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EVALUATION OF HYGRIC PROPERTIES OF CONTEMPORARY PLASTERS

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ABSTRACT

Excessive moisture content poses one of the main problems affecting masonry structures, their durability, thermal performance and health of inhabitants. Moisture removal from damped construction represents an important task for both description of capillary water suction phenomena and technical solution dealing with moisture removal. This study presents an analysis of the properties of cement-lime plasters and their effectivity for drying of masonry walls. The basic physical, mechanical and hygric properties of analyzed plasters are determined in laboratory conditions. The studied plasters are also applied as surface layers of masonry columns, exposed to outdoor climatic conditions and controlled moistening, and their hygric performance in situ is monitored using the time domain reflectometry measurements. The obtained data can be utilized in the subsequent computational service life assessment of the studied plasters.

Keywords: moisture content, hygric properties, time domain reflectometry, plaster, brick.

INTRODUCTION

The building exposure to outdoor climatic conditions is related to deterioration of building materials. A proper understanding of moisture transport in the porous structure of building materials represents an important knowledge for design of effective and durable materials with increased endurance against degradation processes connected with excessive moisture content. Especially, old masonry constructions suffer from disintegration of lime plasters, frost damage during winter period and related biological and chemical corrosion processes accompanied with the moisture uptake (Franzoni, 2014).

The capillary moisture action is responsible as major factor inducing rising damp in masonry structures. The excessive moisture content in building walls represents a significant problem related to the unsuitable indoor thermal-hygrometric conditions (Derluyn *et al.*, 2011). Damped walls often induced very high values of indoor relative humidity together with mold growth. These phenomena are strongly connected also with negative effects on inhabitant health and pose a significant risk (Torres and de Freitas, 2007). Moreover, the occurrence of water in building structures negatively affects their thermal performance due to high thermal conductivity of water, where 1 wt.% can induce an increase of thermal conductivity of masonry wall by about 5 % (Fassina *et al.*, 2002). The water presence in porous structure of building materials is also accompanied with the negative impact on mechanical parameters. The excessive moisture content is often present in the old masonries, namely almost a half of conducted reconstruction works is linked with the occurrence of rising damp and hygroscopic salts (Ahmad and Rahman, 2010). Based on the described reasons, the occurrence of rising damp constitutes a challenging task for consequent remediation provisions. The removal of rising damp constitutes a complicated issue and often the performed work is focused only on the removal of the damaged material and its replacement without any intervention for moisture removal.

Across the literature it is possible to distinguish many repair scenarios aimed at dealing with excessive moisture content in masonry walls (Healy, 2003). These systems can be divided into several categories such as: systems based on the reduction of water flux ingress (D´Agostino, 2013), systems based on the reduction of wall sorptivity (Terheiden, 2008), systems based on electrokinetic phenomena (Bertolini et *al.*, 2009), and those based on evaporation increase (Hughes, 2012). The possibility of reduction of the wall sorptivity is often limited due to the construction problems or other unique issues.

The application of plasters with the improved hygric properties can be perceived as an efficient method how to promote moisture evaporation from the damped masonry. These types of plasters can be divided into several categories, but the mechanism of water transport and salt crystallization is still not fully elucidated (Pavlíková *et al*., 2011; Lubeli *et al*., 2006). An important part of the efficient restoration of damped construction consists in precise evaluation of the initial state of the studied object. The precise measurement of the material moisture content together with the consequent assessment of the adopted precautions represent another important issue (Rirsch, 2010). The estimation of the moisture content by gravimetric methods is the most often employed technique. However, this method has several weaknesses, namely low sensitivity, destructivity, unsuitability for long term evaluation and serious inconsistency (*Roels et al*., 2004). The employment of the non-destructive determination method can be perceived as a more suitable solution for such analysis. The utilization of the Time Domain Reflectrometry (TDR) can be easily adopted for the long-term evaluation and monitoring of moisture content in brick masonry (Pavlík *et al*., 2012). The mentioned method is usually employed for determination of moisture content in soils, but its potential can be utilized also in other fields. The method is based on the measurement of permittivity which can be easily calibrated for determination of the moisture content. The main advantage of this method is based on its applicability for the long-term measurements without any further destructive techniques.

This study is aimed at the evaluation of contemporary plasters and their effectivity in field of material drying. On this account studied materials were characterized and consequently applied on brick columns placed outdoor. The development of moisture content was continuously monitored by the Time Domain Reflectometry (TDR) probes.

