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Can a Wet Wall be Injected in an Effective Way? Experimental Study of Spreading and Effectiveness of Injection Products against Rising Damp

B. Lubelli [1,2], R.P.J. van Hees[1,2] and A. Hacquebord [2]
[1]Faculty of Architecture, Delft University of Technology, Julianalaan 134, 2628 BL, Delft, The Netherlands
[2]TNO Built Environment and Geosciences, Van Mourik Broekmanweg 6, Delft, The Netherlands

Abstract

Rising damp is a well-known phenomenon in ancient buildings. One of the most diffused techniques to tackle rising damp consists in injecting the walls with chemical products. These products should spread in the pore system of the materials composing the wall, react and create a horizontal barrier to capillary rise. Unfortunately practice shows that these interventions are not always successful. An important problem seems constituted by the insufficient spreading of the product in the wall, especially when a high moisture content is present in the substrate.

In this research the transport and the spreading of 15 injection products in a brick substrate with different degrees of water saturation was studied. The selection of products includes pore filling and water repellent products, products both in water and in organic solvent, liquid products as well as products in the form of a cream/gel. At first the spreading of products in water, their hardening/reaction time and percentage of active components were determined. Then the absorption and spreading of the products in dry, partially and fully saturated substrates was studied, using a newly developed experimental procedure. The obtained results show that clear differences in behaviour exist between products in organic solvent and water based products, as well as between creams/gel and liquid products. The consequences for the application method and effectiveness of these products in the practice are discussed.

Keywords: rising damp, injection products, transport

1 Introduction

Rising damp is a well-known phenomenon in ancient buildings. Different techniques (e.g. mechanical interruption, chemical injection, electro-kinetics) are present on the market to stop rising damp in walls. In particular the use of chemical injection is wide spread, since this technique is of much easier execution than mechanical interruption, whereas successful application of techniques like electro-kinetics are still limited to experimental try-outs [1, 2].

Injection and impregnation with chemical products consists in drilling holes in the wall along a horizontal profile, at a distance of 0.1 to 0.4 m from each other. The chemical products can be either introduced with pressure (injection) or without (impregnation). In many cases hydrostatic pressure is used to facilitate the penetration. The chemical product can either fill the pores or make the pore wall water repellent. Paraffin, silicates and acryl-amide gel are examples of pore filling products. Stearate, siliconate and silane/siloxane products are examples of chemicals which work by conferring water repellency to the pores. Some products (e.g. silicate/siliconate mixture) offer a combination of both working principles. A market research carried out by the authors in 2009 in the Netherlands has shown that most of the products present on the market are either water repellent or they combine pore filling and water repellent properties. Because of environmental reasons most of the commercialized products are nowadays water based (in liquid form, or as gel, cream or (micro)emulsion). However, products in organic solvent are still available.

Failure of the chemical interruption can occur in practice and it is often attributed to the presence of high moisture content in the wall [3], as shown by the fact that different solutions have been developed to attempt a (partial) drying of the wall before injection (Figure 1). From this originates the necessity to further investigate the transport of chemical products in (partially) water saturated materials. In spite of the common use of injection of chemical products, little scientific research has been published on the transport mechanism of these products in water filled pore systems [4] and their curing in the presence of water. In the framework of a Dutch research project, extensive research on the transport and effectiveness of chemical products against rising damp is being performed at TNO; the first results are presented in this paper.

