AN ANALYSIS OF WATER-REPELLENT PROPERTIES OF SELECTED COATING MATERIALS ON THE SURFACE OF EXTERNAL LININGS

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ABSTRACT

A simple method for evaluating the water-proofness quality of coating materials on external linings is proposed. The method is based on measuring the integral capillarity in dependence on time and on comparing its value to that determined for the basic lining material. Measurements of water vapor diffusion provide then complementary information on the coating quality. The practical application of the method is performed with four types of lining materials, Dekalux 5, Dekalux 12, Dekalit P6, Dekalit P10, and three types of the surface treatment, Rudicolor, Aquafob and Rudicolor-Aquafob combination. Measuring results show that Aquafob is an effective water-repellent coating material which keeps at the same time high permeability for water vapor, Rudicolor is only effective for short times (~ 1 hour). The positive influence of Aquafob was observed to be increasing with the decreasing volume mass of the underlying lining material which corresponds to its hydrophobic quality, while the plaster material Rudicolor exhibited an opposite trend concerning the volume mass.

1 INTRODUCTION

One of the physical quantities characterizing the behavior of capillary-porous materials in contact with water is the height of capillary rise, i.e., the maximum height h_{max} of the water column in the material above the main water level. However, the measurements of h_{max} are very lengthy and, in the main, inaccurate [1].

As a more suitable quantity for evaluating the water-proofness quality can be considered the capillarity C defined by the relation

$$C = \frac{1}{S}\frac{dm}{dt}, \qquad (1)$$

where S is the surface of the specimen which is in contact with water, m is the mass of the moistened specimen, t is the time. As a matter of fact, the capillarity defined by (1) is identical with the water flux in the material.

The value of C is an instantaneous quantity which does not provide any information on the history of the moistening process. Therefore, it appears reasonable to define the integral capillarity C_{int} (see, e.g., [2])

$$C_{int}(t) = \int_0^t C(\tau)\,\mathrm{d}\tau = \frac{m(t) - m_\mathrm{d}}{S}, \tag{2}$$

where m is the mass of the moist specimen, m_d is the mass of the dried specimen.

The integral capillarity is capable to express not only the absolute amount of water in the specimen but also the time history of the moistening process which is particularly useful in comparing the effectiveness of various coatings on a specified substrate. Therefore, we employ the $C_{int}(\tau)$ function as the main parameter in evaluating the water-proofness quality of coating materials throughout this paper.

Measuring the water vapor diffusion properties of coating-substrate systems can provide useful complementary information on the water-repellent coatings. The coatings applied on external linings should protect the underlying layers from water penetration but on the other hand, they should not oppose water transport from the interior to the exterior to avoid formation of condensing zones in the walls.

Therefore, the effective diffusion coefficient of the coating-substrate system is the second important parameter to evaluate the quality of the coating materials in this paper.

2 EXPERIMENTAL WORK

2.1 INTEGRAL CAPILLARITY

In analysing the water-repellent properties of the coating-lining systems, we studied four lining materials, Dekalux 5, Dekalux 12, Dekalit P6, Dekalit P10, and three types of the surface treatment, Rudicolor, Aquafob and Rudicolor-Aquafob combination (Rudicolor on the face, Aquafob on the back). The

experiments were also performed with the lining materials without any surface treatment in order to evaluate the effect of the coatings in a direct comparison with the basic material.
Dekalux is an environmental friendly fibre-cement board material designated for heat-insulating external linings, internal-wall- and lower-ceiling linings, and wood and steel-structure facings. Dekalux is produced by EZA Šumperk, Czech Republic, and contains cement, organic and inorganic fibre and silicate-based additives. The volume mass of the material is 1860 kgm^{-3} for the material boards 5 mm thick (Dekalux 5) and 1630 kgm^{-3} for the 12 mm boards (Dekalux 12).

Dekalit P is another fibre-cement material of the same producer. The difference between Dekalux and Dekalit P consists in the technology of production and in the ratio between the components. Dekalit P contains less organic substances, has a lower volume mass (830 kgm^{-3} for 6 mm boards - Dekalit P6, and 870 kgm^{-3} for 10 mm boards - Dekalit P10), and its application is directed primarily to increase the fire-protection properties of building structures in the form of internal linings.

