Assessment of The Effectiveness of Secondary Horizontal Insulation Against Rising Damp Performed by Chemical Injection

Bartłomiej Monczynski 1, Barbara Ksit 1, Anna Szymczak-Graczyk 2

1 Poznań University of Technology, Piotrowo 5, 60-965 Poznań, Poland
2 Poznań University of Life Sciences, Piątkowska 94E, 60-649 Poznań, Poland

anna.szymczak-graczyk@up.poznan.pl

Abstract: Dampness in basement walls caused by capillary rise of water from the ground, as well as possible resulting damage, is very unfavourable phenomenon. This problem mainly concerns historical buildings and other structures erected before 1920, and the destruction is caused by lack, damage or technical wear of insulation. However, it can also arise in relatively new buildings where insulation was made incorrectly (or was not made at all). Creating a barrier that interrupts the capillary rise of moisture in the existing wall, i.e. secondary horizontal hydro-insulation is perceived as one of the most difficult, from a technical point of view, tasks in the field of building protection against water and dampness. The so-called mechanical methods are seen as the safest. Assuming that the works will be flawlessly planned and executed, a durable layer, impermeable to water and thus completely inhibiting the capillary transport of moisture, is formed in the cross-section of the wall – in many cases resulting in highly efficient isolation as “in a new building” [1]. However, due to practical limitations, mechanical methods are used much less frequently than injection schemes. By injection, injection technology or chemical injection is meant the introduction of injection fluid into the masonry, with the following three distinguishable ways of applying an injection agent: penetration, pressure and pulse in the form of an aerosol. The technology must ensure equal distribution of an injection agent within the entire wall cross-section, and its principle of operation is to create a continuous layer interrupting capillary rising to obtain (after some time) an area with regular dump in the masonry zone above the membrane. Injection methods, although widely used, are associated with a greater risk of partial or complete failure. The universality of application combined with the risk of failure has encouraged the search for a parameter to assess the effectiveness of secondary horizontal insulation. A suitable parameter is the AQ coefficient (from German - Abdichtungs Qualität) based on the capillary water absorption coefficient, proposed by Venzmer et al.3. The article presents research results on the effectiveness of chemical injections performed in reference walls made of ceramic bricks. The membrane was made using three different injection agents: formulation based on silicates (mixture of silicates and alkaline methyl silicates), silicon micro-emulsion and silane-based injection cream. In the injection zone, the drill cores were taken to perform capillary water absorption coefficient measurements. In order to obtain reference samples, additional drills were made above the impregnation zone protected with the injection agent. Both the measurements made and the calculated AQ coefficients proved the effectiveness of the above-mentioned injection agents.
1. Introduction

By injection, injection technology or chemical injection is meant the introduction of injection material into the masonry in such a way as to ensure equal distribution of an injection agent in its entire cross-section. Application of an injection agent can be carried out in three ways: by penetration, pressure and pulse in the form of an aerosol. The principle of operation in chemical injecting is to create a secondary horizontal insulation i.e. a continuous layer interrupting capillary rising in order to obtain (after some time) an area with permissible dump in the masonry zone above the hydro-insulating membrane (Figure 1). The technical literature provides different values of acceptable dump for the same materials or walls. For a brick wall, the value ranges from 0 to 3% for a wall not laden with salt [1]. Walls in areas not exposed to other types of moisture such as: penetration of splash water, pressure of water under hydrostatic pressure in the underground area, moisture condensation due to ventilation disturbances and increase in relative air humidity, exposure to aggressive salts, dry up to a sorption equilibrium, i.e. to the level of natural dampness.

![Figure 1. Zone of the wall prepared for injection](image)

Injection technology can also be used for recreating secondary horizontal insulation. Current technological guidelines are described in the instruction no. 4-10-15 / D [6] (previously 4-4-04/D) amended in 2015 by the German organization WTA i.e. Scientific Engineering Consortium for Conservation of Constructions and Monuments (in German: Wissenschaftlich-Technische Arbeitsgemeinschaft für Bauwerkserhaltung und Denkmalpflege).