2 Experimental section

2.1 Materials

Fired-clay brick, being the most diffused building material in the Netherlands, was selected as substrate. The open porosity and pore size distribution were measured by Mercury Intrusion Porosimeter (Autopore IV9500 from Micromeritics) (MIP). The brick has an open porosity of 29 vol %, with most of

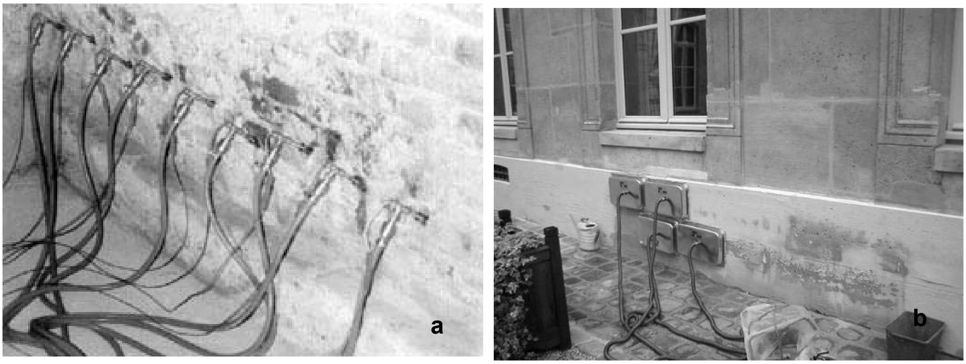

Figure 1: Drying of the wall is attempted prior the injection: drying elements have been inserted in the wall to enhance evaporation (a) or a difference in pressure is created in order to extract water from the wall (b)

the pores between 4 and 10 μm diameter. The Water Absorption Coefficient (WAC), determined by capillary absorption [5] on 3 cores of 40 mm diameter and 80 mm height, is 397 $g/m^2\sqrt{sec}$.

On the basis of the information retrieved from a market research, 15 chemical products were selected (Table 1) in order to include:

- water based as well as solvent based products;
- the most common categories of products: siliconate, silicate, silane, siloxane, stearate;
- different forms of products: liquid, emulsion, micro-emulsion, cream, gel.

Because of the difficulty of finding pure pore filling products on the market, only products with water repellent properties or with a combination of water repellent and pore filling properties have been used in this research. Some of the products were provided as ready-to-use, while other needed to be further diluted in water.

The percentage of components remaining after curing of the products was determined by a simple test. A little amount of each product was mixed with an equal amount of crushed brick in an aluminium container. The specimens were then stored at 20 °C 65 % RH and their weight recorded at regular intervals for a period of 6 months.

The drying curves (Figure 2) show that liquid water based products react and dry fastest (2-5 days); solvent based products need 3 to 6 weeks, whereas creams require several months to reach a constant weight. Regarding the percentage of (active) components left after curing, it can be concluded that most liquid products have a similar percentage of active components, which varies between 5 and 10%. Siliconate and silicate/siliconate products (D1 and

Table 1: Products selected for the 1st phase of the research. The main components, as mentioned in the technical data sheets, are reported

General category	Product	Main components	Solvent	Working principle
Stearate	A	Polyoxoaluminium stearate	Organic (isoparaffin)	WR
Siloxane	B1	Oligomeric alkylsiloxane	Organic (white spirit)	WR
	B2	Siloxane	Water	WR
	B3	Oligomeric siloxane	Organic (isoparaffin)	WR
Siliconate	C1	K-methylsiliconate,potassium hydroxide	Water	WR
	C2	K-methylsiliconate		WR
(K methyl) silicate + siliconate	D1	K-methylsuliconate, Na-metasilicate	Water	WR & PF
	D2	Alkali silicate-siliconate		WR & PF
	D3	K-methylsuliconate +sodium-metasilicate + methoxy terminated aminosilsequioxanes	Water	WR & PF
Cream and gels on basis of silane or siloxane	E1	Silane based + bentonite	Water	WR
	E2	Alkylalkoxysilane and –siloxane	Water	WR
	E3	Silane- siloxane	Water	WR
	E4	silane and siloxane	Water	WR
(Micro)emulsion on basis of alkyl-alkoxy-silane or siloxane	F1	Silane and siloxane	Water	WR
	F2	Silane and siloxane emulsion	Water	WR
	F3	Alkoxysilane, siloxane, tetraethyl silicate	Water	WR

WR = water repellent
PF = pore filling

D2) have generally a higher percentage (up to 45%) of components remaining than siloxane/silane based products. Creams (E1, E2, E3 and E4) have a higher % of components remaining than chemically similar liquid products, but this might partially be due to the fact most of the cream products had not reached a constant weight yet, after 6 months of drying. The drying/reacting/hardening time may have consequences for the spreading of the product and for the application method to be chosen in practice.

