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NEW TEST METHODS TO VERIFY THE PERFORMANCE OF CHEMICAL INJECTIONS TO DEAL WITH RISING DAMP

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ABSTRACT

The injection of chemical products, meant to penetrate in the capillaries of the materials composing an affected wall, is perhaps the most diffused method to deal with rising damp. The majority of these chemical products are hydrophobic treatments; they can be either solvent-based or (increasingly) water-based. Traditionally, these products are liquid. In the last years however, a tendency towards the use of cream-like products can be observed.

From practice quite contradictory opinions arrive with respect to the effectiveness of injections and quite often disputes develop between building owner and executing contractor on the performance of the treatment. Sometimes the slow drying of humid walls is used to cover a failing treatment; in other cases it is not clear whether the injection or a simultaneously applied restoration plaster is responsible for a visual improvement.

Research was performed in order to establish a method to evaluate the effectiveness of injection methods in a simple and quick way, both for assessing performance in practice and for use in laboratory.

Interesting side effect of the research program was that also several essential parameters, influencing the effectiveness of chemical products, became evident.

In this article focus will be on the quick assessment method for practice.

Keywords: rising damp; damp-proof course; injection products; test method

1. INTRODUCTION

1.1. Injection and impregnation with chemical products

Many methods exist to deal with capillary rising damp. In spite of the large quantity of methods and products, scientific literature on their effectiveness, in laboratory and in the field, is rather scarce [Franzoni 2014].

Injection and impregnation with chemical products is one of the most commonly used methods to tackle rising damp problems in buildings. It consists in drilling holes in the wall along a horizontal profile, at a distance of usually 0.1 to 0.15 m. The holes can be drilled from one side only or from two sides of the masonry, mainly depending on the wall thickness.

The chemical products can be either introduced with pressure (injection) or without (impregnation, with the use of hydrostatic pressure). Chemical products can work by filling the pores (and thus creating an impermeable layer in the masonry) and/or by making the pores water repellent, thereby inhibiting capillary transport. Nowadays, most of the products present on the market rely on the last working principle.

The products can have an organic solvent or be aqueous solutions or emulsions in water. In the last years there is a tendency towards water-based products, as they are more environment and user friendly. Products with different viscosities exist, from liquid to cream and gels; cream products are gaining more and more importance in the last years, most probably because of their greater ease of application.

There are several problems related to the application and the effectiveness of chemical products. One of these is the difficulty of introducing the product in pores, which are for a large part filled with water. Some products seem to be more suitable for use on wet walls than others. This problem was extensively described in [Lubelli et al 2013].

In order to be effective the chemical product should reach all pores and voids and create a hydrophobic or impermeable horizontal layer, which does not allow the water to go through. If this horizontal barrier is not continuous, water can still go through and rising damp will not be stopped. The injection or impregnation should therefore be performed in such a way that the treated zones overlap each other.

From practice quite contradictory opinions arrive with respect to the effectiveness [Balak 2007] and often disputes arise between building owner and contractor that performed the work. The slow drying of humid walls can be used to cover a failing treatment; sometimes it is not clear whether a visual improvement is due to the injection or to a simultaneously applied restoration plaster. Research was performed in order to establish a method for the evaluation of the effectiveness of injection methods in a quick and simple way, both for practice and for laboratory. Internationally different procedures exist for the evaluation of injection products in laboratory [BBA 1988, Van Hees & Koek 1995, WTA 2003, Van Hellefont et al 2006].

The aim of the research was to develop a method for the evaluation of the effectiveness of chemical products in a reliable way, within a short time from their application. Two closely related new methods, one for the evaluation of the effectiveness of injection products in laboratory, and another for the evaluation of the effectiveness of products when applied in practice, were developed. The laboratory method is described in [Lubelli et al 2013], [Hacquebord et al 2013] and [Lubelli et al 2014]. Here the quick practice method, which for a part is derived from the laboratory method, will be discussed.

