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The Influence of Injection Agents Applied for Carrying out Secondary Horizontal Damp Proof Courses on Masonry Mortar Properties

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Abstract.*In the article, a comparative analysis of the effects of selected substances applied to create secondary horizontal damp proof courses of masonry walls by means of the chemical injection method on the properties of masonry mortar was carried out. Particular attention was given to the influence of impregnation on the hygric properties of mortar. The resistance to destructive factors accompanying the dampening of masonry wall structures was also subjected to observation.*

Keywords: *Injection, Damp Proof Course, Renovation, Dampening.*

1 Introduction

The problem of the excessive moisture content of brick walls in historical objects is present in many European countries because of their rich cultural heritage and dense accumulation of historical buildings (Hoła, 2017).The masonry walls of historical buildings - made of ceramic brick or stone - are often characterized by a high thickness and a lack of damp insulations. It refers primarily to horizontal insulations, which began to be executed in a modern way at the beginning of the twentieth century. The lack of damp insulations causes direct and prolonged contact of a wall with the ground (Adamowski, in., 2005; Franzoni 2014). As a result, water molecules that are contained in the substrate along with salts dissolved in them penetrate elements of the masonry wall making it damp. These elements are both ceramic brick and mortar from joints, and in walls made of stone these joints are usually of a large width. Capillarity, the process of which was described inter alia in (Camino *et al.* 2014; Raimondo *et al*. 2009, Hoła *et al.* 2017), causes water molecules to be transported into the wall and into its higher parts. In the case of a masonry wall with a large thickness, from which evaporation of moisture is naturally difficult, the degree of moisture content gradually increases with time (Goetzke-Pala *et al.* 2016; Gutarowska *et al.* 2007).

Groundwater together with the salts contained in it rises due to capillary action to ever higher parts of the walls made of capillary-porous materials, such as burnt clay brick, brickwork joint mortar and plaster. Also the concentration of salts in the brickwork and plaster components increases by the year (Rirsch *et al.* 2010; Torres *et al.* 2010; Espinosa;i in.,2008). The negative effects of the excessive build-up of moisture in the wall include: a decrease in brickwork strength, susceptibility to frost damage, falling off plaster, spalling mortar in the joints between bricks, an increase in the heat transfer coefficient of the building envelope and susceptibility to fungal decay and mouldiness(Franzoni *et al.* 2011; Gentillini *et al.* 2012 Solymez,1999; Blaszczynski, 2007).

The dampening of walls as a result of the capillary transport of water is one of the main reasons behind damage in buildings, whereas the drying out of a wall by carrying out a secondary horizontal damp proof course in the wall is the most important element of renovation (Venzmer, 2008). One of the means of recreating horizontal insulation in a wall are injection (chemical) methods. Although the injection membrane, by assumption, is formed in the entire cross-section of the wall, in practice, the injection agent migrates mainly in the masonry mortar (Hölzen, 2006), especially in cases when injection openings are created (when using pressure injection as well as when applying injection creams) horizontally, in the supporting joint of the masonry wall.

2 Capillary Transport of Moisture in Mineral Construction Materials

The vast majority of materials applied in the inside walls of buildings are those described as capillary-porous, and thus characterized by a porous structure, with the pores connected with each other by a system of capillaries or partially separated by walls. The properties of capillary-porous bodies depend largely on the total volume of pores, the volume distribution of pores depending on their diameter (porosity structure), as well as the specific surface area of the pores. Although various criteria can be found in literature as far as the division of pores occurring in a material is concerned, the division given by the International Union of Pure and Applied Chemistry (UPEC) has been generally accepted, which, depending on the so-called effective pore radius (assuming for the sake of simplification their spherical shape) ref, distinguishes three groups:

- micropores: $r_{ef} \leq 2$ nm,
- mezopores: 2 nm < $r_{ef} \leq 50$ nm,
- macropores: $r_{ef} > 50$ nm.

It ought to be noticed, however, that capillary absorption and the transport of water is possible only in pores with a radius from 10-7 to 10-4 m (from 100 nm to 0.1 mm), also referred to as capillary pores. Pores with a diameter of less than 10-7 m, (gel pores), can fill up with water only as a result of capillary condensation, whereas pores greater than 10-4 m (air pores) can fill up with water only under pressure.