Both Dekalux and Dekalit P are designated as replacement materials for asbestoscement based products, containing the cellulose fibre instead of asbestoscement. The main difference between these two materials consists in the content of cement. Therefore, the volume mass of Dekalux with a higher content of cement is higher and its use is mainly for external linings, the lighter Dekalit P is more proper for internal linings. The reason why we always distinguish two types of Dekalux and Dekalit P lies in the differences of the production process particularly in the extent of compacting the surface layers, which result in variations of structure and of the volume mass; generally the thinner boards should be heavier than thicker ones.

The first type of coating, Rudicolor (Teramo Vápenná, Czech Republic), is a thin-layered plaster material on the basis of water dispersion of macromolecular substances, fine-grained filler, pigment, surface active substances and dispersing agent.

The second coating material, Aquafob (Stomix, Czech Republic), is hydrophobic and was developed on the basis of combination of water copolymer dispersion of macromolecular substances with hydrophobic additives, biocide- and surface active substances, fillers and pigments.

The basic lining materials were delivered by the producer in the form of 300x300 mm boards. The lateral area of all specimens was water- and vaporproof insulated by the epoxy resin, and the specimens were placed by their face side into the vessel with water on a soft sponge, so that the upper side of the sponge was just on the water level.

The mass of the specimens absorbing water was then determined at the specified time levels, the experiment was stopped after the period of five days. During the experiment, the level of water in the vessel was kept constant. Finally, the dependence of integral capillarity on time was determined using Eq. (2).

In the building practice, the most frequently used quantity describing the water content in materials is the relative moisture content u,

$$\frac{\mathrm{P}w}{\mathrm{P}w - w} = n \tag{3}$$

where the notation is the same as in Eq. (2).

Comparing Eqs. (2) and (3), we can formulate the relation between the integral capillarity C_{int} and the mean relative moisture content u_m in the specimen in the form

$$u_{\mathrm{m}} = \frac{C_{\mathrm{int}}}{\rho_{\mathrm{d}} \cdot d}, \tag{4}$$

where ρ_d is the volume mass of the dried material, d is the thickness of the material board. Using the $C_{int}(t)$ curves and Eq. (4), we can determine the maximum water absorptivity u_{max} of the material for every particular surface treatment,

$$u_{\mathrm{max}} = \frac{C_{\mathrm{int,max}}}{\rho_{\mathrm{d}} \cdot d}, \tag{5}$$

where $C_{int,max}$ is the maximum integral capillarity determined in the end of the experiment.

2.2 DIFFUSION OF WATER VAPOR

Diffusion properties of the coating-lining systems were studied with the same lining and coating materials as in the previous Subsection. The material specimens were prepared in the same way as for the measurements of integral capillarity, only their dimensions were different, the specimens were cylindrical with the diameter of 90 mm.

In modeling the water vapor diffusion in porous materials, two main phenomenological relations for the flux of water vapor j are used,

