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Improvements in Conservation and Rehabilitation - Integrated Methodologies

PROCEEDINGS

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NEW INSIGTS INTO THE EFFECTIVENESS OF INJECTION PRODUCTS AGAINST RISING DAMP

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ABSTRACT

Rising damp is a hazard to historic buildings and its relevance is expected to increase due to climate changes. The presence of rising damp in walls does not only create an unpleasant climate in buildings, but it also enhances damage processes as frost action, salt crystallization and biological growth.

The relevance of this problem is reflected by the large variety of methods against rising damp present on the market. Among these, the creation of a damp-proof course (DPC) against capillary rise by means of injection of chemical products is one of the most diffused methods. Although many of these products show a satisfactory effectiveness when assessed in laboratory tests, often a less positive result is found when assessed under practice conditions.

In the last years an extensive research on the effectiveness of injection products has been carried out in the framework of a Dutch research program. In this research, the effectiveness of several injection products has been tested in laboratory and in case studies.

The results show how not only the initial saturation degree of the wall, but even more the moisture content in the wall during the curing process of the product, plays a crucial role in whether the product will become effective. This new insight into the product behaviour constituted the starting point for the development of an innovative and quick laboratory test able to simulate the curing conditions present in practice, and provide therefore a reliable prediction of the actual effectiveness of these products.

INTRODUCTION

Rising damp, i.e. capillary rise of water from the ground to the walls of a building, is a well-known phenomenon in ancient buildings and one of the most recurrent hazards to monuments. The phenomenon of rising damp is more recurrent in old than in new constructions, due to the fact that the old buildings have often masonry foundations and lack of a damp-proof course, i.e. of a layer hindering the water transport from the ground to the upper structure.

The high moisture content deriving from the presence of rising damp does not only create an unpleasant climate in a building with possible consequences on the health of the inhabitants, but it also considerably enhances decay processes in the materials composing the wall, as for example salt and frost and biological growth. The relevance and extension of the rising damp problem is reflected by the large offer of methods and products against rising damp present on the market. Existing methods include mechanical cut of the wall [1], injection (with pressure) and impregnation (without pressure or with hydrostatic pressure only) of chemical products [2], wall base ventilation [3] and several electric methods (as electro-osmosis, electro-cybernesis etc.). Next to methods aiming at stopping or reducing the moisture source, other solutions exist, which are mainly tackling the symptoms, such as the use of special dehumidifying and/or macroporous and/or salt resistant plasters [4, 5] or the use of veneer walls.

In spite of the large diffusion of methods and products to stop rising damp, scientific literature on their effectiveness, in laboratory and in the field, is scarce and not conclusive, as confirmed by a recent review on the subject [6]. Literature on laboratory research includes the study of fundamental aspects, as e.g. the transport of immiscible and miscible fluids (water and injection product in organic solvent) in pores [7, 8] and the electro-kinetic processes (e.g. 9), as well as the study of the effectiveness of specific methods and products against rising damp. This second line of research largely focuses on the study of chemical injection products [10-12]. However, results from different literature sources are hardly comparable, as they are strongly dependent on the test procedure. For example, the existing laboratory procedures for the evaluation of chemical injections (e.g. BBA [13], WTA [14], TNO [12], BBRI [15]) differ in size of the specimens, specimens' material(s), initial water saturation degree, use of salt solution or water for saturating the specimens and methods, techniques and criteria used for the evaluation of the effectiveness.

In the following sections a critical overview of the existing laboratory tests for the evaluation of the effectiveness of chemical injections is given (§ 2). The main test variables are identified and their influence on the effectiveness of chemical injections evaluated in the light of laboratory experiments (§ 3-4). On the basis of this evaluation, a new laboratory test procedure for a reliable and quick assessment of the effectiveness of chemical products is proposed (§ 5).

