Air Permeability of Renovation Plasters Evaluated with Torrent’s Method

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Abstract. The aim of research was to determine the air permeability of the renovation plasters, using Torrent’s method. The scope of this research included three renovation plaster systems. Each of them was applied on experimental, masonry element and had a different rendering coat. Permeability measurements were performed after 28 days of curing in a natural state. In order to calculate the coefficient of air permeability (kT), the partial data was registered during the measurements. The test results indicate the possibility of determination the coefficient of air permeability kT in relation to the renovation plasters. At the same time results confirm the high porosity of the renovation plasters.

1. Introduction

One of the basic problem of concrete structures maintenance is to counteract the results of moisture and salt contamination. Amongst many, renovation plasters are a form of structure protection from the harmful nature of water together with dissolved salt. Due to the number of specific parameters and properties of the renovation plasters, their average durability is estimated for at least a dozen years. The assessment of their durability should be performed during their exploitation in terms of the ongoing processes. In the technical guideline used nowadays there is a lack of in situ test, which would enable to assess the features determining the durability of such materials in real structures. In order to do so, possibility of the Torrent air permeability tester usage is verified.

Water, in every form, can be harmful to many materials and objects, especially to the elements of concrete structures, since it causes damage to wall structure as a result of physical, chemical and biological processes, which often occur all together inside the wall or on its surface [1, 2]. The moisture may be triggered of water appearance in different forms and originating from numerous sources. The walls may get moisten both superficially and structurally. The superficial moisture includes water vapour condensation and hygroscopic water migration. The structural one means that water is transported due to capillary suction from the groundwater [3]. Apart from that, the moisture may also be caused by the rain or water carried by the wind, as well as the plumbing systems failure. Therefore, there are numerous reasons of moisture in construction elements and they are hard to identify. In consequence, the protection from the negative effects of water becomes even more difficult. Additionally, in the case of lack of proper water and damp insulation, the level of wall moisture depends on various conditions, such as landform, the type and layers of the ground around and under the object, the level of groundwater and its changes in time, landform and the physicochemical properties of the construction material. Water gathered in the partitions causes
numerous negative results, for instance it decreases their thermal insulating and acoustic properties. It also influences the negative microclimate inside the room and favours the development of fungus [1, 4]. One of the most dangerous issues accompanying the dampness is the presence of salts soluble in water. Unhydrated salts are harmless. But in case of water presence, they dissolve and during the process of structural element drying, ions move together with water towards the surface. During water vaporization, the process of crystallization occurs, and hydrated salts precipitate in the pores, increasing their volume significantly. Consequently, the created pressure is often high enough so it leads to wall destruction, especially on their surface [2]. The result can be visible on the exterior surface of the wall through the presence of stains, discolouration or efflorescence.

Figure 1. View of the exterior surface of the wall with visible effects of moisture migration

It is necessary to perform the tests for the quantitative assessment of moisture, namely its distribution and the type, as well as the concentration of salt in the wall, in order to develop a plan to prevent and renovate the object affected by dampness and salinity. The results of such examination should provide adequate information so to choose the right method of prevention and maintenance of the excessive salinity [4]. It is also crucial to verify the type of salt because it increases the probability of determination the source of dampness [3]. Among the ions causing the process of solidification inside the wall there are mostly chlorides, sulphates VI and IV, nitrates V and III. In addition, there might also appear sodium, potassium, magnesium, calcium, iron or ammonium carbonates [3]. However, it is neither possible to provide constant humidity conditions nor eliminate the presence of salt in those objects which are exposed to the outside environment. Yet it is possible to try to protect them from the negative influence of water and dissolved salts.

Currently, there exists a variety of methods protecting the structures from the intrusive water influence. The most common ones are vertical and horizontal insulation [2]. The usage of these types of insulation significantly reduces the process of further dampness and salinity of the objects; however, it is not possible to eliminate the already existing water and salt [3]. The renovation plasters are the solution to that problem. They are basically a system of several layers of plasters having different properties which together make a complex protection. The first layer which is the closest to the wall is called the rendering coat. It has primarily the mechanical function, namely it increases the adhesion of the subsequent layers to the base. The second layer is the ground plaster coat. It is basically used in case of the higher level of salinity and roughness of the surface. Due to its hydrophilicity, this layer is prone to accumulate water. The next layer is hydrophobic, namely it is not wettable by water, and it comprises of the renovation plaster. Finally, the finishing coat is perceived as a supplemental layer of the whole system [2, 5].