1.2 Test methods for the assessment of the effectiveness of chemical injections in practice

A proven method to obtain reliable data on moisture and salt content is to drill powder samples from the wall at different depths and heights, along a vertical profile. Subsequently, moisture (MC) and hygroscopic moisture content (HMC) can be determined gravimetrically. The hygroscopic moisture content gives a reliable indication of the presence of hygroscopic salts [Lubelli et al 2004]. Based on the comparison between the MC and HMC curves, the presence of rising damp can be assessed (see also [Lubelli et al 2018], in this special issue).

This procedure is initially performed to assess the presence of rising damp and can be repeated one or two years after treatment in order to follow the drying process. It will be clear that in case of doubt or conflict such a long lasting method it not very favorable.

Therefore a quick method has been developed that is derived from the quick laboratory test as described in [Hacquebord et al 2013]. The method includes taking drilled core samples (diameter 10 cm) and powder samples from the treated zone short time (few weeks) after injection has been carried out. Because of its intrusive character, this method should be used with care in case of historic buildings with monumental value.

The test on cores consists of several steps and has, for most injection products, an expected duration of 7 to 8 weeks, starting from the moment of injection. The method and its application on a case study are discussed in this paper.

3. TEST SITE AND PRODUCTS USED

3.1 Selected site

Sint Bernardus Abbey in Hemiksem (Belgium) was selected for the validation of the test (figure 1).



Figure 1. Exterior (left) and interior (right) of the wing in the St. Bernardus Abbey in Hemiksem (Belgium)

A perimetral wall facing the courtyard of the Abbey was selected for injection. This location is very suitable for the assessment of the effectiveness of the injection products and the validation of the test methods, since there is a clear problem of rising damp (see paragraph 3.3). Moreover, the long masonry wall offers the possibility of testing different chemical products in the same wall, thus in very similar materials and exposure conditions, facilitating the comparison.

3.2 Selected products

Four products were selected for injection in the wall of the abbey in Hemiksem. The products represent the main classes of products identified in a market research. The selection includes water-based as well as a product in organic solvent, liquid products as well as a cream:

- C2: silicate (potassium methylsilicate; % active component not specified) in water, liquid
- B3: siloxane (oligomeric siloxane; active component about 10 wt%) in organic solvent (isoparaffin), liquid
- B2: siloxane (no further indication provided) in water, liquid
- E5: silane (no further indication provided; active component ca. 80 Wt%), cream

It should be underlined that manufacturers often only provide limited information on molecular structure, type of solvents and presence of additives, whereas such information is considered important to enhance general scientific knowledge. Unfortunately a cultural gap seems still to be filled in this respect.

The working principle of all products relies on making the pores water repellent, thus hindering capillary transport of water.

3.3 Starting situation

On the wall facing the courtyard six locations were selected for the application: 2 reference locations and 4 locations for injection of the products. Before injection, a moisture profile was determined for every location, in order to have insight in the start situation. Figure 2 shows the 6 locations: the red dotted lines indicate the location of the moisture profile, the black dots the location of the injections.

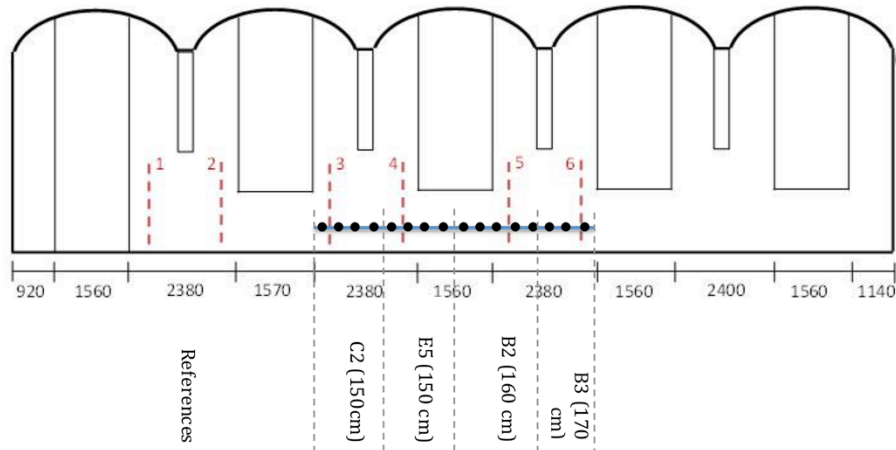


Figure 2. Wall facing the courtyard of the abbey of Hemiksem with indication of the locations of the moisture profiles (red dotted lines) and of the injection (black dots); height of injection ca. 0.40m, height of the window sills ca. 1.50m; length of the injected fields is given between brackets for each of the treatments