2. Overview of existing laboratory tests for the assessment of injection products

Laboratory tests for the assessment of injection products against rising damp propose simplifications of the practice situation, in order to come to the assessment of the effectiveness of injection products within a short period time. Laboratory procedures may differ for several variables:

- Type of specimen (size, specimens' material(s))
- Initial water saturation degree of the to be impregnated/injected material
- Impregnation/injection procedure used (with or without pressure)
- Steps in the testing procedure (pre-wetting, impregnation/injection, drying, absorption)
- Criteria prescribed for the evaluation of the effectiveness.

Table 1 reports some existing procedures for the evaluation of injection products in laboratory and their main variables (type of specimen, initial saturation degree, injection pressure, presence of a drying phase after injection, duration of the test). It is clear that a higher simplification corresponds to a faster test. However, these simplifications should not affect the reliability of obtained results. i.e. the quick laboratory test should still give a good prediction of the effectiveness of the products when applied in practice situations.

Table 1. Overview of some existing procedures for the evaluation of injection products in laboratory

Test	Specimen	Initial saturation degree	Injection pressure	Drying after injection	Test duration (from injection)
BBA pillar test [13]	Fired clay brick/mortar (8 courses)	From 100 to 0% from bottom to top of the wall	Possible	No	90-120 days
BBA Small scale pillar test [13]	Limestone block (250 x 100 x 100) on brick/mortar base (3 courses). The brick/mortar base is injected	From 100 to 0% from bottom to top of the base	?	Yes (2 days)	Minimum 14 days
TNO 1995 [12]	Fired clay brick/mortar (8 courses)	From 100 to 0% from bottom to top of the wall	Yes	No	120-180 days
BBRI [15]	Single material: calcium silicate brick (100 x 100 x 50 mm)	Salt solution:40, 60, 80 %	No	Yes (1w at 20°C 50%RH)	Minimum 49 days
WTA [14]	Fired clay brick/mortar (5 courses)	Water: 60, 80, 95%	Possible	No	Minimum 120 days

3. Effect of the different test variables on the results

The relevance of each of the above mentioned variables for the reliability of the test has been evaluated by an extensive laboratory research and is discussed hereafter using some relevant examples. The complete results of the research are published elsewhere [16, 17].

Type of specimen

In most test procedures the specimen used for testing chemical products is constituted by a brick masonry of variable size. Differently, in the BBRI procedure injection product are tested on one calcium silicate brick unit. Starting from the assumption that the mortar is the weakest link where most injection fails, the test focuses on this material only and, for further simplification and reproducibility, propose the use of a calcium silicate brick, which is for chemical composition similar to a mortar.

In the research recently carried out at TNO, the role of the mortar in the spreading of products has been evaluated by comparing the effectiveness of injection products in brick and mortar, as well as by testing product on combined brick/mortar specimens. On the basis of the obtained results it can be concluded that the absorption of products by hydrostatic pressure in the mortar is much slower than in the brick (24 hours impregnation resulted not always enough to impregnate 10 cm thick mortar core). Moreover, in combined brick/mortar specimens as those shown in figure 1, some products in organic solvents had problems to move through the mortar joint already at an initial water saturation degree of 50%. This can be due to the difference in pore size and moisture content between the brick and the mortar. Due to its fine porosity, the mortar absorbs water from the brick; therefore, when a saturation degree of 50% is measured in the specimen, in the mortar a higher saturation degree will be present; this high moisture content might limit the spreading of products not miscible in water, as those in organic solvent.

From these observations it is clear the necessity of including at least one mortar joint in the specimen used for testing products in laboratory in order to simulate practice in a reliable way.