Practice and the literature distinguish four different principles of action of chemical injection agents [4][5][6]:

- closing (clogging) of the capillary cross-section – injection agent deposits in the partially filled with water pore and capillary system, until it is completely filled and interrupts the capillary transport,
- reducing of the capillary cross-section – injection agent deposits in the pore and capillary system in such a way that the so-called effective capillary radius is reduced whereby capillary active pores are no longer available for moisture transport (capillary rising velocity is reduced to zero),
- hydrophobisation – injection agent deposits on the walls of pores and capillaries and creates, in combination with the material, a water-repellent layer (contact angle ≥ 90 °) that results in the inhibition of capillary moisture,
- closing or reducing of the capillary cross-section in combination with their hydrophobisation.
2. Injection agents

There are used numerous chemical agents for horizontal insulation made with injection methods. These include: alkali silicates, alkali meta silicates, meta silicone resins, bitumen emulsions, epoxy resins, polyurethane resins, methyl polymethacrylates, paraffins and composites of petroleum waxes, cement suspensions, silanes/siloxanes, silicone microemulsions (SMK) and injection creams. In building practice, the most often used are materials based on silicates, silicon micro-emulsions and, still gaining in popularity – silanes – in the form of a concentrated film.

Alkali silicates i.e. sodium, potassium or lithium water glass have been used with varying degrees of success since the 1950s until today. Despite some limitations, they remain in use due to their availability and cost-effectiveness. While in the past mainly sodium-based agents were used, currently, even if rarely, potassium silicates or potassium water glass are used more frequent. Alkali silicates transform into silica gel by reacting with carbon dioxide in the air. Through the deposition of silica gel in pores and capillaries, they become narrowed, and under favourable conditions they might even clog up. What can be problematic when using water glass is to provide access to carbon dioxide, especially in the case of considerably thick walls and high moisture penetration (which is relatively common in older buildings). Durability of membranes made with alkali silicates depends on constant access to moisture. Without it, silica gel shrinks and this leads to the formation of so-called secondary capillaries. An additional disadvantage of this type of agents is the fact that chemical reactions result in the formation of alkaline carbonates that are harmful to buildings. They can also lead to hygroscopic moistening of walls. Another limitation is the fact that in order to be able to apply those agents, the level of moisture penetration should be up to 50%, and the wall thickness should not exceed 60 cm.

Alkali metal silicates – are water-soluble salts of alkali silicate, and the most frequently used is methyl silicic acid. These agents, also by reaction with carbon dioxide, lead to the formation of poly methyl silicic acid and carbonates. Poly methyl silicic acid leads to the hydrophobisation of the capillary cross-section. As in the case of alkaline silicates, it is problematic to ensure access to carbon dioxide and answer to the formation of harmful building salts. For this reason, the use of alkaline methyl silicates in thick walls with high moisture penetration is not recommended. Their strong corrosive properties – commercial products have a caustic effect comparable to 20% of potash liquor [1] – are additionally disadvantageous.

The use of alkaline propyl compounds in place of methyl silicates is a solution that also uses the action of poly methyl silicic acid. In this case, the formation of poly methyl silicon acid, and thus the hydrophobisation of the wall, occurs without carbon dioxide. Thanks to this, the injection can also be carried out in thick walls of considerable moisture penetration. The disadvantage of these materials is the formation of by-products in the form of harmful building salts and fast binding. Although a rapid action may be seen as an advantage in certain situations, it also poses a serious threat to complete and equal distribution of injection agents in the wall (what results in limited penetration i.e. there may appear places without the continuity of dampness protection).