In addition to the structure and distribution of pores in a material, capillary transport of moisture is determined by the wetting properties of a liquid in relation to the material, or in other words – by the properties of the material in relation to water penetrating into the capillaries (Bonk, 2006; Balak, 2007). As a result of the surface tension forces of water, the surface of a liquid, upon contact with a solid body, creates the so-called contact angle, or the angle between the surface of the solid body and that contacting the surface of the liquid drawn at the point of contact (on the border of three phases). The value of angle θ is a measure of wettability:

- $0 < \theta < \pi/2$ – liquid wets, hydrophilic material
- $\pi/2 < \theta < \pi$ – liquid does not wet, hydrophobic material.

In the capillaries of a body characterized by good wettability, the surface of the liquid forms a concave meniscus (slightly rises when making contact with a solid body), whereas in the case of bodies with inadequate wettability – the meniscus is convex (falls).

It is very difficult to construct a model describing the capillary transport of moisture in porous materials, mainly due to the complex geometry of pores – seeing as how the network is formed from pores of various shapes (cylindrical, wedge-shaped, crevicular, spherical) as well as a diverse system of connections (open pores, pocket pores, closed pores). Capillaries also create discontinuous systems, as well as systems of complex shapes.

Attempts at investigating the mechanism of the capillary movement of moisture are described by Pogorzelski (Pogorzelski, 2004), using a simplified model of a capillary body in the form of a bundle of parallel capillaries of an identical radius for this purpose. In accordance with the Young-Laplace equation, a difference in the pressures Δp will occur on both sides of the meniscus causing a rise of liquid in the capillary, up to the differences in the pressure evening out by the forces of inertia, friction (resulting from the Hagen-Poiseuille Law) as well as gravitational force. Basing on these assumptions, formulas for the rate of capillary movement (at vertical movement) were indicated:

$$\upsilon = \frac{dl}{d\tau} = \frac{r^2}{8\eta l}\left(\frac{2\sigma\cos\Theta}{r} - g\rho l\right) \tag{1}$$

As well as maximum capillary rise (determined by Washburn's equation):

$$H = l_{\max} = \frac{2\sigma\cos\Theta}{r\rho g} \tag{2}$$

where:l – length of capillary, τ – time of rise, r – capillary radius, η – dynamic density of liquid, σ – surface tension, Θ – contact angle, g – Earth's pressure, ρ – liquid viscosity.

Formulas (1) and (2) express two basic laws describing the capillary absorption of water. The first states that the rate of the capillary rise is higher in materials with "thick" capillaries than those with thin capillaries. In materials with thin capillaries, the level of rise is significantly higher. At a very small or very large radius of a capillary, the rates as well as the maximum level of rise are reduced to zero (in other words, capillary transport does not take place). In reality, although capillary-porous materials have a significantly more complex structure than that described by the model of a bundle of identical parallel capillaries (Pogorzelski,2004), in the case of capillaries with a radius of less than 0.1 μm, the rate of absorption vanishes, whereas in the case of capillaries with a radius exceeding 100 μm, the maximum possible rise falls to zero.

3 Materials and Methods

A cement-lime mortar with a volumetric composition of 2:0, 5:8 (hydrated lime: CEM I 32.5 Portland cement: sand with a granulation of 0-2 mm). The fresh mortar was placed in a mould made from PVC pipes 200 mm in diameter, cut in 300 mm sections. After the initial hardening of the mortar, that is two days after preparing the moulds, the samples were placed in polyethylene bags for another five days. After a period necessary for the mortar to reach full strength, it was subjected to dampening, placing the moulds in a tray with water (on a grate) so that the samples were constantly submerged in approximately 10 mm. After two days, the moulds were taken out of the water, wrapped in foil and left for two weeks in order to ensure even distribution of moisture in the mortar (Monczynski, 2019) (Figure 1).

Holes were made in the samples and gravitational injection, using an injection cream, and pressure injection (under a pressure of 0.2 MPa increased after 30 s to 0.5 MPa) using methyl silicates as well as silicone microemulsion (SMK), carried out. After a further four weeks, the mortar was taken out of its moulds and cut using a circular saw into cubic samples with sides measuring approx. 45 mm.