Moisture and hygroscopic moisture profiles were obtained for each location before injection; a representative example (location 5) of the profiles for brick and mortar, is presented in figure 3. The profiles clearly show the presence of rising damp in the wall. The amount of hygroscopic salts is low, as shown by the low HMC measured.

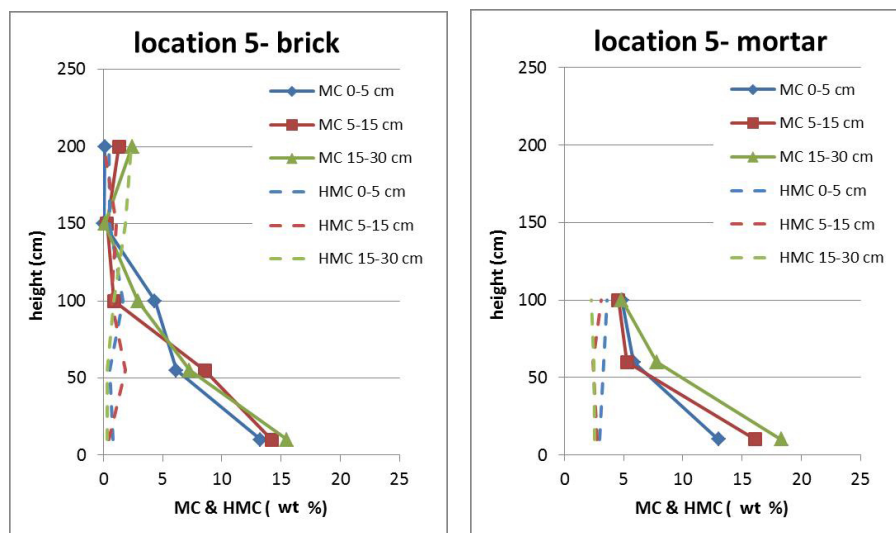


Figure 3. Moisture profiles for one of the locations (start situation), which are representative for the other locations as well

3.4 Injection of the wall test panels

The products were injected in the areas as indicated in figure 2. No space was left between one injected area and the adjacent one; in this way it was not necessary to inject an additional vertical line of holes to separate treated and untreated areas. The length of the injected area varied between 150 and 170 cm (13 to 15 injection holes). The liquid water-based products (C2, B2) and the cream (E5) were injected without pressure, whereas the solvent-based product (B3) was injected with low pressure (2 bar) (figures 4- 6).

Injection holes were drilled in the brick at a height of about 40 cm from the floor. The distance between two adjacent injection holes was about 12 cm; the diameter of the injection holes was 25 mm in the case of the liquid water based and of 14 mm in the case of the cream and the liquid product in organic solvent. The angle of the injection holes was about 25-30° for the liquid products, whereas horizontal holes were used for the cream. The depth of the drilled holes was about 55 cm, the thickness of the wall being 60 cm. After drilling, the holes were cleaned with compressed air, vacuum cleaned and then injected.

The amount of absorbed product (total amount for injected area) was measured during application (based on the amount of product left in the containers used for injection) for each of the products. The most relevant data on the injections are reported in table 1. After the injection, holes were closed at the surface with a mortar.