The combination of silicates and alkaline silicates – combination of both of the aforementioned agents leads to the narrowing of the capillary cross-section with their simultaneous hydrophobisation. In the first stage of operation of this mixture, silica gel deposits in capillaries, which make them narrow, subsequently, the zone of the wall located above the created membrane dries up. The decrease in dampness, in turn, activates the hydrophobising properties of methyl silicate. Hydrophobisation allows the membrane to function, even in the case of silica gel shrinkage, which, when using only silicates, counter the effect of drying. Silicone microemulsion concentrates (SMC), like silanes and siloxanes, show a hydrophobising action. These are pure silanes or modified siloxane compounds in the form of a fine-particle microemulsion. SMCs do not contain organic solvents or alkali and are characterized by low viscosity. They are transparent and odourless liquids, which when added to water form stable small-molecule silicone microemulsions (the particles size is about 10-9 to 10-10 m). The particle size of the injection material remains unchanged even when the concentrate is mixed with water. An important feature of
these solutions is that silicone microemulsions also do not lead to the formation of harmful building salts. The disadvantage, however, is the necessity to provide an alkaline environment when injecting. Considering that in the case of old buildings it is not always possible to provide such conditions, work with a historic wall may require the additional use of alkaline material. In such case, a multistage injection should be carried out, which includes the following procedural steps: stage 1 - injection of cement suspension to fill cracks and voids, stage 2 - injection of silicon microemulsion and stage 3 - injection of an alkaline activator. In order to meet the requirements, it is necessary to carry out stages 1 and 2, or 2 and 3. If pre-filling of cracks and cavities in the wall is required, the activator can be omitted because the required alkaline environment will be ensured by the use of cement suspension. In this case, the microemulsion must be injected one hour after applying the suspension. Another restriction for this method refers to walls in which no cracks and cavities have been found. No later than 24 hours after injecting the silicon microemulsion, the activator should be injected into the same injection openings.

In the case of silicon microemulsion it is possible to perform injection with the pulse method. The injection agent is brought into the wall by an electronically controlled impulsive device through a perforated lance with which it is distributed in the wall. This method allows for injecting both walls that contain cracks and cavities or layered walls, without the need of cement suspension pre-fill [1]. However, it should be noted that the so-called "poor" walls i.e. with a core made of different materials (Figure 2) can be problematic and this method will not meet the requirements for the continuity of waterproofing introduced for hydro-insulation solutions.

Figure 2. Medieval wall

Injection creams – are products created as a result of further work on chemical agents based on silanes, and they do not contain organic solvents. They are characterised by low viscosity and thick cream consistency. Thanks to these properties, the injection agent penetrates very enters into the wall structure, which results in significantly improved penetration. Due to the high content of active substance (above 65%), this product can be used in walls with moisture penetration up to 95%. However, thanks to their thixotropic consistency, injection creams can be applied horizontally (or under only a slight inclination) without the risk of leakage. They can also be used in walls with cracks and/or cavities without the necessity of cement suspension pre-fill. Furthermore, these agents can be used in materials with a neutral pH.

3. Assessment of the effectiveness
The capillary absorption coefficient \( w \) is commonly used in the technology of building materials. The value of the coefficient indicates what amount of water is absorbed by surface (surface unit) at a specified time.
Building materials, in terms of their water absorption properties, can be divided into the following groups [3]:

- water absorbent: $w > 2 \text{ kg/(m}^2 \cdot \text{h}^{0.5})$,
- water inhibiting: $w < 2 \text{ kg/(m}^2 \cdot \text{h}^{0.5})$,
- water repellent: $w < 0.5 \text{ kg/(m}^2 \cdot \text{h}^{0.5})$,
- waterproof: $w < 0.001 \text{ kg/(m}^2 \cdot \text{h}^{0.5})$.

The AQ insulation quality coefficient can be used to assess the effectiveness of the injection (German: Abdichtungsqualität), enabling to determine to what extent, due to the injection, the properties of the material have approached the characteristics of other non-absorbable materials. The insulation quality factor is calculated according to the following formula [3]:

$$AQ = \frac{w_r - w_i}{w_r} - 0.5 \times 100\%$$  \hspace{1cm} (1)

where:  
- $AQ$ – insulation quality coefficient,
- $w_r$ – reference coefficient of capillary absorption (non-injected material),
- $w_i$ – capillary absorption coefficient (injected material),
- $0.5$ – maximum capillary absorption coefficient for water repellent materials.

