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WATER VAPOR TRANSPORT IN PLASTERS CONTAINING SUPERABSORBENT POLYMERS

JAN FOŘT, MARTIN MILDNER, PETR HOTĚK, and ROBERT ČERNÝ

Dept of Materials Engineering and Chemistry, Faculty of Civil Engineering at Czech Technical University, Prague, Czech Republic

A proper characterization of material properties represents an important step towards an efficient building design. Considering the present issues in the construction sector, moisture loads pose a risk not only to increased material deterioration but also to the health of building inhabitants. In this paper, modified plaster mixtures with superabsorbent admixture are designed in order to improve passive moderation of finishing layers against varying humidity conditions. The relationship between the amount of applied superabsorbent admixture and resulting water vapor transport properties is identified and the influence of temperature on water vapor transport is analyzed. The steady-state cup method is used for the determination of water vapor transport properties, namely the water vapor diffusion permeability, water vapor diffusion coefficient and water vapor diffusion resistance factor. The obtained data show temperature as a very significant factor affecting water vapor transport in the analyzed plasters. Considering the dry-cup method arrangement, relative humidity probes should be used for monitoring relative humidity under the sealed sample for a sufficiently precise determination of water vapor pressure gradient.

Keywords: Water vapor diffusion, Relative humidity, Temperature, Interior plaster.

1 INTRODUCTION

Since the moisture transport properties have been recognized as an important factor influencing the building materials durability, a significant attention was aimed at their characterization and precise determination (Maia *et al*. 2018). Besides the material durability issues, the adverse effect of moisture presence in building materials is associated with a simultaneous effect on the energy consumption due to high moisture conductivity of water (about 25-times higher compared to dry air) which reduces the thermal insulation capability of applied materials (Jerman and Cerny 2012). Moreover, the described dependence between the moisture transport properties and thermal conductivity is further driven by temperature variations (Fort *et al*. 2014).

Due to the increased airtightness of modern building envelopes, new challenges associated with the moderation of interior humidity arise (Randazzo *et al*. 2016). Besides the reduced thermal energy performance of building envelopes, the effect of relative humidity is often underestimated despite its significant importance for maintenance of indoor air quality. On this account, the increased hygroscopicity of interior finishing materials became more important to access novel functionalities of applied materials (Xu *et al*. 2018). Besides the unfavorable impact of increased or too low indoor relative humidity on occupants‘ comfort and health, another issues accompanied with adverse effect on materials durability or energy consumption can be identified. To mitigate the negative effect connected with undesirable levels of indoor relative humidity in case of modern passive houses, several studies aimed at passive adjusting of the humidity variations have been published (Fenoglio *et al*. 2018, Winkler *et al*. 2018, Zhang *et al*. 2017). Mostly, various lightweight materials such as charcoal, diatomite, fly ash, perlite and vermiculite have been utilized to increase the open surface area to modify porous structure of plasters but only with a partial success (Pavlik *et al*. 2016).

In the light of previously described findings, the application of innovative materials such as superabsorbent polymers (SAP) have been found as beneficial considering the water absorption capability (Goncalves *et al*. 2014). On this account, SAPs have been subjected a detailed study to prevent self-desiccation, improve mechanical properties and promote hydration of cement mixtures (Song *et al*. 2016). However, superior water absorption capability can also be utilized for passive humidity moderation of building interiors by their use in finishing plasters. Despite the promising benefits pertaining the utilization of SAPs in plasters, this area was studied only rarely, and available results are missing or struggle with issues such as material segregation, clumping, etc.

Within this study, the effect of incorporated SAPs in cement-lime plasters on water vapor transport properties is determined by using a modified cup method. The relationship between the amount of applied superabsorbent admixture and resulting water vapor transport properties is distinguished and the importance of the temperature is highlighted.

2 MATERIALS AND METHODS

2.1 Studied Materials

In this experimental research, the reference samples were based on the commercial cement-lime plaster Weber MV1 in which superabsorbent polymers were incorporated to enhance materials functional properties by increasing moisture transport and storage.

SAP CABLOCK (Evonic, Germany) with spherical shape having d_{50} diameter of about 260 μm was used for modification of reference plaster by 0.5; 1; and 1.5 wt.%. Due to the adverse effect of incorporated SAP particles on the batch water consumption, water dosage had to be substantially adjusted to obtain the same workability of modified plasters, as it was determined for reference one by using the flow table test procedure. The detailed information about designed plasters are given in Table 1.