Figure 4. Impregnation without pressure



Figure 5. Injection with pressure



Figure 6. Impregnation with the cream product

Table 1. The most relevant data on the injections

Product	Diameter holes (mm)/ angle	Pressure	Injection time	Length injected section (m)/n. of injected holes	Total amount of product/amount of product per hole (liter)	Prescribed amount of product/ amount of product per hole (liter)
C2	25 / 25°-30°	Hydrostatic (poured in hole)	About 5+3 h	1.50 / 12	15 / 1.25	15 / 1.15
B2	25 / 25°-30°	Hydrostatic (poured in hole)	About 3+3 h	1.60 / 12	8 / 0.67	14.4 / 1.17
B3	14 / 25°-30°	Low pressure (2 bar)	5 repeated applications up to saturation	1.80 / 13	7 / 0.54	12.2 / 0.94
E5	14 / 0°	No pressure	Single application	1.50 / 14	3.08 / 0.22 (enough to fill injection hole)	3.08 / 0.22 (enough to fill injection hole)

4. QUICK TEST METHOD

4.1 Sampling of cores

Two weeks after injection of the products, five cores (diameter 10 cm) have been sampled (figure 7 and 8), one for each of the injected location plus one in the not injected, reference area. Sampling of the cores for the test was always done in the middle of the injected areas in order to avoid influences/interaction of the product injected in adjacent zones. The cores were taken at an inclination of ca. 30° in areas injected with liquid products and in the reference area. In the area injected with cream, the core was taken horizontally. The cores were taken in between two injection holes for liquid products, in order to be able to check sideward spreading, and concentric to injection holes for the cream, as at the moment of core drilling no sideward spreading of the cream could possibly have occurred. This fact should be taken into account in the evaluation.

Due to the fact that the cores were sampled by drilling with water (to avoid damaging them), the moisture content in the cores may have become higher than originally was the case in the wall. However, it is supposed that the extra moisture uptake was limited, because the wall was (almost) saturated with liquid when cores were sampled (due to the presence of both the original moisture content + the injected product). The mean free water absorption at saturation was ca. 16.5 Wt%.

After pictures had been taken from each core, the cores were wrapped in plastic to avoid evaporation. The weight of the cores (still wrapped in plastic) was recorded once arrived in the lab. The plastic was kept until the start of the test and the weight was controlled again before starting the test: no significant drying of the cores had occurred during storing of the cores.



Figure 7. Drilling cores from treated and untreated masonry

Figure 8. Reference core (untreated)

4.2 Test procedure on cores

From each core, two slices (A and B) with a length of 80 mm were cut (using water, to avoid damaging the material). The distance of the slices from the surface of the wall is given in table 2. It was impossible to cut the slices from the different cores at exactly the same distance, due to the fact that most cores were broken at different locations. In the case of product E5 (cream) only one slice could be obtained.

Table 2. Slices cut from the masonry cores

Code	Type of product	Slice A (distance to surface of the wall)	Slice B (distance to surface of the wall)
Reference	-	Ca. 150-250 mm	Ca. 250-350 mm
B2	siloxane in water, liquid	Ca. 120-220 mm	Ca. 220-320 mm
B3	siloxane in organic solvent, liquid	Ca. 230-330 mm	Ca. 330-430 mm
C2	siliconate in water, liquid	Ca. 200-300 mm	Ca. 300-400 mm
E5	silane, cream	Ca. 240-340 mm	-

One of the most important aspects of the developed test method is the possibility to maintain a constant moisture supply after injection or impregnation. Several experiments with different types of materials were performed. Finally, a relatively constant water supply for a brick core was found in using a brick/clay ‘tower’ with the following structure (figure 9), see [Lubelli et al 2017].

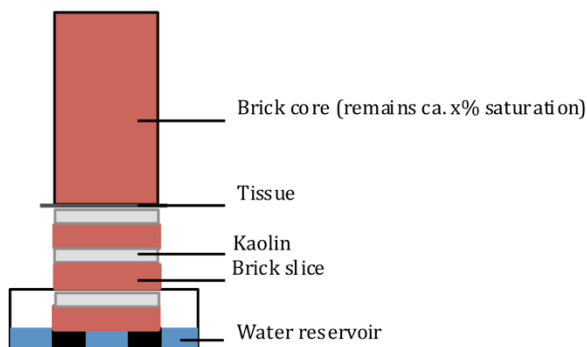


Figure 9. Model of the brick/clay tower, used to maintain a constant moisture supply, intended to maintain a certain % of saturation in the reference bricks. Free evaporation from the brick core can only take place through its upper surface (the lateral sides are sealed).