STUDIED MATERIALS

Three different types of contemporary plasters used in the Czech Republic were subjected to the evaluation of their properties and efficiency for damped masonries. The samples were prepared according to the instructions of the plasters producer (Baumit). All studied plasters contained silica aggregate with dimension to 2 mm. Characterization of studied plasters is given in Table 1.

Casted material samples were stored for 28 days in highly humid environment and consequently dried and subjected to material characterization.

Table 1 - Characterization of studied plasters

Material	Characteristic	w/ds
PL1	Baumit GrobPutz Maschinell - core plaster	0.17
PL2	Baumit Sanova W - renovation plaster	0.40
PL3	Baumit Sanova P - renovation plaster	0.34

MEASUREMENT TECHNIQUES

The determination of basic physical properties of studied plasters included the bulk density, matrix density, and total open porosity. Measurement of the bulk density was done on five cubic samples of 50 mm side and determined from the measurement of sample sizes (using digital caliper) and its dry mass. The matrix density was accessed by helium pycnometry using apparatus Pycnomatic ATC (Thermo Scientific). The accuracy of the gas volume measurement using this device is ±0.01% from the measured value, whereas the accuracy of used analytical balances is ±0.0001 g. The measurement of bulk density uncertainty was 5.3% and 3% for matrix density.

Sorption and desorption isotherms were obtained by dynamic vapor sorption device DVS-Advantage, whereas the measurements were done at 21 °C. Samples were placed into the climatic chamber of the DVS-Advantage instrument and hung on the automatic balances in the special steel tube. The device measures the uptake and loss of vapor gravimetrically, using highly precise balances having the resolution of 1.0 μg. The particular samples were exposed to the following partial water vapor pressure profile: 0; 20; 40; 60; 80; 90; and 98% of relative humidity (RH). Each step in RH during the DVS measurement is incremented either when a stable mass is achieved with mass change less than 0.00004% /min or a maximum time interval of 400 min is reached (Fořt *et al*., 2014).

A hydraulic testing device VEB WPM Leipzig having a stiff loading frame with the capacity of 3000 kN was employed for the measurement of compressive and bending strength.

The cup method was employed for the characterization of water vapor transport. The method is based on one-dimensional water vapor transport and determination of the diffusion water vapor flux through the specimen and measuring partial water vapor pressure in the air under and above specific specimen surface. Plaster samples were placed on the top of a stainless-steel cup sealed by technical plasticine. For the measurement five samples with dimensions of 100 x 100 mm and 50 mm thickness were used. The cup contained sorption material, in our case silica gel. Measuring cups were placed in a controlled climate chamber and weighed periodically. The steady state values of mass gain or mass loss were utilized for the determination of the water vapor transfer properties.

The ability of the plasters to transport liquid water was described by the measurement of the water absorption coefficient A ($kg/m^2s^{1/2}$). The applied sorptivity test is based on one dimensional free water uptake when lateral sides of a sample are insulated by a waterproof material.

The TDR method is based on launching electromagnetic waves and measuring the time interval between launching waves and detecting the reflections from the end of the transmission line. The device used for observation of the electromagnetic pulse echo in the time domain is an important element in any TDR equipment. TDR/MUX/mts cable tester (Easy Test) connected with PC for data logging and equipped by 8 miniprobes LP/mt was used in the measurements in this paper. Sensors consisted of two 53 mm long parallel stainless-steel rods, 0.8 mm in diameter and separated by 5 mm. According to the information provided by the producer, the measuring range of the relative permittivity is from 2 to 90, the absolute uncertainty is 2 for $\varepsilon \geq 6$ and 1 for $2 \leq \varepsilon \leq 6$ (Pavlík *et al.*, 2012). The probes were placed into the tested brick masonry columns built from bricks with following parameters: bulk density - 1 691 kg/m^3, matrix density - 2 659 kg/m^3 and total open porosity - 36.4%. The TDR probe arrangement is given in Figure 1. Columns were moistened in order to simulate damped construction and continuously monitored by TDR probes to access the effectivity of the applied plasters to evaporation of moisture.

