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Drying of red ceramic brick. Effect of five silicone-based water-repellent treatments.

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Abstract:

The presence of moisture inside a material whose surface was treated with a water repellent agent may give rise to unwanted side-effects. Indeed, the temporal and spatial significance of moistening events may be intensified if a water-repellent, as any other kind of treatment, hinders drying. This effect can be particularly relevant for historical buildings, where moisture from varied origins is recurrently present in the masonry, but is also pertinent for more recent constructions since water often finds ways to penetrate the building elements, through cracks or joints.

This article discusses the application of water repellent treatments on ceramic brick, with regard to drying of the masonry. The influence of cracks parallel or perpendicular to the surface is taken into account.

Five silicone-based treatments were studied. The treated or untreated material was subjected to capillary absorption tests by which the effectiveness of the water repellent effect was estimated, as well as water vapour permeability tests and drying tests.

The effectiveness of four out of the five treatments is high. Vapour permeability is not much affected in one case, when the cracks are parallel to the surface, and in none of the cases, when they are perpendicular. Nonetheless, drying is significantly delayed by any of the five products, both in the case where the cracks are parallel to the surface as when they are perpendicular.

Key words: ceramic brick, water-repellent, hydrophobic treatments, surface treatments, drying

1 Introduction

Water repellent treatments are often used for the protection of facades, namely in the case of exposed brick walls [1], which are present in many buildings throughout Europe. These products are aimed at reducing the capillary suction of the material in order to prevent the ingress of moisture in the wall, as well as the staining and the occurrence of moisture related deterioration of the material itself.

The assessment of water repellent treatments is based on evaluating, on the one hand, their efficacy and, on the other hand, their harmfulness. In general, efficacy is appraised by measuring the reduction in capillary suction provided by the treatment, and harmfulness by evaluating the change in vapour permeability. The effect of the water repellent on drying of the porous material is also sometimes evaluated [2,3], though not in a systematic way. Indeed, drying is an important issue because masonry walls have very often, particularly in the case of old buildings, non-negligible moisture content. Therefore, surface products that hinder drying can give rise to or aggravate dampness-related problems [4].

This article is aimed at discussing the influence that some current water repellent treatments may have on the drying of ceramic materials. The subject is approached in a short or medium term perspective that does not, therefore, addresses the possible alteration of the treatments over time.

For that, five silicone-based treatments were applied to specimens of a single type of solid red ceramic brick. All the materials, treatments and brick, were acquired in the market.

The selected brick shows relevant internal cracking of the ceramic material. The same had been observed in a totally different brand of brick, previously considered to serve as substrate, as well as with the old bricks from a monument in Lisbon (Praça de Touros do Campo Pequeno) which were also initially evaluated as an alternative. This recurrence suggested that internal cracking may be relatively current in ceramic bricks. Therefore, it was decided to use the material and take the predominant direction of the cracks as a testing variable. Indeed, bricks can be used in different positions and, therefore, the cracks can appear in different directions

The brick specimens, either treated with each of the five water repellents or untreated, were subjected to capillary water absorption tests, vapour permeability tests and evaporative drying tests.

In this article, the experimental work and the results it allowed achieving are presented and discussed.

2 Materials

The brick used as substrate is a red solid brick from Cerâmica do Vale de Gândara, Portugal, with dimensions of 228 mm x 108 mm x 70 mm. As mentioned, this type of brick shows internal cracks which, however, are apparently small in size and amount when compared to those found in a previously considered type of recent brick (Figure 1).

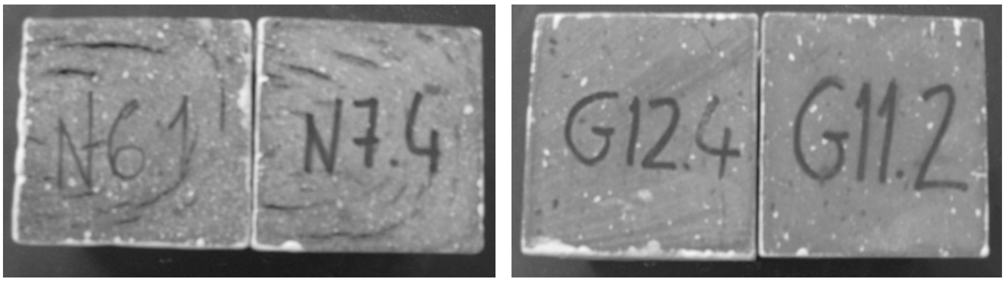

Figure 1: First considered type of recent brick (left) and selected Vale de Gândara brick (right)

Because drying and moisture transport mechanisms in general can be significantly influenced by the presence of soluble salts in the porous material [4], the salt content of the brick was previously appraised by means of the hygroscopic moisture content (HMC) method. This method [4-6] assumes that the salt content of the material is proportional to its HMC.