Injection membranes are defined as functional when the AQ factor is not less than 90%.

4. Performance tests

4.1. Reference walls

In the laboratory of the Institute of Building Structures, Poznań University of Technology, three experimental reference walls were erected. Dimensions, mortar brand and thickness of joints were adopted by analogy to "large" experimental walls for effectiveness checks using WTA method [2][6]. Each wall with a length of about 0.75 m consisted of thirteen layers of full ceramic brick 15, laid (one brick thick) in a combined bond (English bond). Lime-cement mortar with a volume ratio of 2:0.5:8 was used for bricklaying (hydrated lime: cement CEM I 32.5 R: sand). Support joints and horizontal joints had a thickness of 12 mm and 10 mm, respectively. The side faces of walls were secured with sealing mortar.

The seasoned walls were exposed to moisture, by submerging them in water to a depth of approx. 15 cm (the water level was maintained throughout the duration of the study). After three weeks, some of the walls above the water level were wrapped on four sides with foil in order to create the so-called capillary column i.e. to intensify the moistening process due to capillary action. Six weeks after placing the walls in water, a horizontal membrane started to be made with the chemical injection method (Figure 3).

4.2. Injection

In each of the three reference walls there was made a membrane against capillary action, and each membrane used a different chemical injection agent. The study used the following agents: formulation based on silicates (mixture of silicates and alkaline methyl silicates), silicon microemulsion and silane-based injection cream. Injection holes were drilled at an angle of approx. 45° in axial spacing approx. 12.5 cm, in two rows. Borings were removed by blowing holes with non-lubricated compressed air.

In the case of the silicate-based agent and the silicon microemulsion, the injection was carried out in accordance with the manufacturers’ recommendations, using a low-pressure pneumatic pump and plastic driven packers. The injection cream was applied under gravity conditions, by filling in injection holes once.
4.3. Performance control
In order to take measurements of the capillary water absorption coefficient, after three months after the injections, there were collected drill cores from the injection zones of each wall. In addition, reference samples were taken from the area above the injection belt. All cores were dried up to a constant mass, by storing them at 40°C. Such prepared samples were immersed in water (with the immersion level of approx. 12 mm) and weighed after five minutes, twenty minutes and one, four, eight, sixteen and twenty-four hours accordingly (Figure 4).

The results of measurements, the calculated capillary water absorption coefficients after 24 hours of water immersion (w24) and the coefficients of insulation quality are presented in Table 1.
Table 1. Results of capillary absorption measurements

| Sample no. | Weight in kg after "x" hours after immersion | w24 [kg/m²·h0.5] | AQ  |
|------------|--------------------------------------------|------------------|-----|
| A0         | 0.016 3.640 3.650 3.655 3.665 3.695 3.720 3.760 3.795 | 1.93             |
| B0         | 0.016 3.660 3.665 3.670 3.680 3.730 3.785 3.860 3.905 | 3.05 2.73 -      |
| C0         | 0.016 3.750 3.750 3.760 3.780 3.840 3.915 3.970 4.005 | 3.23             |
| A1         | 0.016 3.770 3.770 3.775 3.780 3.795 3.815 3.855 3.880 | 1.39 0.94 81%    |
| A2         | 0.016 3.770 3.775 3.775 3.775 3.775 3.780 3.785 3.800 | 0.39             |
| A3         | 0.016 3.770 3.775 3.775 3.775 3.775 3.780 3.785 3.800 | 0.39             |
| B1         | 0.015 3.610 3.615 3.615 3.615 3.615 3.620 3.620 3.625 | 0.20 0.22 113%   |
| B2         | 0.016 3.745 3.745 3.745 3.745 3.745 3.745 3.750 3.750 | 0.07             |
| B3         | 0.016 3.745 3.745 3.745 3.745 3.745 3.745 3.745 3.750 | 0.07             |
| C1         | 0.015 3.665 3.665 3.665 3.670 3.675 3.685 3.700 3.715 | 0.70             |
| C2         | 0.016 3.735 3.740 3.740 3.740 3.740 3.740 3.740 3.740 | 0.06 0.40 104%   |
| C3         | 0.016 3.745 3.750 3.750 3.750 3.750 3.750 3.770 3.775 | 0.44             |