Table 1. Composition of studied plasters with SAP admixture.

Mixture	**Dry plaster mixture (kg)**	**Water dosage (kg)**	**SAP (g)**
REF	1	0.16	-
0.5SA	1	0.192	5
1SA	1	0.245	10
1.5SA	1	0.295	15

2.2 Experimental Methods

The samples were dried firstly and then subjected to experimental analysis. Basic material properties such as the bulk density, matrix density, and total open porosity were determined. The bulk density was calculated on the gravimetric principle by estimation of samples volume and weighing the dry mass. The matrix density was measured using a helium pycnometry device

Pycnomatic ATC (Thermo Scientific) having the accuracy of analytical balances of about ±0.0001 g and the accuracy of gas volume measurement of about ±0.01% from measured value.

A modified cup method was used under isothermal conditions at 10, 20, 30, and 40 °C. This method is based on 1-D water vapor diffusion through the laterally sealed sample while the diffusion water vapor flux is measured. Simultaneously the partial water vapor pressure under and above the sample surface is evaluated. The laterally insulated plaster samples by epoxy resin were sealed into metal cup filled by silica gel which ensures a low relative humidity under the sample. For a precise determination of the relative humidity and thus water vapor pressure, the relative humidity/temperature mini-sensor (Ahlborn FHAD46C2) was placed under the sample for continuous recording using a datalogger (Ahlborn 2470-2SKN). The sealed cup with sample was placed into a climate chamber (maintaining particular temperatures and 50 %RH) and periodically weighted to obtain steady-state values of mass gain. When the measurement for one temperature was completed, the samples were removed, dried, and used again for another temperature.

The water vapor diffusion permeability was calculated by continuous monitoring of the mass gain based on the Eq. (1):

$$\delta = \frac{\Delta m \cdot d}{S \cdot \tau \cdot \Delta p_p} \tag{1}$$

where Δm is amount of water vapor diffused through the sample, d (m) the sample thickness, S (m^2) the specimen surface, τ (s) the period of time relevant to the transport of mass of water vapor, and Δp_p (Pa) is the difference between partial water vapor pressure in the air under and above sample surface.

The coefficient of water vapor diffusion D was accessed according to the Eq. (2):

$$D = \frac{\delta \cdot R \cdot T}{M} \tag{2}$$

where T (K) is the temperature, R (8.314 J/K/mol) the universal gas constant, M (18.02 g/mol) is the molar mass of water.

Consequently, the water vapor diffusion resistance factor μ (-) was calculated in order to provide a better clarity and comparability for the building practice. This often-used indicator for benchmarking of building materials is defined as in Eq. (3):

$$\mu = \frac{D_a}{D} \tag{3}$$

where D_a (m^2/s) is water vapor diffusion coefficient in air.

3 RESULTS AND DISCUSSION

The obtained basic physical properties of designed plasters with SAP admixture, which were determined on prismatic samples having dimensions of about 40 x 40 x 160 mm, are given and compared in Table 2. As one can see, the total open porosity was gradually increased from 38.2 % (reference plaster) to almost 50 % (1.5SA). The observed change in the pore volume was induced by a significantly higher water consumption during mixture preparation due to immense absorption capacity of the applied SAP admixture. This fact can be clearly seen from the bulk density, which decreased considerably (a drop of about 20 % was noted). Despite of the low density of SAP, the matrix density was influenced only in a minor extent, accordingly to low applied SAP dosages.

Table 2. Basic physical properties of studied plasters.

Mixture	Bulk density (kg/m^3)	Matrix density (kg/m^3)	Total open porosity (%)
REF	1597	2574	38.2
0.5SA	1482	2557	42.0
1SA	1420	2541	44.1
1.5SA	1284	2550	49.6

The water vapor transport properties were substantially influenced by both changes in the material microstructure and tremendous water absorption capability of used SAPs. The water vapor diffusion properties obtained at reference 20 °C by the modified cup method are shown in Table 3, while summarized results comparing the water vapor diffusion resistance factor at all applied temperatures (i.e., 10, 20, 30 and 40 °C) are plotted in Figure 1.

Table 3. Water vapor diffusion properties of studied plaster at 20 °C.