The HMC was measured by exposing six crushed brick specimens (each three collected from a different brick) to an environment of 20ºC and 95%RH, in a climatic chamber, until hygroscopic equilibrium was attained. Eight specimens composed of pure sodium chloride were simultaneously tested which allowed verifying [5,6] that the RH in the chamber was in fact of 96.4% with a standard deviation of 0.1%.

The results of the HMC test are presented in Table 1 and show that the salt content of the brick should be irrelevant.

Table 1: Results of the hygroscopic moisture content (HMC) test

Material	Specimen	HMC (%)			HR in the chamber (%)		
		Individual	Average	Standard deviation	Individual	Average	Standard deviation
Brick	G7-1	0.1	0.0	0.0	-	-	-
	G7-2	0.0			-	-	-
	G7-3	0.0			-	-	-
	G20-1	0.0	0.0	0.0	-	-	-
	G20-2	0.0			-	-	-
	G20-3	0.0			-	-	-
NaCl	P1	1535.9	1579.8	55.8	96.3	96.4	0.1
	P2	1571.6			96.4		
	P3	1606.5			96.5		
	P4	1691.2			96.7		
	P5	1566.3			96.4		
	P6	1546.2			96.3		
	P7	1512.2			96.2		
	P8	1608.2			96.5		

The bricks were cut in cubic specimens with 50 mm x 50 mm x 50 mm. These specimens were laterally sealed with a bicomponent epoxy resin (Icosit 101 from Sika) to promote unidirectional transport of water (liquid and vapour) during the tests. Afterwards, the water repellent treatments were applied on the top surface of the specimens. Table 2 describes these five treatments.

Table 2: Water repellent treatments

Reference	**A**	**B**	**C**	**D**	**E**
Composition*	Polysiloxane dispersion in mineral turpentine	Based on acrylic copolymers and silica in aqueous dispersion	Silicone and acrylic copolymers in aqueous dispersion	Polysiloxane in aliphatic hydrocarbons solution	Reactive silicone solution dispersed in water.

* as reported in the technical data sheets

The water repellent treatments were applied by brushing, respecting the number of coats and drying intervals indicated in the product data sheets. Four of the treatments were applied in two cross hatched coats. Treatment ***E*** used three cross hatched coats

The consumption of the products is in all cases within the thresholds indicated by the respective producers. In general, there was a slightly higher consumption for the specimens with cracks perpendicular to the surface (Figure 2).

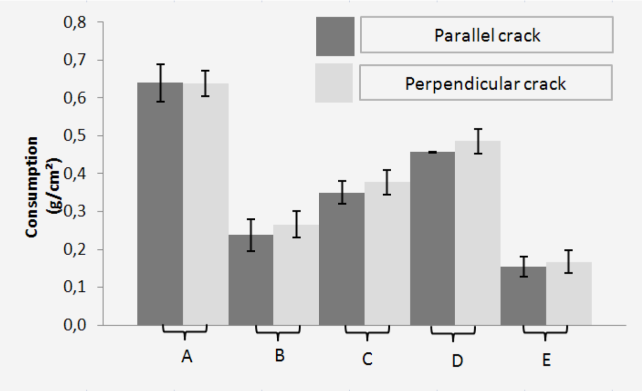

Figure 2: Consumption of the water repellent treatments

3 Methods and results

The three tests (capillary absorption, vapour permeability and drying) were sequentially performed on the same specimens. This allowed minimizing the variability associated to the heterogeneity of the material.

The tests were carried out on 8 specimens of each type of treatment plus 8 untreated specimens. Within each type, the 8 specimens included 4 specimens with cracks predominantly perpendicular to the top surface and 4 with cracks predominantly parallel to that surface.