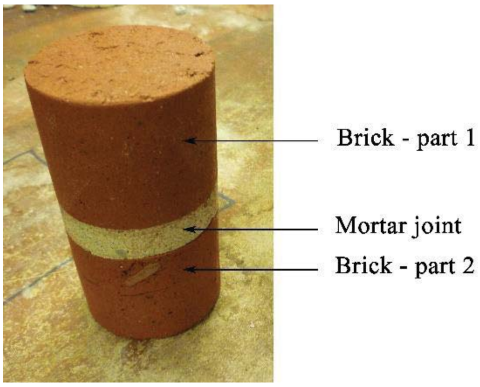

Figure 1. Core specimen composed by two bricks and a horizontal mortar joint, used for testing chemical injection products in TNO experiments

Injection pressure

Not all the test procedures reported in table 1 foresee the possibility of using pressure by the application of the products. However, in the practice, generally pressure is applied in order to speed up the injection. In the case the use of pressure would influence the effectiveness of chemical injections, a laboratory test should consider this parameter.

The influence of the use of pressure on the effectiveness of injections has been investigated within the mentioned TNO research. The difference in spreading of products injected with hydrostatic pressure and with an applied pressure of 2 and 5 bar has been measured. Masonry cores (65 mm diameter 80 mm height), with an initial water saturation degree of 50%, were impregnated with hydrostatic pressure or injected with 2 bar pressure. After drying and slicing of the core in three parts (brick part 1, mortar and brick part 2), the water absorption of each slice was measured and the moisture content after absorption calculated. A high MC indicates an insufficient spreading of the treatment. The results show that, for products in organic solvent, a moderate pressure (2 bar) improves their spreading in the mortar joint (figure 2). The use of 5 bar pressure does not further improve the results.

These observations support the need to include the possibility of applying (moderate) injection pressure in a laboratory test procedure for the assessment of the effectiveness of injection products.

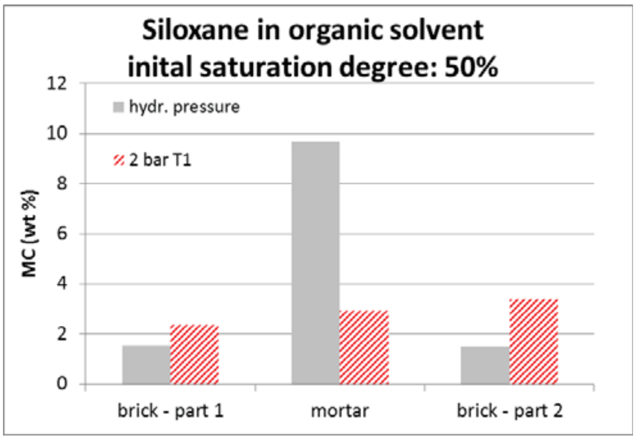

Figure 2. Moisture content (MC) of brick and mortar layers from treated masonry cores. A high MC indicates an insufficient spreading of the treatment

Initial saturation degree

All the considered test procedures (table 1) foresee the possibility of introducing a certain water amount in the specimen prior to injection. The initial saturation degree of the material is in fact unanimously recognized as the main threat to the effectiveness of an injection.
In our research the influence of the initial moisture content on the spreading of the products has been evaluated according to the following procedure:

- Brick cores (diameter 40 mm height 80 mm) with different water saturation degrees (0, 50 and 100%) have been impregnated with hydrostatic pressure (figure 3 left).
- The brick cores have been dried at room temperature for 3 weeks and then sliced in three parts (figure 3 right).
- The water absorption of each of the three slices has been measured and the average calculated.

Figure 4 reports the reduction in water absorption measured on impregnated brick specimens (average of 3 slices) having initial saturation degrees of 0, 50, 100%. The water absorption was measured after full drying of the impregnated specimens. A high reduction of the water absorption corresponds to a good spreading of the product. It is possible to conclude that for some products, higher initial water saturation degrees of the specimen lead to a poor spreading of the product; however, for many products a very good spreading is still measured in specimens with 100% initial saturation degree.

The good results measured for some injection products even in 100% saturated walls is in contrast with the practice of conservation, which suggests that a high moisture content increases the risk of failure of the intervention. The reason of this discrepancy lays most probably in the fact that the effectiveness measured after drying of the injected wall, as done in the described TNO experiments and in many other test procedures, is not representative of the practice situation, where the moisture supply from the ground can not be removed (see following section). On the other hand, the results suggest that, if the injected wall can sufficiently dry out after injection, a good effectiveness can be reached even in walls with a high initial saturation degree.