- The tower consists of 1, 2 or 3 layers brick/kaolin, depending on the required moisture supply to maintain the saturation level of the reference cores;
- Kaolin powder is mixed with water in ratio water/kaolin: 40/60 by weight;
- Brick/kaolin ‘tower’ is placed on a grid (5 mm height);
- A tissue filter avoids the brick core from contamination with kaolin/water mixture.

During the test the weight of the cores has to be monitored and the weight of the untreated specimens is used as reference to eventually adjust the water supply, by adding or removing brick and clay layers.

The following criterion was used to evaluate the *actual effectiveness* of a product: a product is considered effective when, at the end of the test, the moisture content in treated cores is lower than the MC in reference cores. In fact, this would mean that the product is able to react in wet conditions and that, thanks to the developed water repellency, no water is absorbed anymore due to capillarity; in this case the core would dry and its weight decreases.

At the end of the water absorption period (ca. 4 weeks) the *actual effectiveness* of the products was evaluated. The *actual effectiveness* of the product can be defined as the effectiveness of the product in a situation in which the moisture supply is kept constant during and after injection.

The cores were then dried in an oven at 40 °C and afterwards the capillary water absorption of the dry cores was measured through their bottom surface. On the basis of the moisture content measured after 3 weeks of capillary water absorption the *potential effectiveness* (see 5.1.1) of the products was evaluated. The *potential effectiveness* of the product can be defined as the effectiveness the product would have in a situation in which the moisture supply is interrupted after injection and the product can polymerize in dry conditions.

4.3 Additional test on powder samples

An additional test for the evaluation of the presence and spreading of water repellent products in a masonry wall was developed in the project. This test (so-called “drop test”) consists in assessing the water repellency of drilled powder by the use of a drop of water. In the case of the Hemiksem case-study the powder for the test was collected from the drilled cores (in mortar and brick). In general, powder could be collected at different depth from a location in between injection holes.

Advantage of the drop test is that no further investigation of the samples is necessary to assess the presence of the product, resulting in a quick assessment and consequently in low costs. The “drop test” is performed by observing the shape of water drops applied on the dried powder samples drilled from the treated area of the wall. This test gives a first, indicative evaluation of the presence of the water repellent product. Whenever hydrophobic particles are present (e.g. due to injection with water repellent chemical product), the drop is repelled and assumes a spherical or elliptical shape, while in the absence of a water repellent product, the drop is absorbed (figure 10). With the help of this test procedure, it appears in most cases easy to draw conclusions about the spreading of a water repellent product in different materials and, in case cores are sampled, even through the section of the wall. It should be reminded that the drop test can only indicatively evaluate the spreading of a water repellent product and

its potential effectiveness. The actual effectiveness of an intervention needs to be evaluated according to the test described in paragraph 5.



Figure 10. Sample with clear water repellent properties (left) and without these properties (right). A distinction can easily be made

5. DISCUSSION OF RESULTS

5.1 Test on cores - actual effectiveness of the products

The moisture content (MC) of the cores sampled from the masonry at the start of the test varied between 12 and 16.5%, depending on differences in composition of the cores (different brick/mortar volume ratio) and most probably also on differences in properties between different bricks. The MC of the cores at the start of the test was higher than the actual MC that had been measured in the wall; it is supposed that it corresponds to saturation of the masonry: the high moisture content in the cores is mainly due to the fact that sampling and subsequent slicing took place with the use of water. This means that the test is executed under conditions that are harsher than those in practice.

The following criterion was used to evaluate the *actual effectiveness* of a product: a product is considered effective when, at the end of the test, the moisture content in treated cores is lower than the MC in reference cores. In fact, this would mean that the product is able to react in wet conditions and that, thanks to the developed water repellency, no water is absorbed anymore due to capillarity; in this case the core would dry and its weight decreases.

Figure 11 reports the weight change of the core slices during the test. Changes in moisture content were measured gravimetrically; dry weight was assessed at the very end of the test. At the beginning of the test the weight of the reference cores decreased considerably (as can be seen in the first part of the curves), suggesting that the water supply through the brick/clay layers was not sufficient; in order to adjust the water supply, some clay and brick layers were removed and the cores were placed back on the brick/clay “tower”.