3.1 Capillary water absorption

The capillary absorption test was performed according to RILLEM procedure No.II.6 [7]. Water absorption was carried out through the treated face of the specimens.

First, the specimens were oven dried at 40ºC until constant weight. Afterwards, they were put in partial immersion, the free water surface being 5 mm above their bottom surface. They were then periodically weighted to monitor the absorption of water. The test was carried out in a conditioned room at 20ºC and 50% RH.

The obtained results are presented in Figure 3 which depicts the values of the water absorption coefficient (or coefficient of capillarity) of the different types of specimen. This coefficient corresponds to the slope of the first linear section of the absorption curve which expresses the amount of absorbed water as a function of the square root of time.

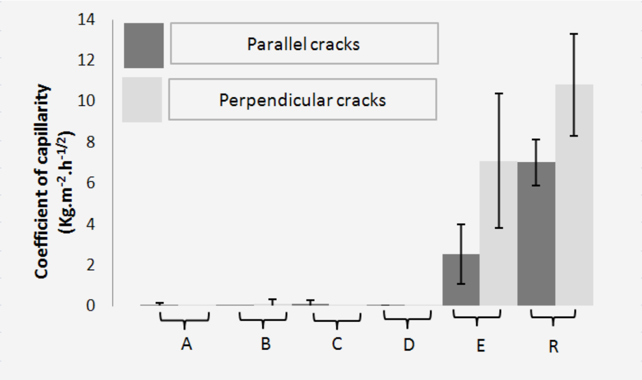

Figure 3: Mean coefficient of capillarity and standard deviation obtained for the five water repellents and the untreated reference material (R)

Figure 3 shows that:

- The capillary absorption of the treated specimens is very low, except for treatment ***E*** whose values are close to the ones of the untreated material.
- For the ***E*** and ***R*** specimens, the only that present a significant capillary absorption, the coefficient of capillarity is higher when the cracks are perpendicular to the absorption surface. For the remaining types of specimen (***A***, ***B***, ***C*** e ***D***) the measured values are so low that the differences cannot be considered significant.

3.2 Water vapour permeability

The water vapour permeability test followed RILLEM procedure No.II.2 [7].

After the capillary absorption tests, the specimens were left to dry in the conditioned room at 20ºC and 50% RH for five days. They were oven dried at 40ºC until constant mass and then let cool in the same conditioned room.

The specimens were mounted on the top of acrylic cups containing a certain amount of anhydrous calcium chloride. The assemblage was sealed with mastic and plastic tape to ensure that all the exchanges of vapour took place through the specimen. Then, the specimens were placed in a climatic chamber, a FITOCLIMA 500 EDTU® from Aralab, at 50% H.R and 23ºC. At this temperature, the anhydrous calcium chloride generates a RH of around 0% [8] inside the cups. A RH gradient that promotes the transport of vapour from the exterior to the interior of the cups is, therefore, created which corresponds to the “dry cup” method.

The specimens were weighted periodically until the gain in mass became constant over time, which means that equilibrium was attained.

The equivalent air layer thickness (Sd) is one of the parameters that can be used to express the results of this test. Sd is the thickness of a motionless air layer with the same resistance to water vapour diffusion as the tested specimen. Sd (m) is given by expression (1):

$$\mathrm{Sd} = \frac{\Pi^{\mathrm{ar}}.\mathrm{S}.\Delta \mathrm{P}}{\mathrm{G}} \qquad (1)$$

Π^{ar} (1.95 x 10^{-10} kg.m^{-1}.s^{-1}.Pa^{-1}) is the diffusion coefficient for water vapour in air at atmospheric pressure;

S (m^2) is the test area of the specimen;

G (kg/s) is the rate of water vapour flow across the specimen in steady state conditions;

ΔP (Pa) is the vapour pressure difference between the top and bottom surfaces of the specimen, that is, between the interior of the chamber and the interior of the cup.

Test area *S* is 0.0024 m^2 and corresponds [1] to the average of the top (0.0025 m^2) and bottom (0.0023 m^2) areas of the specimen (the bottom area is smaller because it is in contact with the border that supports the specimen).