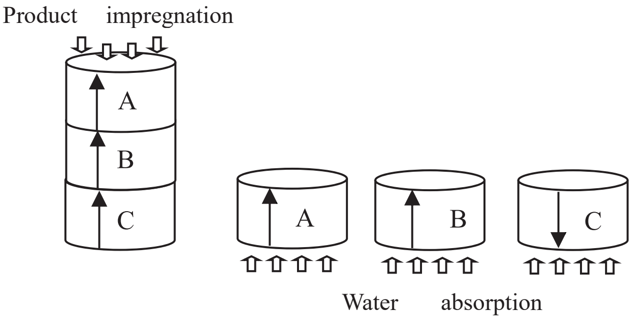

Figure 3 left. Impregnation of brick cores by hydrostatic pressure (left)
Figure 3 right. Sketch showing the slicing of brick core and the direction of the water absorption measurements on the three brick parts

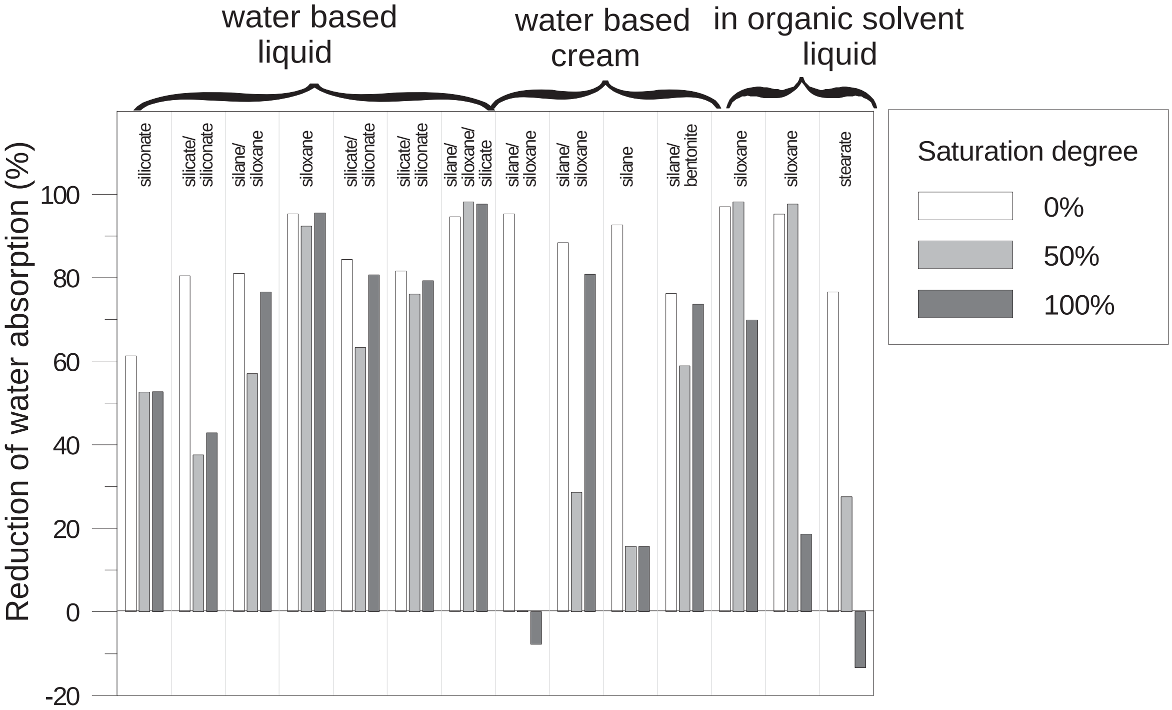

Figure 4. Spreading (measured as reduction of water absorption with respect to untreated specimens) in brick cores with different initial saturation degrees (0%, 50% and 100%). Each bar is the average if the water absorption measured on 3 slices from the same core

Drying phase after application

The quickest and most simplified test procedures (BBA on small scale pillar and BBRI procedure) foresee drying of the injected specimens, by removal of the moisture supply, before the assessment of the effectiveness of injection products. This is not a realistic simulation of the practice; however, the use of a drying phase might be accepted if this does not significantly affect the results of the test.