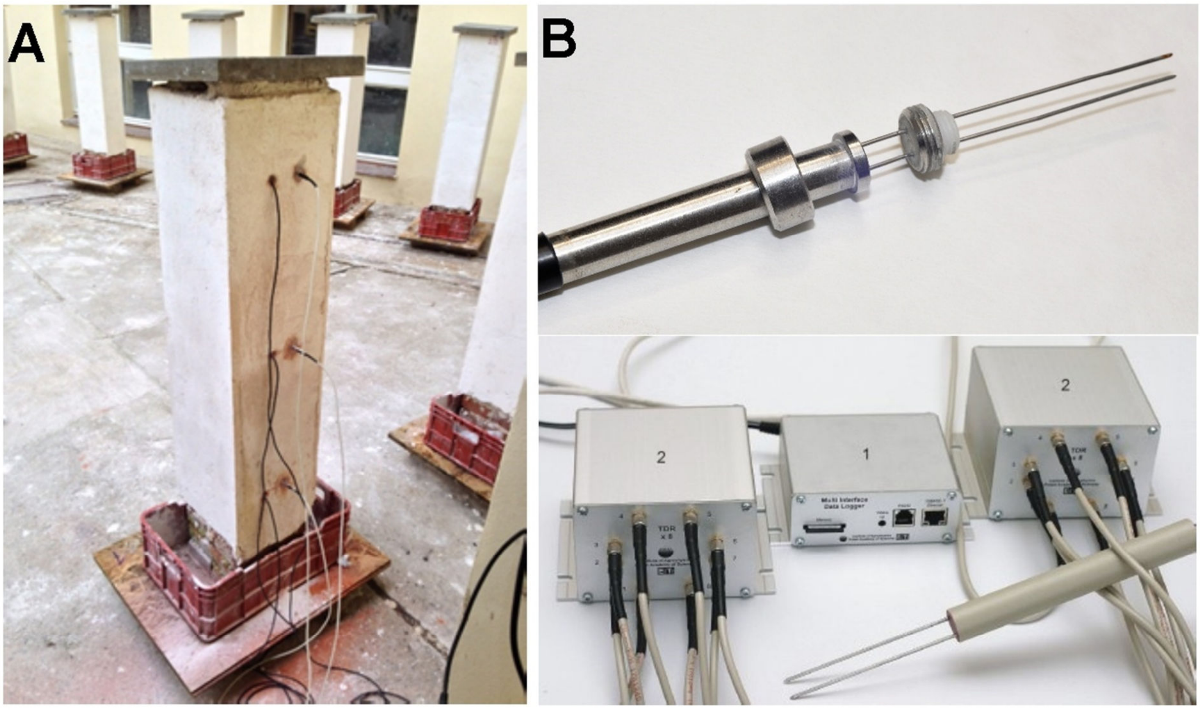

Fig. 1 - A: TDR probes placement; B: detail of the TDR probe and multiplex

RESULTS AND DISSCUSION

The basic material properties of applied plasters were firstly determined in order to provide a coherent comparison of used materials. The obtained results pointed at similar characteristics of applied plasters with only minor differences. Namely, a higher bulk density of Baumit core plaster denoted as PL1 was in a relation to its lower total open porosity, as compared to the renovation plasters PL2 and PL3. The basic material properties of applied plasters are given in Table 2.

Table 2 - Basic material properties of studied plasters

Material	Bulk density (kg/m^3)	Matrix density (kg/m^3)	Total open porosity (%)
PL1	1 621	2 643	45.1
PL2	1 110	2 495	56.1
PL3	1 145	2 480	53.6

Mechanical properties of the studied plasters were analyzed by the measurement of the compressive and flexural strength. The obtained results are given in Table 3. Considering the values of the total open porosity, the correlation between basic physical properties and strength can be find. PL1 and PL3 plasters exhibited better mechanical performance compared to the PL2. Notwithstanding, the achieved values were still satisfactory and comparable with the plasters investigated by other researchers.

Table 3 Mechanical properties of studied plasters

Material	Compressive strength (MPa)	Flexural strength (MPa)
PL1	5.98	2.84
PL2	4.65	1.91
PL3	6.36	2.43

Moisture transport properties are showed in Table 4. Here, the information on the ability of a material to transport liquid water by determination of water absorption coefficient factor is accessed. The water vapor transport properties are described by the water vapor diffusion resistance factor. The transport parameters of liquid water exhibited significant differences, the water absorption coefficient of both renovation plasters (PL2, PL3) was substantially reduces compared to the PL1 core plaster. The water vapor diffusion resistance factor was almost the same for all plasters, despite of the producer's statement of the enhanced diffusion properties of renovation plasters.