Mixture	δ (s)	D (m^2/s^1)	μ (-)
REF	2.62E-11	3.55E-06	7.05
0.5SA	3.46E-09	4.68E-06	5.28
1SA	4.59E-09	6.21E-06	3.98
1.5SA	5.27E-09	7.46E-06	2.83

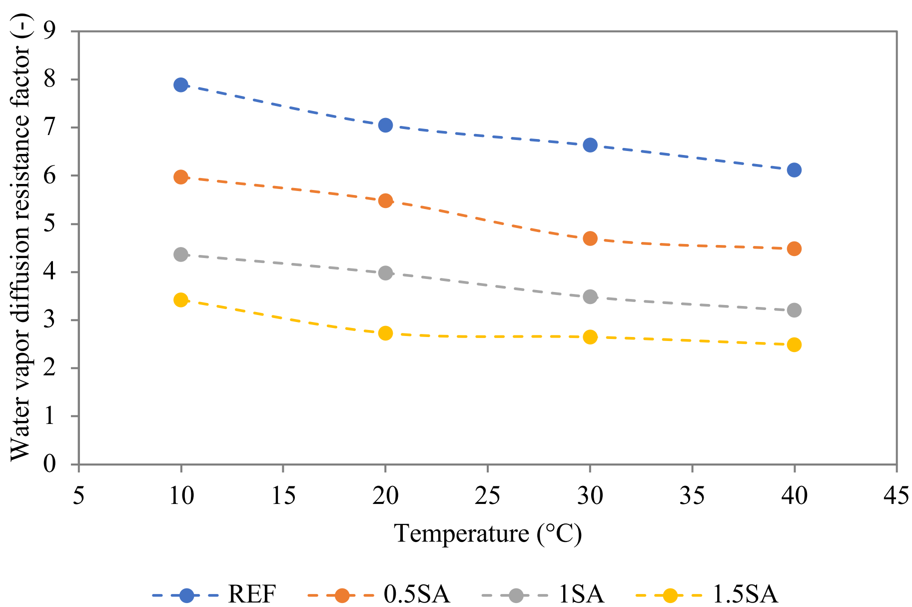

Figure 1. Temperature dependent water vapor diffusion resistance factor of studied plasters.

Considering the effect of applied SAPs in cement-lime plasters, the water vapor diffusion properties were significantly modified. The water vapor diffusion resistance factor at 20 °C substantially dropped from initial 7.05 (REF) to 2.83 (1.5SA). The reduction of the material resistance to water vapor diffusion can be explained by the formation of large voids in material microstructure. If the temperature effect was taken into account, a clear dependence was possible to be distinguished. While the temperature drop to 10 °C caused an increase of water vapor diffusion resistance factor by about 10 %, the rise up to 40 °C resulted in its significant decrease. Apparently, the increased temperature increased the kinetic energy of water vapor molecules and consequently promoted water vapor diffusion through the specimens.

4 CONCLUSIONS

The incorporation of superabsorbent polymers into cementitious building materials struggles with several issues including the aggravated workability of the fresh mixture, increased water consumption, segregation of applied SAP particles or reduced mechanical properties (Goncalves *et al*. 2014). On the other hand, several benefits can be achieved thanks to increased water retention capacity. In this paper, experimental analysis of cement-lime plasters modified by using 0.5, 1, and 1.5 wt.% of SAP confirmed the above-mentioned problems, but on the other hand substantial material modification was achieved. The tendency for worsening common functional properties, namely the total open porosity which is strongly correlated with the mechanical performance, was revealed. This fact limits the amount of applied dosages, especially due to a high swelling capacity of SAPs. Nevertheless, the utilized SAPs caused a significant decrease in the water vapor diffusion resistance and the material thus exhibited favorable properties for moderation of interior humidity. A strong dependence of water vapor diffusion properties on the applied temperature was revealed, when in line with the temperature increase the water vapor diffusion resistance factor was substantially reduced. The presented results can be easily utilized in the consequent development of novel humidity-responsive plasters which allow a passive moderation of the ambient climate. Considering the dry-cup method arrangement, relative humidity probes should be used for monitoring of relative humidity under the sealed sample for a precise determination of water vapor pressure gradient and refinement of calculated values. A significant measurement error can arise if inaccurately estimated relative humidity under the sample is used for the calculation of water vapor diffusion properties.

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