In the TNO research, the influence of the drying phase on the effectiveness of the products has been evaluated by the following procedure:

- Brick cores (diameter 40 mm, height 80 mm) have been sealed with epoxy resin on the lateral sides and wetted with water up to reach 50% saturation. The top and bottom of the cores have been then sealed with Parafilm (by Pechiney Plastic Packaging Company) for 24h in order to allow homogenous distribution of the water in the pore network of the brick.
- After removal of the Parafilm, the cores have been impregnated with hydrostatic pressure during 24 hours with different products.
- The specimens have been then positioned on brick cores of the same diameter and 20 mm height which were on their turn partially immersed in water and thus 100% saturated. The small core and the impregnated brick specimen were sawn to ensure intimate contact, so that a continuous and constant moisture supply was provided to the impregnated core.
- The weight of the impregnated cores was monitored during a period of 15 weeks. A decrease in weight of the impregnated core indicates that the injection product is effective. After 15 weeks no significant decrease in weight was observed for any of the specimen, showing that none of the products had become effective in the very harsh conditions of the test (Figure 5).

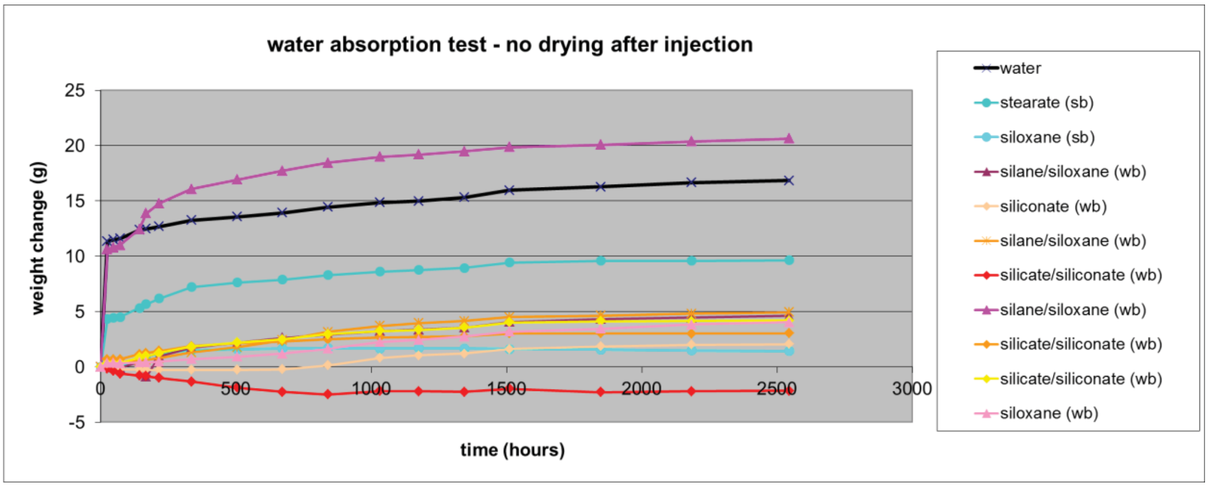

Figure 5. Water absorption of cores (50% initial saturation degree) impregnated with different products by hydrostatic pressure (no drying of the specimen took place between impregnation and measurements of the water absorption). A decreasing moisture content identifies an effective product. A constant weight indicates a not effective product. An increasing moisture content indicates an incomplete saturation of the specimen during impregnation

The same cores were then dried at 20 °C 50% for about 3 weeks and the effectiveness of the injection products tested again by measuring the water absorption of the injected cores. Most of the cores absorbed no or little water (figure 6), showing that the presence of a drying phase after injection is crucial for the effectiveness of injection products. This implies that a laboratory test, which allows (partial) drying of the impregnated specimens before testing, does not give a fully reliable simulation of the practice.