Table 4 - Hygric properties of studied plasters

Material	Water absorption coefficient ($kg/m^2s^{1/2}$)	Water vapor diffusion resistance factor (-)
PL1	0.1203	9.94
PL2	0.0366	8.23
PL3	0.0257	8.84

Moisture storage parameters of studied plasters were accessed by the measurement of sorption and desorption isotherms (Figure 2).

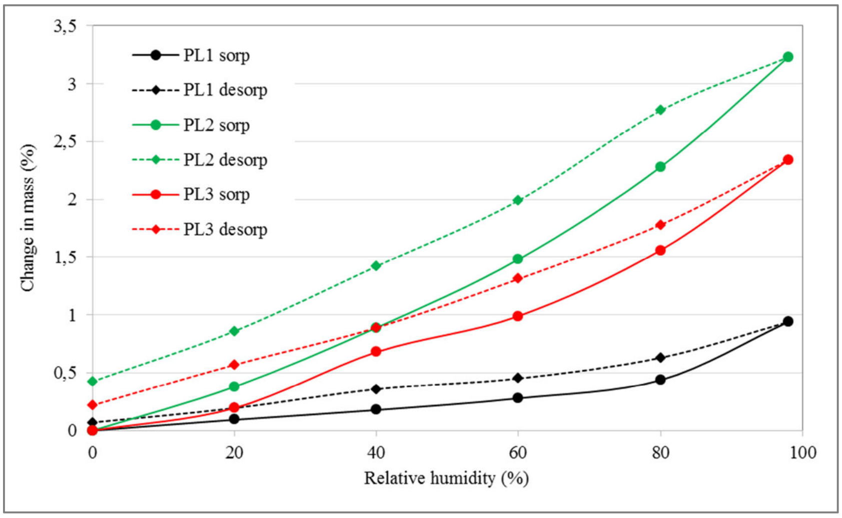

Fig. 2 - Sorption and desorption isotherms

The highest moisture storage capacity was achieved by the renovation plaster PL2, for PL3 it was somewhat lower, and the lowest capacity showed the core plaster PL1, which agreed with the designation of the particular plasters. The explanation lays probably in the characteristics of the pore system. According to the findings of Abadie and Mendoca (2009) it is possible find correlation between pore size distribution and moisture storage parameters. In general, materials with the lower pore diameter provide significantly higher moisture storage capability in comparison with materials formed by larger pores.

The results of moisture monitoring are presented in Figure 3, where a comparison of moisture content in tested columns is showed. The data point at a different effectivity of the applied plasters for moisture evaporation. Here, an overall better capability to remove excessive moisture content from masonry was found for PL2 restoration plaster, as compared to the other two applied plasters. PL3 renovation plaster, despite of the similar material properties did not provide a better ability for moisture removal than the ordinary core PL1 plaster. After 60 days of continuous monitoring of moisture content by TDR probes calibrated by periodical gravimetrical measurement, the moisture content was decreased by about 0.02 kg/kg for PL2. Other two applied plasters induced a moisture decrease of only about 0.005 kg/kg.

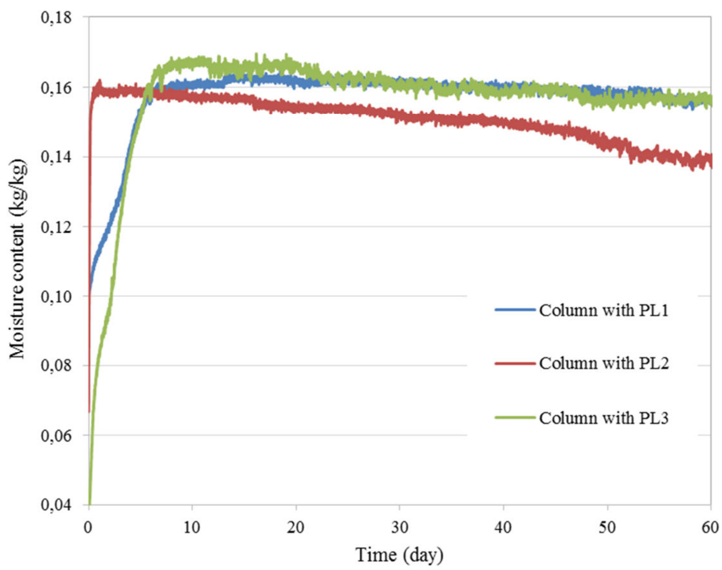

Fig. 3 - Development of moisture content in studied brick columns

In the light of results from the performed measurement it is possible to distinguish a good correlation between the laboratory obtained material properties and the effectivity in the field measurements of masonry moisture removal. The elucidation of the overall better effectivity of PL2 plaster for masonry moisture removal can be assigned to the lower water vapor diffusion resistance factor and higher moisture storage capacity of PL2, as compared to the other two plasters.