Figure 1. Mortar samples during moulding, dampening and carrying out injections.

4 Results

Studies on absorbability were carried out on twenty-four cubic samples which, after drying at a temperature of 105±5°C and weighing, were placed in a tub, on a grate, and then submerged in water to approximately a quarter of their height (Wójcik, 2008). After 24 hours, that is after the completion of sample dampening as a result of capillary rise the samples were submerged to half their height and, following another 3 hours, to three-quarters of their height. The complete submersion of samples (minimum of 20 mm above the upper edge of the samples) took place 30 h after the commencement of the experiment. After complete impregnation, the samples were removed from water, dried with a rag and weighed (WTA, 2015). Absorbability in relation to the dry mass of the mortar was described according to the formula:

$$n_m = \frac{m_m - m_s}{m_s} \cdot 100\% \tag{3}$$

where: n_m – absorbability in relation to mortar mass [%], m_m – mass of sample saturated with water [g], m_s – mass of sample dried to a constant mass [g].

Studies on the phenomenon of capillary rise carried out on twenty-four cubic samples of a mortar dried to a constant mass, which, upon weighing, were placed on a grate in a flat tray which was then filled with water so that they would be submerged in water at a depth of approx. 10 mm. The measurement of capillary rise was carried out 1, 3, 6 and 24 h after submersion, weighing the samples (after first drying them with a rag). The increase in the mass of samples during individual measurements was calculated according to the formula:

$$m_i = \frac{m_c - m_s}{m_s} \cdot 100\% \tag{4}$$

where: m_i – increase in sample mass [%], m_c – mass of sample dampened by capillary rise of water, after 1, 3, 6 and 24 h respectively [g], m_s – mass of dried sample [g].

The water absorption coefficient was indicated according to the expression:

$$w_{24} = \frac{m}{A \cdot \sqrt{t}} \tag{5}$$

where: w_{24} – water absorption coefficient after 24 hours following submersion [$kg/m^2 \cdot h^{0,5}$], m – mass of absorbed water [kg], A- absorption surface [m^2],t – absorption time [h].

The results of studies on absorbability and capillary rise have been presented in Table 1.The compression test was carried out in an Instron 8500 Plus testing machine. Forty cubic samples

were used for the tests. The applied load was controlled by a force of 50 N/s – this value was selected so that the compression test of an individual sample would fell in the range of 30 to 90s. Due to the irregular shape of the samples, they underwent evening/smoothing with 220 grit sanding mesh (Gutarowska *et al.* 2004). Determining the resistance to frost is carried out by determining the mass loss caused by periodic freezing and thawing. Twenty-four samples were prepared for the test.
The samples were marked as follows:

- MKA – mortar impregnated with alkaline methyl silicate, ,
- SMK – mortar impregnated with silicone microemulsion,
- KI – mortar impregnated with injection cream,
- 0 – mortar lacking impregnation (controls).

Table 1. Results of studies on capillary rise and absorbability.

	m_1	m_3	m_6	m_{24}	w_{24}	n_m
0	11.7%	11.8%	11.8%	11.9%	1.89	11.8%
MKA	12.0%	12.1%	12.2%	12.3%	1.93	12.0%
SMK	11.5%	11.7%	11.7%	11.9%	1.87	12.0%
KI	7.8%	8.0%	8.1%	8.4%	1.35	10.2%

The compressive load (including breaking load), as well as movement under compression, were measured. The average compressive strength is presented in Figure 2.

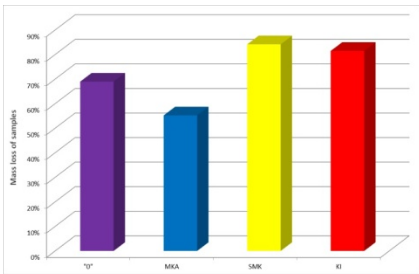

Figure 2. Average loss (percent) in mortar mass after freeze/thaw cycles.

