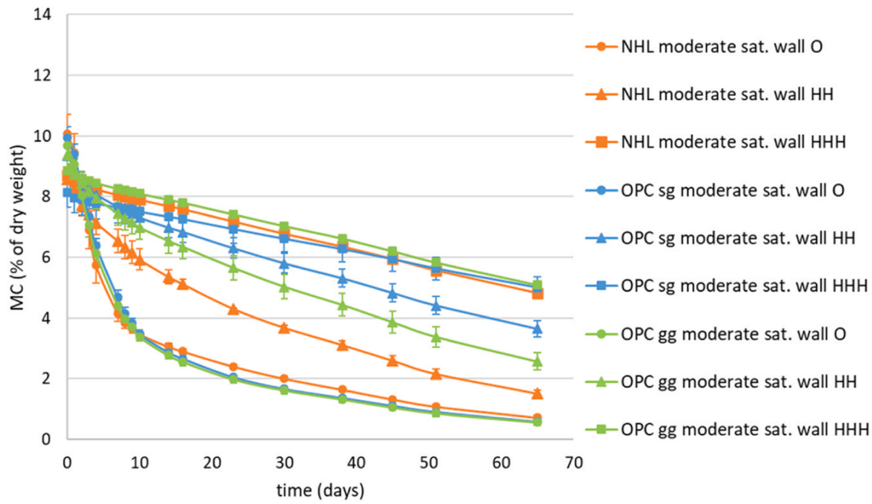

Fig. 13. Effect of one or two treatments with water repellent for specimens with moderate saturation. The graph shows the drying curves of the untreated walls (O), of the walls with treatment and subsequent repointing (HH) and of the walls treated, repointed and re-treated (HHH). Each line represents the average of 3 specimens, the vertical bars report the standard variation.

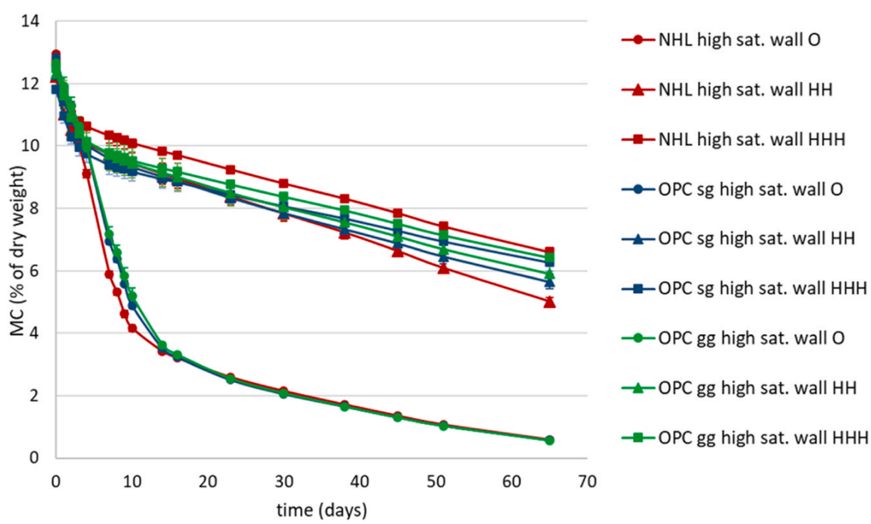

Fig. 14. Effect of one or two treatments with water repellent of samples at high saturation. The graph shows the drying curves of the untreated walls (O), of the walls with one treatment and subsequent repointing (HH) and of the walls treated, repointed and re-treated (HHH). Each line represents the average of 3 specimens, the vertical bars report the standard variation.

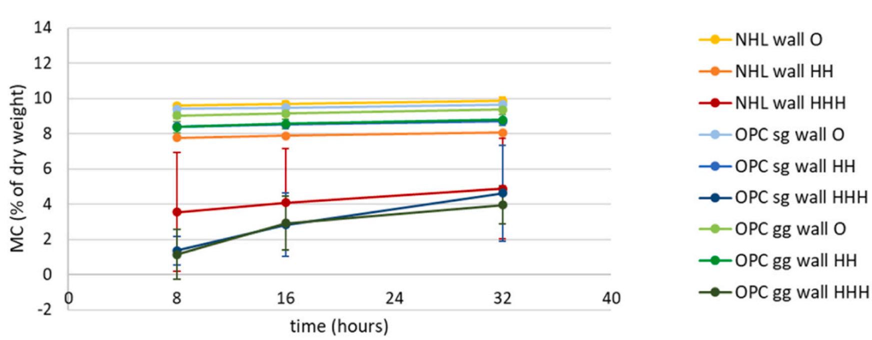

Fig. 15. Moisture content of the masonry walls as function of the hours of rain. Each line represents the average of 3 specimens, the vertical bars report the standard variation.

content in retreated repointed walls with respect to repointed but not retreated ones, indicates that retreatment of a repointed hydrophobic masonry reduces the saturation degree and thus the potential risk of e.g. frost damage. Nevertheless, none of the test specimens shows any damage after 2,5 years outdoor exposition.