a A0-C0 – reference samples, A – samples injected with a silicate-based agent, B – samples injected with silicon microemulsion, C – samples injected with injection cream.

5. Summary and Conclusions

In the analysed cases, the application of all the three injection agents was reported to improve parameters in the masonry in terms of capillary water absorption. However, only the parameters obtained using the injection of the silicone microemulsion agent and the injection cream can be considered as satisfactory (AQ ≥ 90%). It should be emphasised that for the last two injection agents not only was it possible to exceed the limit value of the insulation quality coefficient but also to obtain an absorption coefficient lower than the limit value for non-absorbent materials. Nevertheless, it should be also noted that the analysed materials showed different values of the w24 coefficient. This differentiation also applies to reference samples. The value of w24 coefficient in one case was lower than the guideline for highly absorbent materials, amounting to w > 2 kg/(m²·h⁰.⁵). According to the authors, this may have resulted from the uncontrolled movement of the injection agent beyond the planned injection zone during pressure application. The risk of such a phenomenon is a frequent disqualifying argument when choosing this method for secondary horizontal insulation against capillary rising damp. The method of assessing the effectiveness of injection procedures described in the article allows for very accurate verification of the effects obtained in relation to the expected ones. However, due to the necessity of collecting core cores and the time needed for verification of the obtained results, it should not be expected that it will become widely and commonly used practice. It should also be noted that in the case of historical walls, any damage to the masonry structure is not recommended. Hydro-renovation of buildings requires a thorough verification of corrective methods planed for use, because in reality the problems with moisture can appear again after some time from the drying process due improper corrective methods applied earlier.

When choosing a method and an injection agent, it is also necessary to pay attention to the occurrence of pressurized water in the ground. The wall soaked with water impedes the action of many injection materials. What is of key importance then is to appropriately apply an agent that is under constant pressurized water action. In repair and renovation works that restore horizontal and vertical insulation, special attention should also be paid to the presence of salt compounds in the damp wall, since their excessive occurrence limits the selection of the agent and the method of secondary waterproofing.

References

1. F. Frössel, Osuszanie murów i renowacja piwnic, Warsaw: Polcen, 2007.
2. B. Ksüt, B. Monczyński, Analiza wpływu środków iniekyjnych, stosowanych do wykonywania wewnętrznych hydroizolacji poziomych, na właściwości zaprawy murarskiej Materiały Budowlane 11/2016 pp76-77 (in Polish)
3. H. Venzmer, N. Lesnych, L. Koss and L. Shchukina, “Tight or leaking? Four building
diagnostics assessment of grouting horizontal seals by experts”, Europäischer Sanierungskalender 2010, pp. 53–63, 2010, (in German).
4. J. Weber, „Horizontal barriers in the injection process“ in Structural waterproofing in old building renovation: procedure and legal approach, Wiesbaden, Vieweg+Teubner Verlag, 2012, pp. 205-235, (in German).
5. R. Wójcik, Hydrofobizacja i uszczelnianie przegród murowych metodą iniekcji termicznej, Olsztyn: Wydawnictwo Uniwersytetu Warmińsko-Mazurskiego, 2006.
6. WTA Merkblatt 4-10-15/D, Injektionsverfahren mit zertifizierten Injektionsstoffen gegen kapillaren Feuchtetransport, München: Wissenschaftlich-Technische Arbeitsgemeinschaft für Bauwerkserhaltung und Denkmalpflege e.V., 2015.