As a result of capillary flow, dampness that is present in the wall moves towards the outside surface of the partition. However, this process can reach only 5 mm deep into the renovation plaster coat. Further, only a relatively quick process of water vapour diffusion takes place, enabling the plaster to...
remain dry. The area of diffusion is moved from the outer surface of the plaster into the inside, where the salts are assembled in the pores, in which the process of crystallization happens. It prevents from creating the damage visible on the surface. After the nucleation and growth, the salt crystals fill the available space in the plaster pores. As a result of this growth, there occurs an increase in tensile stress, which is taken over by the filler dispersed in the form of fibres, most often glass ones. This process lasts until all of the pores are completely filled in the renovation plaster coat, and the end of accumulation means the end of proper plaster functioning, and simultaneously its destruction. Yet its average durability is estimated for at least a dozen of years. It is possible to obtain such a result if the system that is used meets the specific requirements ascribed to its parameters and properties [2, 5, 6].

Among the range of properties that characterise the renovation plaster, three of them are perceived as fundamental and they provide the proper system functioning. First of them is low capillary conductivity, which reduces salt transportation towards the surface of the plaster. Second is the high water vapour permeability (diffusivity), which serves to ease dampness removal and thus partition drying. The last one is high porosity which enables salt accumulation inside the plaster. Moreover, inner hydrophobisation of the material structure reduces the capillary flow in the pores system and protects the renovation plaster from both the external salt influence and the weather factors [2, 5, 6].

As aforementioned, the choice of a particular renovation and maintenance method must be preceded by the proper tests for moisture and salinity extent. The composition of the renovation plasters system, namely the arrangement and thickness of the coats, depends on the level of salinity and the technical condition of the base. Yet, one should bear in mind the fundamental restoration assumptions which ensure the possibility of reversed work, namely an option to remove the plaster from the wall in case of losing its capability of further salt accumulation. Thus, the type of the rendering coat should be strictly dependent on the particular base material according to its durability. It is the rendering coat that has a decisive role about the required adhesion of the renovation plasters.

2. Experimental procedures – methods and test results

The durability of the renovation plasters is yet limited. It is mainly determined by the duration and ability of salt crystals accumulation in the pores. The aim of the conducted research was to assess the usefulness of the renovation plasters air permeability evaluated with Torrent’s method. Since several years, this method is successfully used in assessing air permeability of concrete coating in reinforced concrete structures. It is anticipated that there is a correlation between the air permeability of a renovation plaster and its porosity. One of the documents that regulate the requirements of the renovation plastiers is WTA 2-9-04 instruction from 2004 [7]. However, it includes no data regarding the required air permeability for the renovation plasters. Arguably, the reason for that lies in the lack of awareness of such method’s appointment. Similarly, the recommended norm EN 998-1 misses the data about the required air permeability.

The Torrent permeability tester is a device, which is used for non-destructive determination of concrete structures permeability. Two distinctive features of Torrent’s method are a two-chamber vacuum cell (see figure 1.) and a pressure regulator. The two-chamber vacuum cell is based on the guard-ring principle and contains an inner chamber and an outer chamber. The regulator is designed to keep both chambers always at the same pressure [8]. The cell is applied on a tested surface, the pump is turned on and a vacuum is created in both chambers. It is pressed against the surface because of the external atmospheric pressure and the rubber rings. Therefore, both chambers are sealed, making the cell self-supported. After 1 min, when the required vacuum level is reached, one of the stop-cocks is closed. The inner chamber system is insulated and the pump can only act on the outer chamber in order to balance the pressure in both chambers. Due to the equal of pressures, the outer chamber acts as a "guard-ring" and helps to create a controlled air flow into the inner chamber. The pressure in the inner chamber starts to increase, as air passes through a material surface. The indicator records the rate
of pressure raise, which is directly related to the permeability of the tested material [9, 10]. As the result of the measurements, the Torrent permeability tester calculates and displays the values of the coefficient of permeability \( k_T \) [m\(^2\)] and the depth of the vacuum penetration \( L \) [m] affected by the test. 