It can be objected that the moisture supply leading to 100% saturation, as used in the TNO test described above, is too high, and it does not represent the moisture supply commonly present in injected walls. Actually, a reliable laboratory test should keep the moisture supply after injection constant and equal to that present before injection.

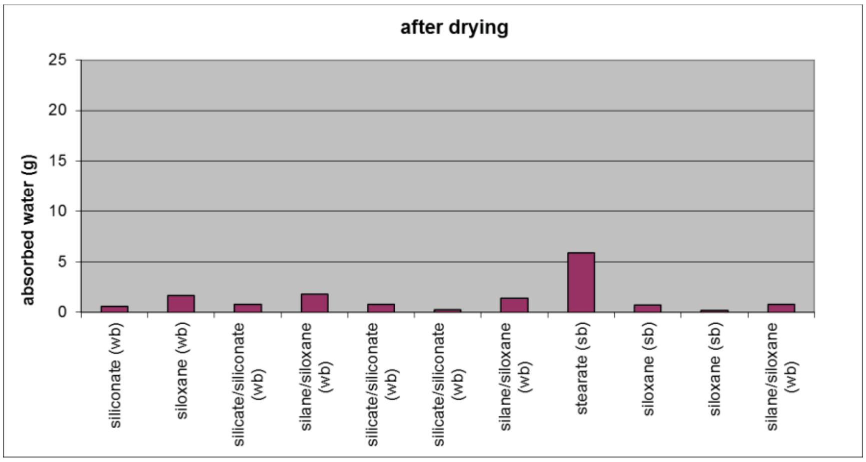

Figure 6. Water absorption of impregnated cores, measured after impregnation and drying. A low water absorption indicates a good effectiveness of the products

4. Requirements for a new test

Summarizing the considerations discussed in the previous section, it is possible to conclude that a quick and reliable test for the evaluation of the effectiveness of injection products should provide results within 2-3 months period and include the possibility of testing:

1. different substrate materials (e.g. material with different pore size, alkalinity, mechanical strength) and materials' combinations (e.g. mortar/brick)
2. different initial saturation degrees of the substrate, from dry to fully saturated.
3. different injection pressures (from hydrostatic pressure to 5 bar) and injection times
4. different injection products (e.g. in water or organic solvent, liquid or crème)

At the same time, the test should provide a constant moisture supply continuously before and after the application of the products. This moisture supply should be a realistic simulation of the practice situation.

5. Description of the newly developed test

With the above reported requirements in mind, TNO has developed a quick laboratory test for the assessment of injection products. The test procedure is shortly described hereafter.

Specimens preparation

The test can be carried out either on single material or on combination of brick or stone and mortar. In the first case, cores of 40 mm diameter and 8 mm height are cut from brick or stone units, or moulded with mortar. In the second case cores of 65 mm diameter and 80 mm height are drilled from 2 courses little walls. The height of the cores corresponds to the half of the distance between two adjacent injection holes in a wall. The full impregnation of the cores means therefore sufficient spreading of the product in the practice.

The cores can be pre-wetted with a defined moisture content prior to the injection. In order to guarantee a homogenous distribution of the water in the specimen, this is sealed with parafilm for 24 h after pre-wetting.

Impregnation

The cores can then be impregnated with liquid products (in water or in organic solvent) by hydrostatic pressure or injected by the use of pressure (up to a maximum of 5 bar). In order to apply the pressure without damaging the small specimen, the core is sealed within a PVC tube and inserted in a metal and plexiglas frame. The injection liquid is poured in the tube and air pressure is applied (figure 7). In the case crème products need to be tested, larger cores (diameter 100 mm) are used, in which a hole of 10 mm diameter is made in the centre for insertion of the cream.