2.2 Test procedures

2.2.1 Determination of the uptake of the product in a dry substrate

At first the capillary absorption of the products in a dry substrate was measured and compared to that of water. Brick cores of 40 mm diameter and 80 mm height were cut from brick units. The height of the specimens was chosen equal to half of the average distance between two contiguous holes in an injected wall. Full impregnation of the specimen would thus mean overlapping of contiguous injected areas in practice.

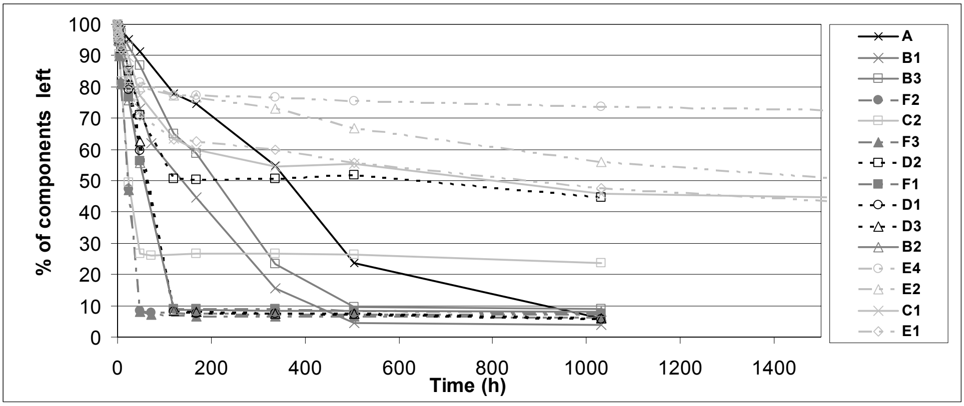

Figure 2: Drying curves of products

The brick cores were put with their bottom surface in contact with the product and their weight change during time was measured at regular intervals for a period of 24 h. The height of the capillary rise, as visible on the lateral surface of the specimen, was recorded too.

2.2.2 Determination of the uptake of product in 50% and 100% water saturated substrate

In order to study the penetration of chemical products in a material (partially) saturated with water, the brick cores were wetted with water before measuring the uptake of chemical products. Water (50% and 100% of the saturation amount) was introduced in the bricks by capillary suction, then the specimens were sealed with parafilm to prevent evaporation and kept sealed for one week to allow redistribution of the water in the pores. Subsequently the parafilm was removed from the bottom and upper side of the brick core and the (product) uptake test started. A special test set-up and procedure were developed to measure the uptake of the product in a substrate (partially) saturated with water. Plastic tubes with mm scale were glued to the upper surface of the specimens. The products were poured in the plastic tubes up to a defined level and the weight of both the product and of the assembling was recorded at the beginning and at the end of the test, 24 h later. If any outflow of the product occurred from the bottom of the specimen, the amount of product/water which flew out was recorded too. After 24 h, the tubes were removed and the brick cores, still sealed on the lateral surface, but not on the top and bottom sides, were stored at 20 °C / 50% RH for a period of at least 3 weeks.

2.2.3 Measurement of the spreading and effectiveness of the products

After a period of at least 3 weeks, the cores were sliced in 3 parts. On each of these parts the water absorption by capillarity was measured: in this way the spreading of the products could be evaluated. On the basis of the water absorption results, the effectiveness (average of the three slices) of each product was calculated according to the following formula:

$$E = 100 * \frac{(\%\ MC\ untreated\ brick - \%\ MC\ brick\ after\ treatment)}{\%\ MC\ untreated\ brick} \quad (1)$$

where MC = moisture content, calculated as follows:

$$MC = 100 * (weight\ after\ absorption - dry\ weight) / dry\ weight \quad (2)$$

It should be mentioned that these measurements aim at determining the spreading of the product, and measuring their effectiveness is a way to achieve this aim. Therefore, in this case the effectiveness was measured after complete drying and reaction of the products. The actual effectiveness of the product should be measured reproducing the practice situation where the moisture supply to the treated zone remains constant after impregnation. Measurements incorporating those conditions are running at the moment and will be the subject of a future paper.