The following conclusions can be drawn for the different products on the basis of the results of this test (figure 11):

For B3 (solvent-based siloxane), C2 (water-based silicate) and B2 (siloxane in water) the actual effectiveness could not be confirmed, either because the moisture content values are in the range of those of the references (B3, C2) or because the two slices from the same core do

not give a consistent result (B2). Only for E5 (silane cream) the moisture content (for the only core available) was lower than for the reference specimens. However, for this product the core was (and had to be) sampled on the injection hole (and not in between two injection holes as done for the other products) (see paragraph 4.1); the results therefore cannot be fully compared with the ones for the other products.

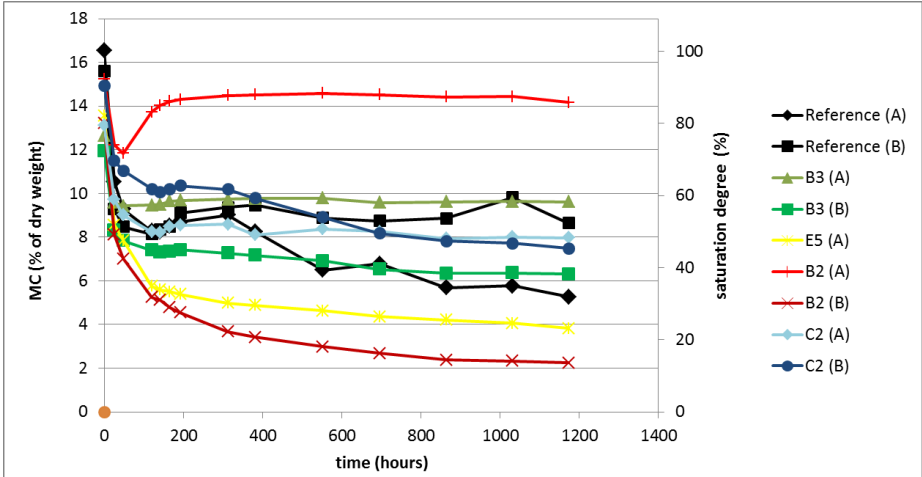


Figure 11. Moisture content (MC) in treated and reference masonry cores from Hemiksem during the test with constant moisture supply; the suffixes A and B indicate the slices at the surface and from the depth of the masonry respectively.

5.2 Test on cores - potential effectiveness of the products

After drying of the cores, their capillary water absorption was measured in order to determine the *potential effectiveness* of the products. Figure 12 shows the MC of the cores after drying and subsequent water absorption.

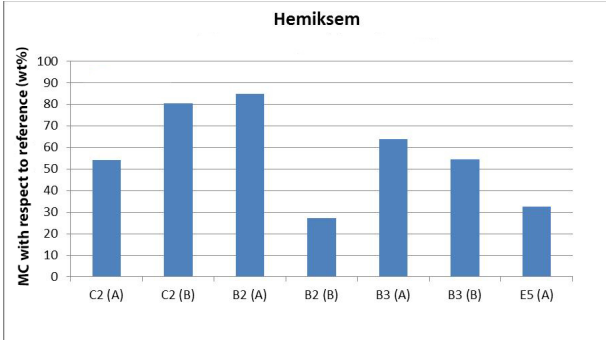


Figure 12. Moisture content (MC) in treated masonry cores from Hemiksem (as a percentage of the MC in reference cores) after three weeks of capillary water absorption. The cores were previously dried at 40 °C. A = core nearby the masonry surface; B = core from the depth of the masonry

Product E5 again shows a rather good potential performance. Product B3 shows a mediocre potential effectiveness, which most probably indicates a lack of spreading. Product B2 shows a not homogeneous result through the section of the wall: a good potential effectiveness for the center of the masonry, whereas only a slight reduction of the water absorption was observed nearby the masonry surface. This might be due to the fact that in the depth of the masonry the product remains for a longer time in the impregnation hole (holes were drilled with a slope). Product C2 shows a moderate potential reduction of the water absorption.

5.4 Drop test

The results of the drop test are summarized in table 3. The drop test was in this case carried out after drying of the powder, as a support for the assessment of the potential effectiveness.