Evaluation of the effectiveness

The effectiveness of the products is evaluated in two steps. In the first step the *actual effectiveness* (i.e. the effectiveness the product would have when no drying of the material after impregnation is allowed) is measured. In the second step the potential effectiveness, (i.e. the effectiveness the product would have when drying of the impregnated material is allowed after impregnation) is evaluated. The potential impregnation gives also a measure of the spreading of the product.

Figure 7. Pouring of the product in the PVC tube (left), application of the pressure (middle), testing of actual effectiveness of the product on a layered structure of brick and clay

1. Evaluation of the actual effectiveness: The water absorption of the impregnated specimens is measured directly after injection. The moisture supply to the specimens is maintained constant at about 50% of the saturation before and after treatment by the use of a layered structure of brick and clay layers positioned on one side in water and on the other in contact with the bottom of the impregnated specimen. A not-injected specimen is used as reference to control that the moisture supply remains constant during the test. A treatment is considered effective if the moisture content in the core decreases below that of the reference specimen (figure 8). A treatment resulting effective in these conditions, is supposed to be effective also when injected in a wall with a similar moisture content (provided the application is carried out appropriately).

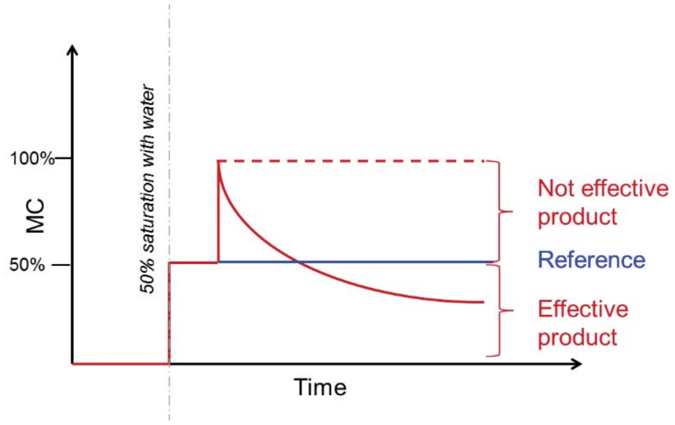

Figure 8. Criteria for the evaluation of the actual effectiveness of the products

2. Evaluation of the potential effectiveness. In case the actual effectiveness of the injection, measured as described above, results to be low, the impregnated specimens are dried at room temperature and their water absorption by capillarity measured. The reduction in water absorption with respect to an untreated reference specimen, gives the potential effectiveness, i.e. the effectiveness the treatment have when drying after injection is allowed. In a practice situation it would mean that the product might become effective if the wall is (artificially) dried after injection.

At the moment, the developed test allows to keep the moisture content constant at about 50% during the execution of the test. Further research is needed to improve the test and make it possible to control different moisture supply.

CONCLUSIONS

Conservation practice shows that often products which are found to be effective in laboratory do not show a similar behaviour when injected in wet walls in practice.

One of the reasons of these discrepancies can be found in the simplifications foreseen in the laboratory test procedures. The use of a single material instead of material combinations, the different application procedure and the presence of a drying phase after injection all contribute to decrease the reliability of laboratory tests. In particular, research has shown that the presence of a drying phase between the injection and the evaluation of the effectiveness, significantly affect the reliability of the obtained results: when a drying phase is included in the test a higher effectiveness of the products is obtained. This drying phase is generally not present in the field, where the moisture supply (rising damp) to the injected part of the wall is not removed.

On the basis of these findings, a new test has been developed at TNO for the assessment of injection products against rising damp. The new test foresees the possibility of using small specimens, made of a combination of materials, which can be impregnated or injected with different procedures depending on the type of product, and tested while keeping a constant moisture supply during the execution of the test. The duration of the test is, thanks to the use of small specimens, reduced to 12-16 weeks, including the preparation of the specimens.

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