$$j = -D\,\mathrm{grad}\rho_c, \tag{6}$$

$$j = -\delta\,\mathrm{grad}p_v, \tag{7}$$

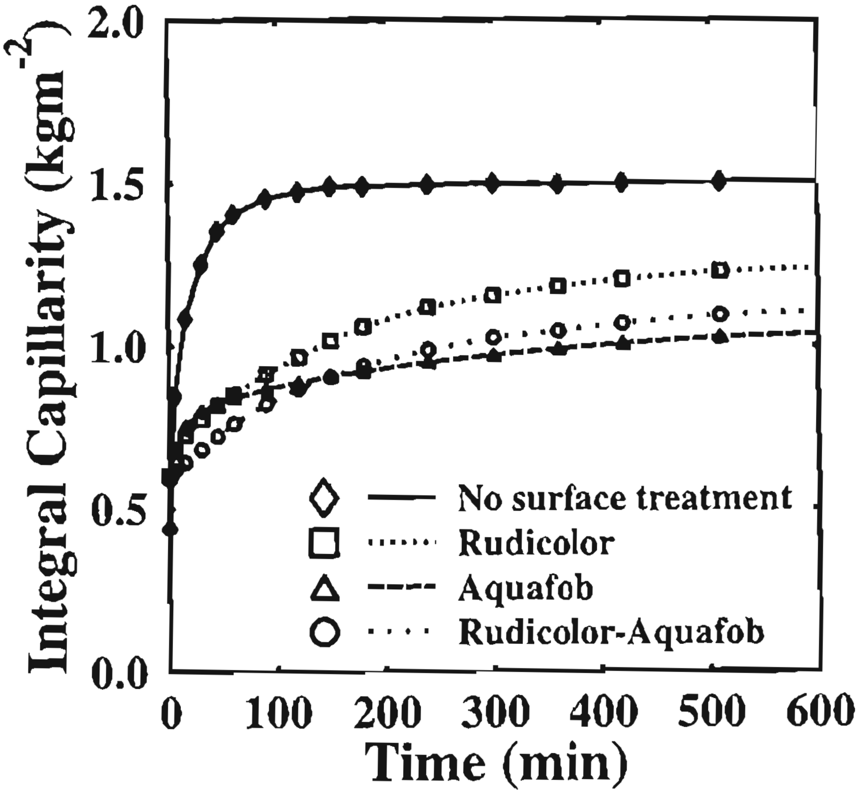
where ρ_c is the mass of water vapor per unit volume of the porous material, D is the diffusion coefficient of water vapor in the porous material, p_v is the partial pressure of water vapor, δ is the water vapor permeability.
Besides D and δ, several other coefficients are introduced in building physics for the sake of better clarity for the building practice. Among them, the vapor diffusion resistance number μ (e.g., [3]), the water vapor resistance Z (e.g., [4]) or the equivalent air layer thickness S_D (e.g., [5]) belong to the most frequently used.

In measuring the diffusion of water vapor in the coating-lining systems, as a matter of fact, we do not determine the exact diffusion material parameters, but only their effective values for the two-layer system. However, knowing the diffusion parameters of the basic lining materials and the thickness of the coating, we can calculate the diffusion parameters of the coating materials using the water-vapor resistance Z, since in an analogous way as with the electric resistances, the watervapor resistance of a series of elements equals to the sum of the resistances of the particular elements.

For measuring the diffusion coefficient of water vapor D we have chosen a steadystate method, commonly used for experimental work on other materials. The measuring apparatus consists of two airtight glass chambers separated by the sample of the measured material, which is typically board-type. In the first chamber, a state near to 100% relative humidity is kept (achieved with the help of a cup of water), while in the second one a state close to 0% relative humidity (set up using some absorption material, such as silica gel).

After certain time, measurement is interrupted, and the changes in the mass of water in the cup, Δm_w, and of the silica gel, Δm_a, during the chosen time interval [0,τ] are determined. If $|\Delta m_w| = |\Delta m_a|$, i.e., if the steady state is established within the measuring system, the experiment is terminated. Otherwise, the measurement continues in the same way as before. The experiment is carried out under isothermal conditions.

FIG. 1
Dependence of integral capillarity on time for Dekalux 5.



3 RESULTS AND DISCUSSION

The results of integral-capillarity measurements show that the influence of Rudicolor on the water-proofness of the system was qualitatively very similar for all the lining materials we studied. The Rudicolor layer was effective only for short-time water influence, typically 1 hour. This is illustrated in Figs. 1, 2 for Dekalux 5 and Dekalit P10. The integral capillarities $C_{rel} = (C_{int}/C_{max}) \cdot 100$ [%] achieve 30-50% after 1.5 hours and after 8.5 hours already 80-90%.

The absolute values of water absorptivities are summarized in Table 1, and logically, they increase with decreasing volume mass of the material.