In general, the brick powder shows a stronger water repellent (beading) effect than the mortar powder treated with the same product. Only the silane-siloxane in organic solvent (C2) shows good water repellent properties both to mortar and brick. The mortar treated with the cream product (E5) shows very strong water repellent properties, but only after wetting and re-drying of the sample.

The results of the drop test are in most cases in accordance with those obtained from the test on the cores; however, in some cases (C2) a good water repellency has been measured on the powder and a low performance on the cores. It should be mentioned that the drop test is carried out on a sample from a very small location (the size of the drill is about 5 mm); for a more representative evaluation several samples should be taken (or the test on cores should be used).

Table 3. Results of the drop test on brick and mortar powder

Product	Material	Water repellency
B2	Mortar	--
B2	Brick	+ -
C2	Mortar	+
C2	Brick	+ +
E5	Mortar	++ *
E5	Brick	++
B3	Mortar	--
B3	Brick	+
Reference	Mortar	--
Reference	Brick	--

Evaluation	Explanation
--	No water repellent properties at all: water is absorbed by the material immediately.
-	Weak water repellent properties: water is absorbed by the material after few seconds
+ -	Medium water repellent properties: water is not absorbed, drops remain in their position.
+	Strong water repellent properties: beading effect visible; drops are repelled or remain in their position
++	Very strong water repellent properties: strong beading effect visible; drops are repelled immediately.

* Mortar is not water repellent in first test, but after wetting and drying of the sample, the mortar has very strong water repellent properties

6. DISCUSSION AND CONCLUSIONS

6.1 Test methods

The practice test method allows the assessment of the effectiveness of injections soon after application, even if no (hygroscopic) moisture profiles of the wall before treatment are available.

The new test method carried out on cores sampled from a treated wall can be considered reliable for forecasting, within short time from the application, the behavior of injection products when applied on site. It functions adequately and is able to distinguish between different levels of effectiveness, both actual and potential. The test gives not only an objective evaluation of the actual effectiveness including the spreading of the treatment, but also suggestions for measures to improve the effectiveness, like additional injection or additional drying of the masonry. The period necessary to assess the effectiveness of liquid products is limited to ca. 8 weeks from the moment of application, for cream products the period is estimated at ca. 16 weeks, as in this last case collection of the cores should be better done after few months from application as, due to the nature of these products, no spreading may be expected before that time.

The test procedure might be further improved by collecting cores both on and in between injection holes. Some further development in fine-tuning of the principle of the brick / clay tower used in the laboratory experiments is necessary in order to facilitate a constant and controlled water supply to the core.

Limitations of the method are i) its intrusive character and ii) the risk that the drilled core, even if wet drilling is applied may fall apart, making interpretation sometimes impossible. Wet drilling as such is not considered an important limitation, as the cores are drilled from the injection zone, where a high moisture content will usually be present.

The drop test provides an indicative evaluation of the presence and potential effectiveness of the water repellent injection products; it allows to differentiate between the behavior of an injection product in the different materials composing a masonry (e.g. mortar, brick, stone). It can therefore be of support to the test on the core specimens. When used as the only test, it should be carried out on a significant number of samples and its results should be considered only indicative for the effectiveness of the tested products.

6.2 Effectiveness of injection products

On the basis of the results assessed for the products that have been applied in the test site, it can be concluded that both the actual and the potential effectiveness of most products are quite low. The results of the test suggest that a very high MC of the wall (in this case MC values near to saturation have been measured at the level of the injection) forms a limitation not only for the polymerization reaction, but also for the spreading of the products, as shown by the low potential effectiveness measured on most of the cores.

On the basis of the results of this research it can be concluded that a high saturation degree in the wall is the main factor limiting the effectiveness of injections. A high moisture content in the wall negatively affects both the spreading and the reaction process. This has also been clearly demonstrated in laboratory [Lubelli et al 2014]. Drying of the masonry after application might therefore help to improve the effectiveness of an intervention.

Further research is necessary to establish the necessary conditions (maximum acceptable moisture content, period of drying, method and conditions for drying etc.).

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