CONCLUSIONS

The presented study revealed a different behavior of analyzed plasters in the relation to the excessive moisture content in masonry columns. Therefore, a detailed understanding of used materials constitutes the basic prerequisite for a successful application of protective and remediation measures in damped constructions. The employed TDR measurement technique was proved as an efficient technology for the continuous monitoring of moisture content development. The performed moisture removal experiment carried out pointed at a different effectivity of the applied plasters on the brick columns. The best capability in that respect was achieved by the PL2 renovation plaster. The apparent reason was the lower water vapor diffusion resistance factor and higher moisture storage capacity of PL2, as compared to the other two plasters.

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REFERENCES

[1] Fassina V, Favaro M, Naccari A, Pígo M, Evaluation of compatibility and durability of a hydraulic lime-based plaster applied in brick wall masonry of historical buildings affected by rising damp phenomena. J. Cult. Herit., 2002, 3, pp. 45-51.

[2] Franzoni E, Rising damp removal from historical masonries: A still open challenge. Contr. Build. Mater., 2014, 54, pp. 123-136.

[3] Torres MIM, de Freitas VP, Treatment of rising damp in historical buildings: wall base ventilation. Build Environ., 2007, 42, pp. 424-35.

[4] Ahmad AG, Rahman HFA. Treatment of salt attack and rising damp in heritage building in Penang, Malaysia. J. Constr. Dev. Countries, 2010, 15(1), pp. 93-113.

[5] Pavlíková M, Pavlík Z, Keppert M, Černý R. Salt transport and storage parameters of renovation plasters and their possible effects on restored buildings walls. Constr. Build. Mater., 2011, 25, pp. 1205-1212.

[6] Lubelli B, van Hees RPJ, Groot CWP. Sodium chloride crystallization in a salt transporting restoration plaster. Cem. Concr. Res., 2006, 36, pp. 1467-1474.

[7] Pavlík Z, Mihulka J, Fiala L, Černý R. Application of Time-Domain reflectometry for measurement of moisture profiles in a drying experiment. Int. J. Thermophys., 2012, 33, pp. 1661-1673.

[8] Bertolini L, Coppola L, Gastaldi M, Redaelli E. Electroosmotic transport in porous construction materials and dehumidification of masonry. Contr. Build. Mater., 2009, 23, pp. 254-263.

[9] Hughes JJ. The role of mortar in masonry: an introduction to requirements for the design of repair mortars. Mater. Struct., 2012, 45, pp. 1287-1294.

[10] D´Agostino D. Moisture dynamics in a historical masonry structure: the cathedral of Lecce (South Italy). Build. Environ., 2013, 63, pp. 122-133.

[11] Derluyn H, Janssen H, Carmeliet J. Influence of the nature of interfaces on the capillary transport in layered materials. Contr. Build. Mater., 2011, 25, pp. 685-693.

[12] Healy WM. Moisture sensor technology: a summary of techniques for measuring moisture levels in building envelopes. ASHRAE Trans. Res., 2003, 109(1), pp. 232-242.

[13] Rirsch E, Zhang Z. Rising damp in masonry walls and the importance of mortar properties. Constr. Build. Mater., 2010, 24, pp. 1815-1820.

[14] Terheiden K, Simultaneous measurement of vapor and liquid moisture transport in porous building materials. Build. Environ., 2008, 43, pp. 2188-2192.

[15] Abadie MO, Mendoca KC, Moisture performance of building materials: from material characterization to building simulation using the moisture buffer value concept. Build. Environ., 2009, 44(2), pp. 388-401.

[16] Fořt J, Pavlík Z, Žumár J, Pavlíková M, Černý R. Effect of temperature on water vapor transport properties. J. Build. Phys., 2014, 38(2), pp. 156-169.

[17] Roels S, Adan O, Brocken H, Černý R, Pavlík Z, Ellis A. A comparison of different techniques to quantify moisture content profiles in porous building materials. J. Therm. Enve. Build. Sci., 2004, 25, pp. 1205-1212.