TABLE 1
Water absorptivities of selected lining materials and the effect of aquafob on the maximum integral capillarity

material	ρ_d [kg m^{-3}]	u_{max} [%]	$\frac{C_{A,max}}{C_{max}} \cdot 100$ [%]
Dekalux 5	1860	14,5	84
Dekalux 12	1630	22	70
Dekalit P 10	870	60	59
Dekalit P 6	830	65	51

FIG.2
Dependence of integral capillarity on time for Dekalit P10

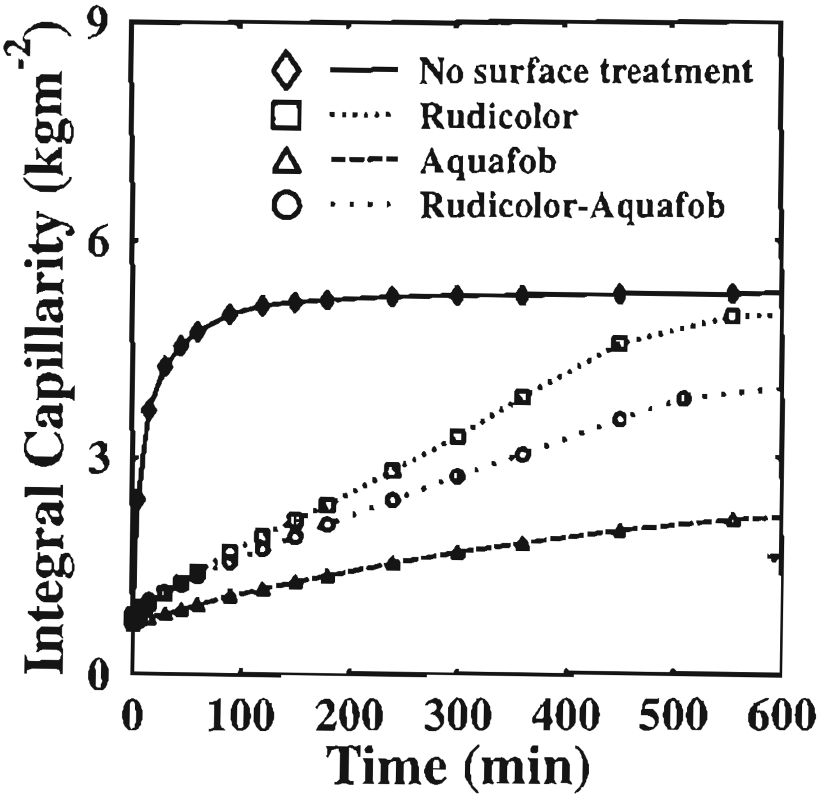


TABLE 2
Effective diffusion parameters of selected coating-Dekalux 5 systems

Coating	d (m)	D (m^{2}s^{-1})	δ (s)	μ (-)	Z (ms^{-1})	S_D (m)
none	$5.50 \cdot 10^{-3}$	$1.88 \cdot 10^{-7}$	$1.37 \cdot 10^{-12}$	122	$4.01 \cdot 10^{9}$	0.68
Rudicolor	$5.75 \cdot 10^{-3}$	$1.48 \cdot 10^{-7}$	$1.08 \cdot 10^{-12}$	154	$5.32 \cdot 10^{9}$	0.88
Aquafob	$5.04 \cdot 10^{-3}$	$1.34 \cdot 10^{-7}$	$0.98 \cdot 10^{-12}$	171	$5.14 \cdot 10^{9}$	0.86
Rud.-Aq.	$5.53 \cdot 10^{-3}$	$1.43 \cdot 10^{-7}$	$1.04 \cdot 10^{-12}$	160	$5.31 \cdot 10^{9}$	0.89

The quantitative effect of the Rudicolor coating on the studied lining materials differed significantly. We have observed that this effect increases with the increasing volume mass of the lining, which is more pronounced for longer times.

The possible explanation lies in the fact that the adhesive properties of the plaster to the materials with higher porosity (Dekalit P, for instance) are better since the plaster penetrates easier into the porous structure. Consequently, the moisture transfer coefficient is higher and the moisture content reaches relatively high values already after a short time - 90% of the maximum moisture content, u_{max}, in 8-10 hours for Dekalit P6. On the other hand, the heavier materials such as Dekalux 5 reach comparable values after more than 48 hours. It should be noted, however, that after several days both Dekalux and Dekalit P achieved 100% u_{max} despite the presence of Rudicolor coating.