The present work is the first research to investigate whether masonry

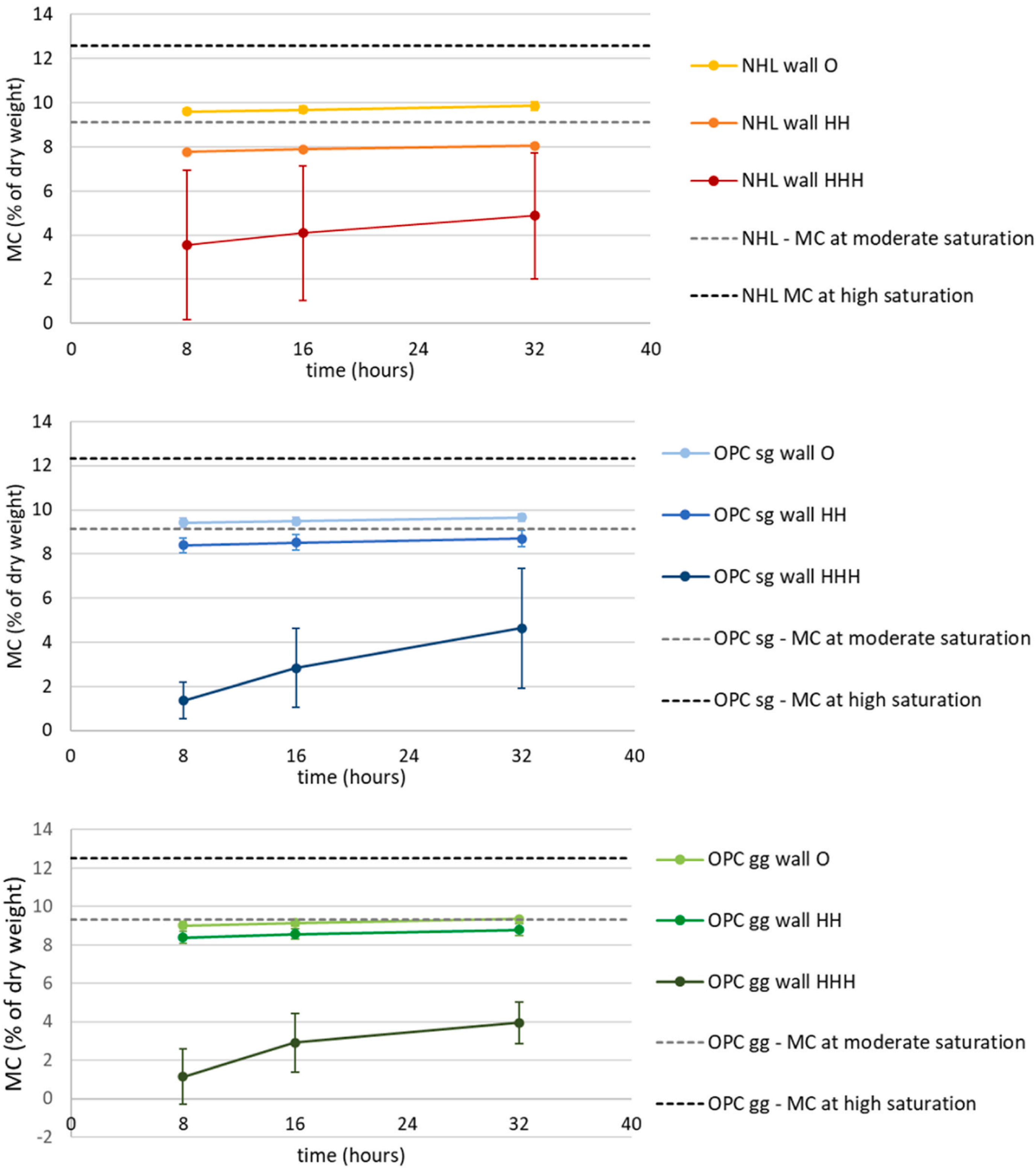

Fig. 16. Moisture content of the masonry walls, pointed with NHL (top), OPC sg (middle) and OPC gg mortars (bottom), as function of the hours of rain compared to the moisture contents of untreated walls obtained by preconditioning to moderate and high moisture loads for the freeze-thaw test for masonry bricks. Each line represents the average of 3 specimens.

treated with a water repellent should be retreated or not after repointing. Therefore, it has considered and tested "extreme" situations, i.e. situations in which the entire surface of a previously treated masonry is either treated or not after repointing, and showed the consequences of both choices. In conservation/renovation practice, sometimes only the damaged pointing is removed and replaced. To investigate this in-between scenario in more detail, the results obtained for these two extreme situations could be used for simulations to assess the effect of the extent of the ratio between treated/untreated area, or experimental research on larger walls, partially repointed, can be set up using a