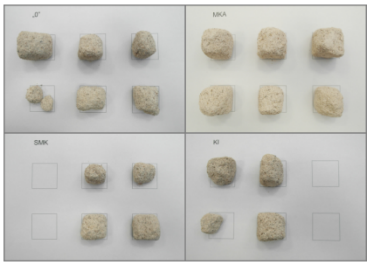

Figure 3. Mortar samples after 25 freeze/thaw cycles.

All were dried to a constant mass and next weighed. Next, the samples were submerged in water in order to completely dampen them. The saturated samples were removed from the water and placed for 4 h in a freezer, at a temperature of −20±2°C.Upon freezing, they were transferred to a tub with water at a temperature of 20±2°C for at least 4 h. Twenty-five freeze–thaw cycles were carried out, and next the sample was dried to a constant mass and weighed once again. The freeze-thaw resistance was indicated based on the formula:

$$\Delta m = \frac{m_d - m_f}{m_d} \cdot 100\% \tag{5}$$

where:Δm – the difference in the mass of the sample prior to testing and after testing [%], m_d– the mass of the sample dried to a constant mass prior to the first cycle [g], m_f – mass of sample dried to a constant mass following the last cycle [g].

Average losses in mass expressed as percentages are presented in Figure 2. Figure 3 shows the appearance of the samples upon the completion of the test. Testing the resistance to the crystallization of salts was carried out on twenty-four cubic samples which, after drying and weighing, were placed for 2 h in 14% solution of sodium sulphatedecahydrate ($Na2SO4 \cdot 10$ $H2O$). Next, the samples were dried at a temperature of 105 ±5°C for a minimum of 16 h. In order to ensure high air humidity at the first stage of drying, a tray containing water was placed in the dryer prior to its initiation. After completion of the drying process, the samples were cooled for approx. 2 h to room temperature and once again submerged in a saline solution.

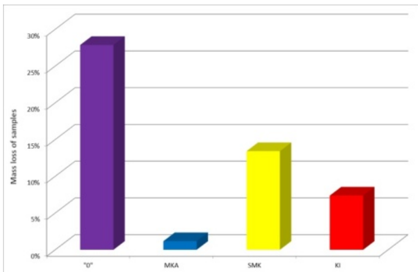

Figure 4. Average percentage loss of mass after testing the resistance to the crystallization of salts.

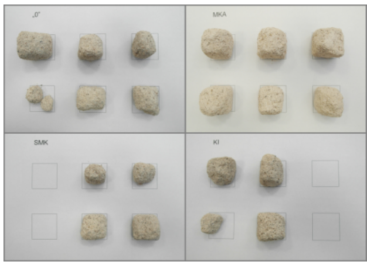

Figure 5. Mortar samples after 15 cycles of testing resistance to salinification.

Upon carrying out 15 such cycles, the samples were stored in water at room temperature for 24 h and next dried to a constant mass and weighed. The resistance to the crystallization of salts was indicated analogously to freeze-thaw resistance. Figure 4 shows the average percentage loss in mass, whereas Figure 5 presents the appearance of the samples after testing.

5 Conclusions

Impregnation of mortar was carried out with dampness resulting from close to maximal capillary rise of water. The results of studies on the capillary rise of water and total absorbability confirm that a high level of dampness makes it difficult or even impossible to apply agents based on alkaline methyl silicates and silicone micro emulsion. Injection creams, on the other hand, work very well in such cases (an over 13% reduction in total absorbability and nearly 29% decrease the capillary absorption coefficient were observed). All analyzed injection agents had a beneficial effect on the compressive strength as well as resistance to the harmful effects of construction salts. Alkaline Methyl silicates caused an increase in freeze-thaw resistance of the mortar. Due to the fact that the mortar subjected to the effects of agents based solely on hydrophobisation (silicone microemulsion and injection creams) caused a decrease in resistance to freezing and thawing, these substances should not be applied if there is no possibility to dry the wall before winter and it is not protected against freezing.

The results of the carried out studies also confirm that chemical injection treatment of the wall should not be carried out without accounting for specific conditions, such as the level of dampness, the location of the wall, conditions of the surroundings, etc. It should also be kept in mind that walls are conglomerates comprising materials characterized by various technical parameters.

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