\( L \) value is defined as a function of \( k_T \) [8]. It is also related to the open porosity and the duration of the test [9]. Air permeability is heavily dependent on the moisture conditions of the concrete. Thus, authors of Torrent’s method experimentally determine the influence of moisture content on its air permeability and equipped the device with Wenner resistance probe [11]. It enables to measure the electrical resistivity \( \rho [k \, \Omega \, cm] \) by applying four electrodes on tested surface. The probe produces a current between the two exterior electrodes and measures the potential drop between the two inner electrodes [12].

The principal idea of this research was to use Torrent permeability tester in order to try to evaluate the air permeability of the tested renovation plaster systems. The research covered testing three renovation plaster systems which were superimposed onto the brick wall. This wall was made of the antique brick obtained from the demolition of the exterior walls of the building from 1880 in Cracow. It is worth noticing, that these 19th century bricks, produced in Cracow, measure \( \sim 290 \, mm \times \sim 140 \, mm \times 65 \, mm \), therefore they are slightly bigger than those produced nowadays [13]. Each of the systems was composed of three layers. In each of them, 1 cm thick ground plaster coat and 2 cm thick renovation plaster coat were used. The difference among the systems lied in the rendering coat, thus in the first layer. System I – standard rendering coat, system II – rendering coat was made of ground plaster with the additive of the water polymer dispersion and system III – rendering coat was made of standard ground plaster without any additives. All the measurements were taken after 28 days of curing in a natural state.

Prior to conducting the air permeability tests, the dampness of the particular material was evaluated by marking the electrical resistivity of the coat. The obtained results of electrical resistivity \( \rho [k \, \Omega \, cm] \) were used to evaluate the air permeability. During the measurements of air permeability, the partial data essential to evaluate the coefficient of air permeability \( k_T \) was registered. The knowledge of open porosity typical of a particular material was used in computation.

The percentage of open pores by volume in tested renovation plaster was determined by comparing bulk density with true density. Open porosity \( (p_o) \) was calculated using the following relationship [14]:

\[
\rho_{\text{H}} = \left( 1 - \frac{\rho_{\text{bulk}}}{\rho_{\text{true}}} \right) 100 [\% \text{vol.}],
\]

where: 
- \( \rho_{\text{bulk}} \) – bulk density [g/cm\(^3\)],
- \( \rho_{\text{true}} \) – true density (helium pycnometry) [g/cm\(^3\)].

The bulk density of samples was determined by a powder pycnometry method, using the Micrometrics GeoPyc 1360. This method is based in on displacement theory which an enables sample volume determination. Knowing the accurate mass of the sample, envelope density can by established. The procedure was described in [15] in detail.

This method has been successfully implemented for determinations of the density of many materials. In the tests, a chamber 19.1 mm in diameter was used, the consolidation force amounted to 38 N and the conversion factor was as recommended by the operating manual, i.e. 0.2907 cm\(^3\)/mm [15].

True density was determined using a helium pycnometer. In essence, this instrument measures the volume of the skeleton of the material tested with an accuracy of 0.0001 cm\(^3\). A measurement chamber
with a rated volume of 10 cm$^3$ was used in the tests, with the specimens filling the chamber to about 40% as recommended in the method that was followed [16]. In presented studies the Quantachrome Ultrapycnometer 1200e was used.

Table 1. Results of open porosity measurements

| Sample number | Bulk density $\rho_{\text{bulk}}$ [kg/m$^3$] | True density $\rho_{\text{true}}$ [kg/m$^3$] | Open porosity $p_o$ [%] | Average open porosity $p_o$ [%] |
|---------------|---------------------------------------------|---------------------------------------------|--------------------------|-------------------------------|
| 1             | 848                                         | 2413                                        | 64.9                     |                               |
| 2             | 828                                         | 2396                                        | 65.4                     | 65.1                          |
| 3             | 844                                         | 2419                                        | 65.1                     |                               |

The value of the coefficient of air permeability $k_T$ was calculated using the following equation (2) and taking into consideration the porosity of tested material [17]:

$$k_T = \left( \frac{V_c}{A} \right)^2 \times \frac{\mu}{2\varepsilon P_a} \times \left( \frac{P_a + \Delta P(t_f)}{\frac{P_a - \Delta P(t_f)}{\sqrt{t_f - t_0}}} \right)^2,$$

where:
- $V_c$ – volume of measuring (inner) cell (2.2 $\times$ 10$^{-6}$ m$^3$)
- $A$ – cross section of measuring cell (19.6 $\times$ 10$^{-4}$ m$^2$)
- $\mu$ – viscosity of air at 20° C (2.0 $\times$ 10$^{-5}$ N$\cdot$s/m$^2$)
- $\varepsilon$ – porosity of material,
- $P_a$ – atmospheric pressure [N/m$^2$]
- $\Delta P$ – pressure increase, measuring cell [N/m$^2$]
- $t_f$ – duration of measurement [s]
- $t_0$ – setting of stopcock, start of measurement (60 s)