3 Results

3.1 Uptake of product in a dry substrate

The absorption curves of the products have been assessed. Because of the difference in density between the products and water, the absorption of the products has been recalculated in cm^3/cm^2, in order to make a comparison possible. On the basis of the obtained results (Figures 3-4), the following conclusions can be drawn:

- Solvent based liquid products: full impregnation is obtained. The absorption rate is lower than that for water, but saturation is reached within 2h.
- Water based liquid products: in the case of silicate and/or siliconate based products, full impregnation is rarely obtained. This might be due either to the fast reaction of the product which occludes the pores and/or make them water repellent and slows down or stops further absorption or to a high viscosity of the products. In the case of silane and/or siloxane based products generally saturation is reached, but it may take a long time.
- Water based cream and gel products: Due to their high viscosity absorption is very slow and saturation is not reached after 24 h.

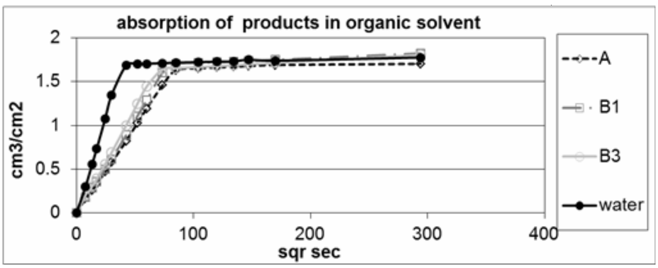

Figure 3: Absorption of products in organic solvent in a dry brick substrate

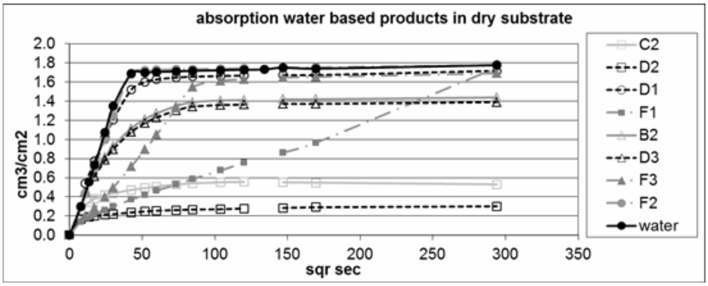

Figure 4: Absorption of water based products in a dry brick substrate

3.2 Uptake of product in a (partially) saturated substrate

The uptake of products in the brick previously wetted with water was measured by recording the level of the product in the tube at regular time intervals during a period of 24 h.

Liquid water based products penetrated by capillarity in empty pores and by diffusion in water filled pores. During the uptake test with water based products, a mixture of product and water flew out of the specimens. It should be kept in mind that flowing out of product does not always mean a full impregnation of the pores. In fact, it is possible that the products get into and flow out the larger pores without accessing smaller pores.

The uptake of organic solvent based products, which can not diffuse into water, was limited to the amount necessary to fill the empty pores (Figure 5), showing that these products can hardly penetrate in water filled pores. No significant uptake of solvent based products was in fact measured in 100% saturated bricks. This means that solvent based products have a lower wettability than water, i.e. they do not have the capability of displacing water from the pores. The only way to get products in organic solvent in water filled pores, is therefore by means of pressure. The hydrostatic pressure used in this case, was not sufficient.