Vapour pressure difference *ΔP* is a function of temperature T (ºC) and RH (%) and is given by the following expression:

$$\Delta \mathrm{P} = 610.5 e^{\frac{17.269T}{273.3+T}} \left(\frac{RH_{chamber} - RH_{cup}}{100}\right) \qquad (3)$$

The results of the vapour permeability test are presented in Figure 4.

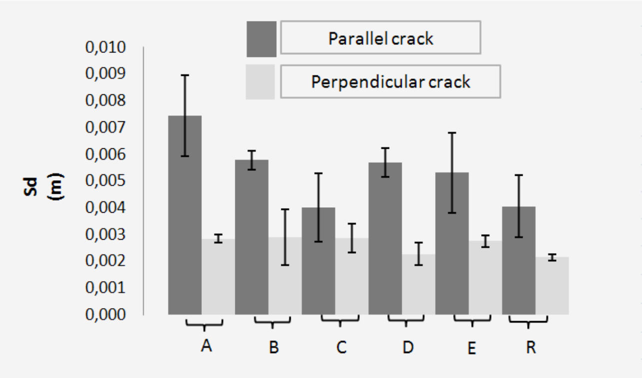

Figure 4: Mean equivalent air layer thickness (Sd) and standard deviation for the five water repellents and the untreated reference specimens (R).

Figure 4 shows that:

- Vapour permeability is always higher (Sd is lower) when the cracks are perpendicular to the brick surface, as it would be expected.

- For these perpendiculars cracks, the mean Sd is reasonably similar for all the treated and untreated specimens, which suggests that vapour transport happens mostly through the cracks.

- Treatments ***A***, ***B*** and ***D*** have Sd values that are clearly higher than the one obtained for reference specimens R, even taking into account the magnitude of the standard deviation obtained in each case. This means that these treatments hinder vapour transport. For treatment ***E***, there is a high level of uncertainty due the significant value of the standard deviation. However, in relation to the average, there seems to be also a hindering effect. Differently, treatment ***C*** does not seem to affect much the vapour permeability of the material.

3.3 Evaporative drying

The drying experiments were performed according to RILLEM procedure No. II.5 [7].

First, the specimens were placed in partial immersion, with the bottom (untreated) surface in contact with the water, inside closed plastic boxes during two days until they achieved moisture content close to capillary saturation. Afterwards, they were removed from immersion and their bottom surface was immediately sealed with plastic film.

Drying took place in the conditioned room at 20ºC and 50% RH which has a low air velocity. The specimens were placed as far as possible from obstacles such as walls. Their weight was measured periodically until it stabilised.

The results of this test are expressed by the evaporation curve (Figure 5) which can then be quantitatively translated into a numerical parameter, the drying index [9]. The drying index (DI) is given by expression (4).

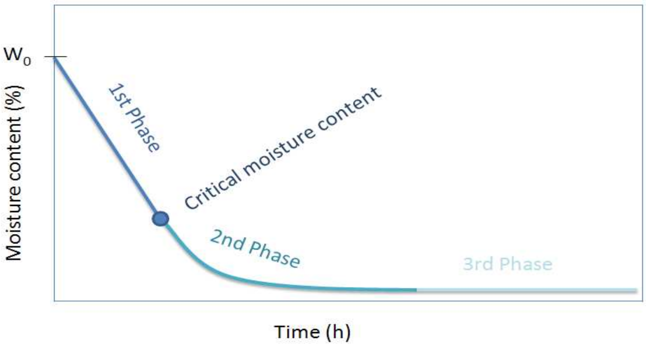

Figure 5: Typical drying curve of porous materials. In the 1st phase the drying front is located at the material surface and the drying rate is constant. At the critical moisture content, the drying front starts receding into the material and the drying rate to decrease progressively.

$$DI = \frac{\int_0^{t_i} w(t) \times dt}{w_0 \times t_i} \qquad (4)$$

w(t) is a function that describes the variation of the moisture content over time;
w_0 is the initial moisture content of the material;
t_i is the total duration of the test.

The results of the drying test are summarized in Figure 6.