Figure 2. Air flow to the two chambers of the vacuum cell [18]/
1 – Inner chamber, pressure $p_i$  2 – Outer chamber, pressure $p_o$
3 – Air flow to the outer chamber  4 – Air flow to the inner chamber
L – Depth of penetration of the vacuum
Figure 3. Two-chamber vacuum cell with sealing rings during measurements

Figure 4. Air permeability measurements evaluated with Torrent’s method

Table 2. The results of the coefficient of air permeability kT measurements

| Systems variant | Sample number | Porosity ε [% vol.] | Atmospheric pressure Pa $[10^3 \text{ N/m}^2]$ | Duration measurement $t_f$ [s] | Pressure increase $\Delta P_i$ $[10^3 \text{ N/m}^2]$ | Coefficient of permeability $k_T$ $[10^{-14} \text{ m}^2]$ | Average coefficient of permeability $k_T$ $[10^{-14} \text{ m}^2]$ |
|-----------------|---------------|---------------------|---------------------------------|-------------------------|--------------------------|-----------------|-----------------|
| I               | 1             | 99.34               | 99.00                           | 90                      | 15.20                     | 6.2             | 6.8             |
|                 | 2             | 99.18               |                                 |                         | 15.41                     | 6.5             |                 |
|                 | 3             | 99.16               |                                 |                         | 16.98                     | 7.8             |                 |
| II              | 1             | 99.16               | 99.16                           | 90                      | 27.85                     | 21.9            | 17.7            |
|                 | 2             | 99.15               |                                 |                         | 21.78                     | 13.1            |                 |
|                 | 3             | 99.16               |                                 |                         | 25.48                     | 18.1            |                 |
| III             | 1             | 99.16               | 99.14                           | 90                      | 17.39                     | 8.2             | 8.3             |
|                 | 2             | 99.14               |                                 |                         | 14.13                     | 5.4             |                 |
|                 | 3             | 98.89               |                                 |                         | 20.18                     | 11.3            |                 |

3. Concluding remarks
After analysing the results, it can be stated that the renovation plaster systems tested in this research are characterised by high air permeability, evaluated with Torrent’s method, which appears to be two to three times higher than the air permeability of the ordinary concrete. Generally, all average coefficients of permeability are on similar level. The observed diversity of partial results is natural for
examined feature. The factor responsible for such level of permeability is a high open porosity of the tested materials. In general, the gas permeability of the mineral building materials is a very sensitive factor to the changes in porosity. If the porosity of an ordinary concrete (15%) is compared to the one of the renovation plasters (65%), the difference is fourfold. By comparing the values of the coefficients of air permeability kT of these materials, it may be noticed that the difference is significant.

The obtained results conclusively prove the possibility of using the Torrent permeability tester in setting the coefficient of air permeability of the renovation plasters. Additionally, the results of air permeability and open porosity assessment unequivocally prove that the structure of the renovation plasters is available for environmental media. The relationship between the air permeability of a renovation plaster and its porosity suggests the possibility of using the Torrent’s method in evaluating the durability of the renovation plaster systems. The estimation of the high likelihood of correlation between these properties would enable to control the level of salt accumulation process in the pores of a renovation plaster. The lower the value of the air permeability, the higher the filling of the pores, which would thereby decrease the porosity of a renovation plaster. Due to the ease of measuring with the Torrent permeability tester it becomes possible to monitor the air permeability of a renovation plaster systems used in real structures during their long exploitation. Measuring at the agreed intervals, for instance every couple of years, will allow to observe the dynamics of changes in air permeability caused by the progressive processes present during the plaster exploitation. Therefore, it will be possible to anticipate the potential durability of the renovation plasters.

In conclusion, the usage of Torrent’s method to evaluate the air permeability of the renovation plasters is possible. This method belongs to the group on non-destructive testing used in situ during the typical material exploitation. To monitor the changes of material permeability of the renovation plasters during their functioning may become a highly valuable information about the assessment of potential durability of these materials. This knowledge will definitely contribute to the aware planning of the restoration conducted on the heritage buildings.

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