The uptake of cream and gel products (all silane-siloxane in water) is very low, due to the high viscosity of the products. Longer application times are needed in these cases. These results, summarized in Figure 6, have the following consequences for the practice:

- Water based products can be used, without the use of pressure injection, in substrates with a high degree of saturation. Since water based product penetrated in water filled pores by diffusion, a longer application time (provided that the product does not react) favours a good spreading of the treatment.
- Solvent based products require to be injected with pressure in order to reach water filled pores.

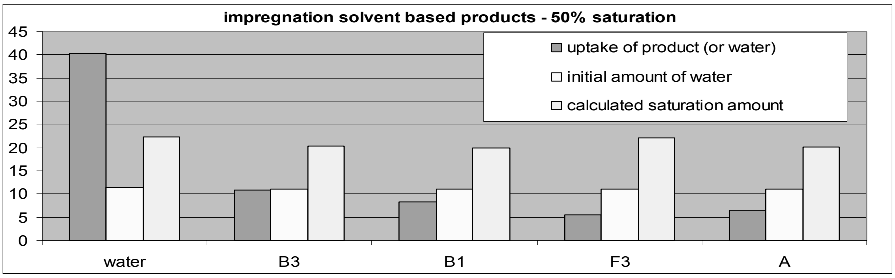

Figure 5: Initial water content, uptake of product and calculated saturation amount

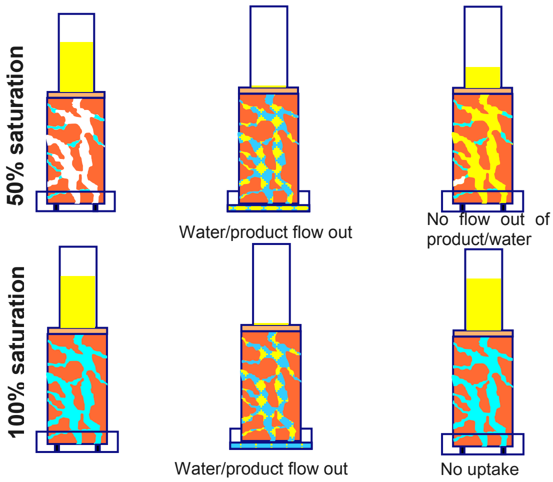

Figure 6: Scheme summarizing the results obtained by impregnation with hydrostatic pressure of 50% and 100% saturated brick specimens

3.3 Spreading and effectiveness of the products

The spreading of the products was checked by measuring the water absorption of the impregnated brick cores, after slicing them in three parts.

3.3.1 Dry substrate

Figure 7 reports the moisture content (MC) measured in the brick slices (three for each core treated with one product); Homogenous values between the slides treated with the same product mean a good spreading of the product in the brick core; the lower the measured MC, the better the effectiveness of the product. The graph shows that:

- For some products (F2, C2, F3, D1, D3, B2, B3 and B1) similar water absorption values have been measured in each of the slices: this suggests a good spreading of the product. In some other cases (D2, F1, A, E4, E2 and E1) there is a large difference between the water absorption values of the three different slices of the core. The reason of this behaviour is not always straightforward. In some cases (D2), it is due to the fact that the product did not reach the complete core during impregnation.

- All products show some effectiveness. Also on slices which were not visibly reached by the product during the impregnation, a reduction of the water absorption is measured, indicating that the product must have spread and react, becoming effective.
- Cream products show some effectiveness even in those parts of the cores which were not visibly reached during impregnation by capillary absorption. It can be supposed that, thanks to diffusion in air, the silane molecules could reach the lateral and upper surfaces of the core and made them water repellent.

3.3.2 50% water saturated substrate

Following the same procedure as for dry specimens, the spreading and effectiveness (after drying) of the products in 50 % water saturated specimens was measured. It is possible to observe that (Figure 8):

- For some products (F1, A and all cream products) a higher water absorption is measured in those parts of the brick which were further from the absorption surface during the impregnation process. This denotes a not optimal spreading of the product in the core. All other products show homogenous MC at different distances from the absorption surface, denoting a good spreading of the product.