The hydrophobic coating material Aquafob exhibited water-proofness much better than Rudicolor - the moisture maxima after 4.5 days were in the range of 50% to 80% u_{max}. However, the effectiveness of Aquafob increased with the decreasing volume mass of the basic material as demonstrated in Table 1, where $C_{A,max}$ is the maximum integral capillarity of the specimens with the Aquafob coating and C_{max} is the maximum integral capillarity of the basic lining materials.

The probable reason of this fact was that also here the coating penetrated deeper into the material with lower volume mass but due to its water-repellent properties the larger contact area acted in an opposite way than in the case of the plaster material Rudicolor.

The Aquafob coating on the back side of the specimen in the Rudicolor-Aquafob combination was observed not to have any additional water-proofness effect compared to the specimens with Rudicolor only.

The measurements of effective diffusion parameters of the analyzed coating-lining systems have shown, that the compacting of surface layers of the thinner boards, which already has exhibited its influence on the integral capillarity, affected significantly also the diffusion parameters. This is demonstrated in Tables 2, 3 where the reader can observe that the diffusion coefficient of Dekalux 5 is more than two times lower than that of Dekalux 12.

TABLE 3
Effective diffusion parameters of selected coating-Dekalux 12 systems

Coating	d (m)	D (m^2s^{-1})	δ (s)	μ (-)	Z (ms^{-1})	S_D (m)
none	$12.05 \cdot 10^{-3}$	$4.05 \cdot 10^{-7}$	$2.93 \cdot 10^{-12}$	57.2	$4.11 \cdot 10^{9}$	0.69
Rudicolor	$13.40 \cdot 10^{-3}$	$3.80 \cdot 10^{-7}$	$2.76 \cdot 10^{-12}$	60.4	$4.86 \cdot 10^{9}$	0.81
Aquafob	$12.54 \cdot 10^{-3}$	$3.87 \cdot 10^{-7}$	$2.82 \cdot 10^{-12}$	59.3	$4.45 \cdot 10^{9}$	0.74
Rud.-Aq.	$12.20 \cdot 10^{-3}$	$3.70 \cdot 10^{-7}$	$2.71 \cdot 10^{-12}$	61.7	$4.50 \cdot 10^{9}$	0.75

TABLE 4
Diffusion parameters of selected coatings

Coating	d_c (mm)	δ_c (s)	D_c (m^2s^{-1})	j ($kgm^{-2}s^{-1}$)
Rudicolor	0.75	$2.41 \cdot 10^{-13}$	$3.31 \cdot 10^{-8}$	$9.59 \cdot 10^{-7}$
Aquafob	0.10	$8.23 \cdot 10^{-13}$	$1.13 \cdot 10^{-7}$	$2.46 \cdot 10^{-5}$

However, the influence of both Rudicolor and Aquafob on the diffusion properties was relatively small, 20-30% in average. This is a favorable feature from the point of view of the water balance of the external walls since the main flux of water vapor is usually in the direction from the interior to the exterior.

The approximate values of diffusion parameters of the coatings themselves which are presented in Table 4 illustrate their favorable diffusion properties directly, we can see that the diffusion coefficients of both Rudicolor and Aquafob are only several times lower than those of the studied lining materials.

4 CONCLUSIONS

We have studied the water-repellent properties of 12 selected coating-lining systems together with their diffusion properties to evaluate their influence on the water balance of the external walls.

The two main parameters applied in this evaluation, the time-dependent integral capillarity and the effective diffusion coefficient of water vapor have appeared as effective tools in this evaluation.

Among the coating-lining systems we studied, the systems with Aquafob were more effective than the remaining ones, no matter what type of lining was used. The practical application of Aquafob as a water-repellent coating can be recommended since besides the good hydrophobic quality it keeps a relatively high permeability for water vapor which is desirable for external surface of envelope parts of building structures.

On the other hand, the Rudicolor coating can be recommended for short-time water influence only, as for instance in regions with moderate rains, because its effectiveness as a water-repellent protection layer decreases relatively fast.

ACKNOWLEDGEMENT
This paper is based upon work supported by the Grant Agency of the Czech Republic, under grants # 103/94/0140 and 103/94/0595.

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