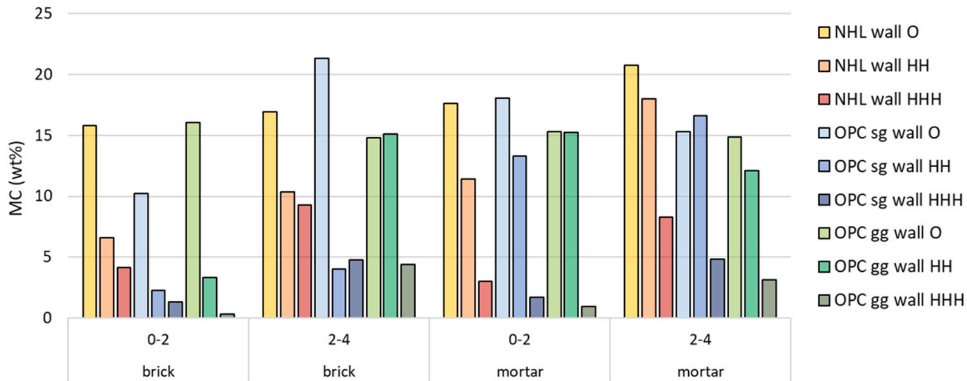

Fig. 17. Moisture content (MC) of brick and mortar at different depths in the masonry walls at the end of the rain test in walls O, HH and HHH, with pointing mortars NHL, OPC sg and OPC gg.

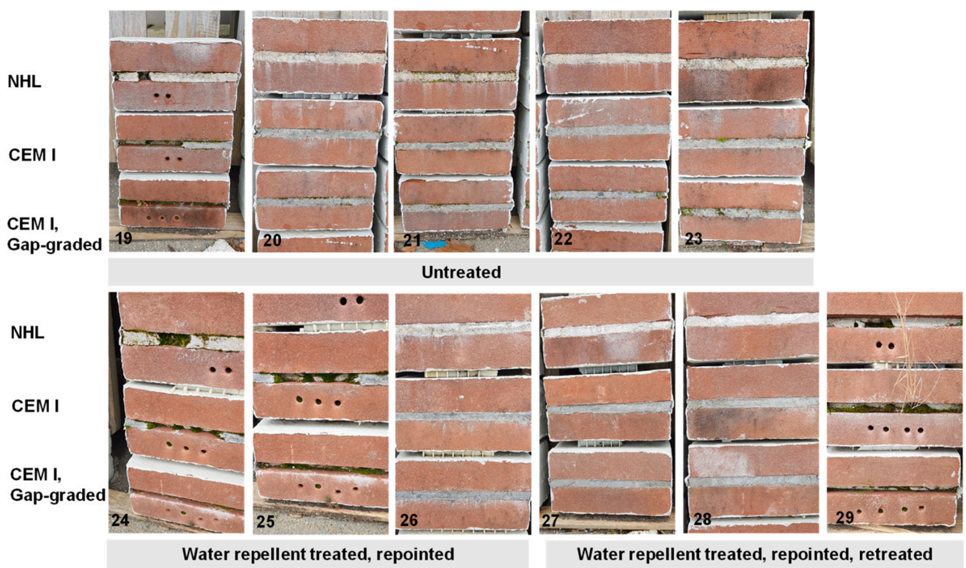

Fig. 18. Masonry walls after 2.5 years outdoor exposition. The absence of the pointings and the holes in some of the bricks are due to previous sampling.

methodologic approach similar to that proposed in this work.

5. Conclusion

In this study, the dilemma has been investigated whether masonry treated with a water repellent should be retreated or not after repointing. It appears that, after 8 h of rain, the water uptake by repointed but not retreated masonry is comparable to that of untreated, non-hydrophobic masonry, whereas drying is considerably slower. This increases the saturation degree of the masonry, leading to a higher risk of damage to the masonry by e.g. frost. Therefore, retreating repointed hydrophobic masonry should definitively be considered. Results, however, may be different for masonry with different bricks and mortars (because of different porosity and pore structure, and thus absorption and drying behaviour.). In general, the negative effect of not retreating a hydrophobic repointed masonry is expected to be higher in the case of pointing mortars with a higher water absorption.

CRediT authorship contribution statement

Nijland Timo G.: Writing – original draft, Methodology, Funding acquisition, Conceptualization. **van Zundert Kim:** Investigation, Data curation. **Lubelli Barbara:** Writing – original draft, Visualization, Methodology, Formal analysis. **van Hunen Michiel:** Writing – review & editing, Conceptualization.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests. Timo G. Nijland, Barbara Lubelli, Michiel van Hunen, Kim van Zundert reports financial support was provided by Dutch Ministry of Education, Culture and Science.

Data availability

Data will be made available on request.

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