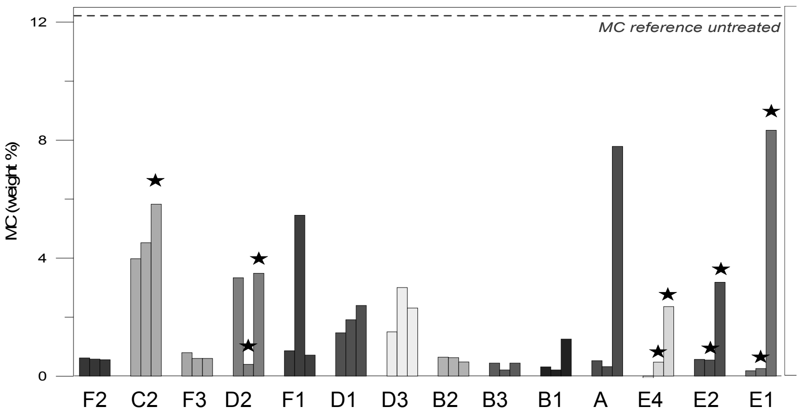

Figure 7: Water absorption measured after impregnation on dry substrates; values measured on each of the three parts of the core (the star indicates the part of the cores which were not (visually) reached by the product during the impregnation phase)

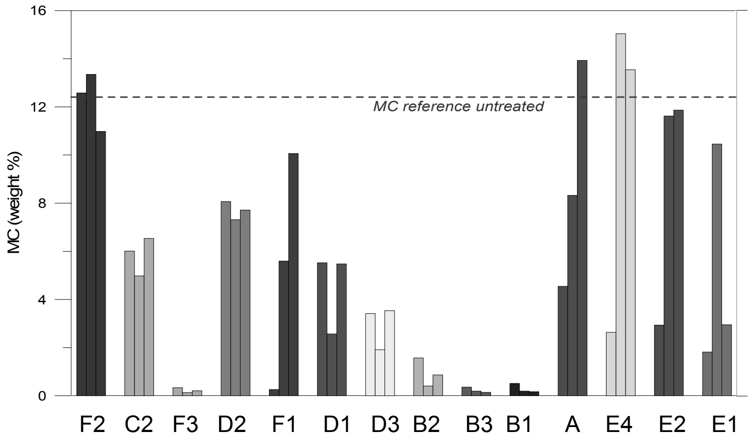

Figure 8: Water absorption measured after impregnation on 50% saturated substrates; values measured on each of the three parts of the core (the absorption values higher than the reference can be due either to hygroscopic properties of the product or to differences in the porosity of the brick)

- Some solvent based products (B3 and B1, both siloxanes) seem to have spread sufficiently and to have become effective even if the amount of product absorbed was enough to fill only 50% of the pore volume (left empty by water).
- Product F2 did not spread at all because, during impregnation, reaction took place in the tube, closing the absorption surface and inhibiting any penetration of the product into the brick.

3.3.3 100% water saturated substrate

Following the same procedure as for dry specimens, the spreading and effectiveness (after drying) of the products when used to impregnate 100% water saturated specimens was measured (Figure 9). It is possible to observe that:

- Some products (F1) show a different effectiveness at different depths;
- Solvent based products are not effective (they did not penetrate the brick);
- F2 is not effective at any depth because reaction took place in the tube occluding the absorption surface and inhibiting product penetration;
- There are still 2 products which show a very good effectiveness (F3 and B2). They are both siloxanes and water based;
- The solvent based products show generally an insufficient or low effectiveness, due to the fact they can not penetrate in a saturated substrate.