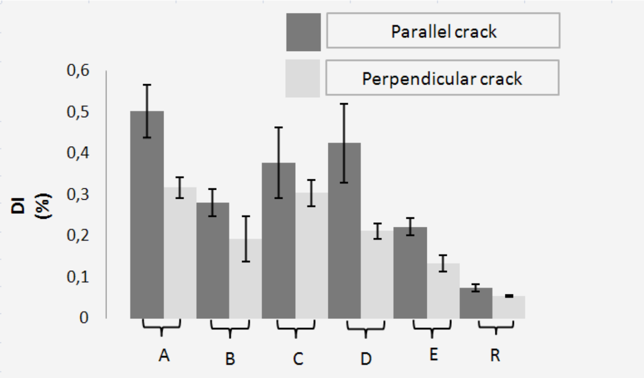

Figure 6: Drying index (DI) and respective standard deviation obtained for the five water repellents and the untreated reference specimens (R).

Figure 6 shows that:

- The fact that DI is clearly lower for untreated specimens ***R*** indicates that drying is hindered by all the five tested treatments. Hindering of the drying of stones treated with water repellent products has been reported by other authors [10, for example].
- This effect is evident for both crack directions, though drying is systematically faster when the cracks are perpendicular to the surface.
- Drying is hindered both by treatments ***A***, ***B*** and ***D*** which reduce vapour transport as by treatment ***C*** which doesn't seem to affect that transport (Figure 4).

4 Discussion and conclusions

The results of the experimental work indicate that the effectiveness and harmfulness of water repellent treatments can be independent of each other. Indeed, out of the five tested treatments, four products (***A***, ***B***, ***C*** and ***D***) showed to be very effective in reducing the capillary suction of the ceramic material, while the fifth treatment (***E***) induced only a moderate reduction. In spite of this difference, all the tested treatments hindered drying.

As seen by the low correlations found between Sd and DI (Figure 7), vapour permeability can be an insufficient measure of the effect that water repellents have on drying processes. Evaporative drying tests are probably a better way of assessing that influence. In fact, the obtained results showed that drying was hindered both by the treatments that reduce vapour transport as by the one that did not affect that transport.

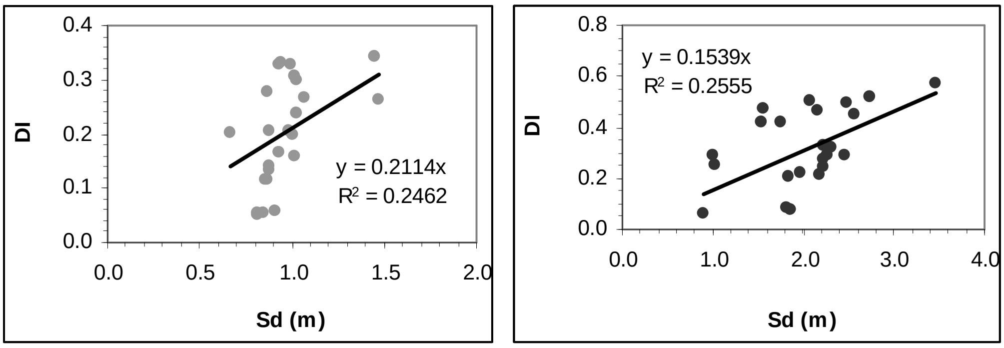

Figure 7: Correlation between the equivalent air layer thickness (Sd) and the drying index (DI) for the specimens with cracks perpendicular (left) and parallel (right) to the surface

The direction of the cracks present in the ceramic material did not show to be relevant as regards the treatments effectiveness, but this only for the five treatments that generated a drastic reduction of the capillary suction of the material. In the case of treatment ***E***, which induced only a moderate reduction of that capillary suction, the specimens with cracks perpendicular to the surface showed a higher capillary suction than the ones with cracks parallel to the surface, and the same happened with the untreated brick. This confirms that the application of water repellents may be a good way to reduce the penetration of moisture in materials with cracks perpendicular to their surface, cracks which, otherwise, would enhance the capillary suction of the material.

The direction of the cracks is also very relevant as regards the transport of vapour. Indeed, the vapour permeability of the specimens with cracks perpendicular to the surface is similar for all the treated and for the untreated material. This leaded to the conclusion that, for perpendicular cracks, vapour transport occurs essentially trough the cracks.

Accordingly, drying is influenced by the direction of the cracks. As expected, the specimens with cracks perpendicular to the surface dry faster. This indicates that the presence of cracks in a material and their predominant direction should always be taken into consideration.

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