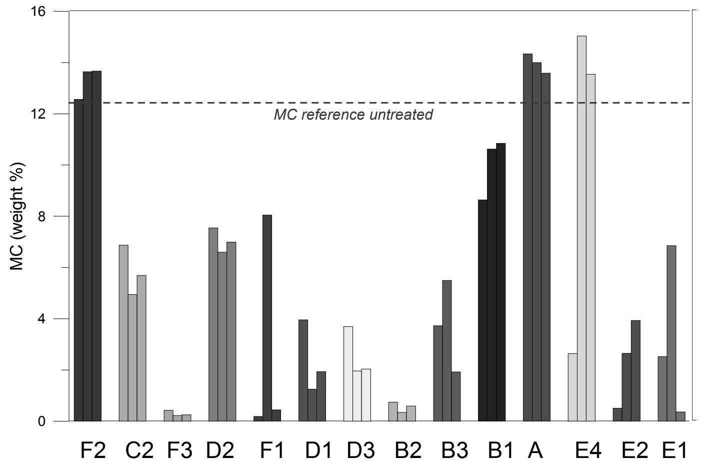

Figure 9: Water absorption of the specimens impregnated when wetted with 100% of the saturation water content (the absorption values higher than the reference can be due either to hygroscopic properties of the product or to differences in the porosity of the brick)

4 Discussion and conclusions

On the basis of the obtained results, summarized in figure 10, it is possible to conclude that the influence of the water saturation degree on the spreading and effectiveness of the products depends on the product type.

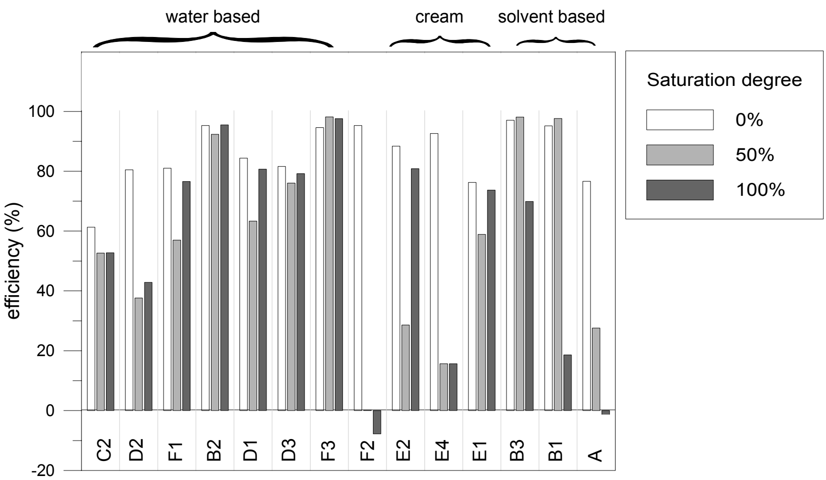

Figure 10: Effectiveness of the different products tested on dry and 50% and 100% saturated specimens

In the case of most water based products (C2, B2, D3, F3) the effectiveness is not strongly affected by the MC in the substrate. In the case of D2 (silicate/siliconate) the presence of water in the pores seems to allow a better spreading of the product (this product shows a very slow absorption curve in dry material; in wet material diffusion may have contributed to distribute the product better in the pore network). The effectiveness of solvent based products is strongly affected by the presence of water in the substrate. As a consequence the effectiveness of solvent based products in 100% saturated substrates is, in most of the cases, strongly reduced. Nevertheless, in 50% saturated substrates some solvent based products (B3 and B1) showed a very high effectiveness: it is possible that the product, which initially penetrated only in the empty pores, could spread by capillarity into the complete pore network, after the water filled pores had dried out (if the reaction process of solvent based products takes longer than for water to evaporate from the brick). Highest effectiveness values are generally measured with siloxane based products. Two products (B2 and F3), both water based siloxane, show a very good effectiveness at all moisture contents of the substrate. This shows that an efficient treatment can be obtained by just using hydrostatic pressure, even in water saturated substrates.

However, it should be underlined here that in all tests described until now the specimens could dry after impregnation. This is generally not the case in practice, where the treated section of the wall is subjected to a constant moisture supply. The practice situation will be simulated in further laboratory experiments which will be the subject of a future paper.

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