Desalination of historical masonry using hydrophilic mineral wool boards

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Abstract

In the desalination measures hydrophilic mineral wool can be considered as a possible alternative to the commonly used cellulose. Contrary to cellulose, it can be used repeatedly, and its effectiveness is higher because of the dominant mode of water transport along the hydrophilic fibers. In this paper, experimental investigation of desalination potential of several different types of hydrophilic mineral wools is performed. The obtained results show that high-density materials are the most effective for this type of application.
Keywords: desalination, hydrophilic mineral wool, water transport, salt solution transport.

1 Introduction

Avoiding water penetration into components of building structures is a fundamental principle for their maintenance. The most important mitigation method is prevention through the physical separation of building materials from soil moisture and salts with the traditional damp-proof course. This is typically an impermeable barrier such as plastic, glazed brick, bitumen. Using such protection measures in historical masonry is, however, mostly not feasible. Therefore, it is necessary to deal with consequences of salt penetration into the structural elements and use repeatedly desalination techniques.

In existing salt-laden structures salts can be removed through poulticing and in some cases the affected masonry may be replaced. However, in the past few decades the cost of such replacement has led to increasing use of chemical damp-proof courses in the form of injected siloxane.

Hydrophilic mineral wool seems to be a perspective material for desalination purposes. Hydrophilic admixtures in mineral wool accelerate liquid moisture

WIT Transactions on Modelling and Simulation, Vol 46, © 2007 WIT Press
www.witpress.com, ISSN 1743-355X (on-line)
doi:10.2495/CMEM070391

transport, and thus make new applications possible for mineral wool products. Apart from the interior thermal insulation where the usefulness of hydrophilic fiber treatment has already been proven in couple of cases, desalination or dehumidification of historical masonry can be considered as typical examples where one can take advantage of the superior water transport capability of this type of materials.

In this paper, basic material parameter data of several hydrophilic mineral wool materials are presented which can serve as input parameters for computational models of service life prediction analyses, namely the water vapour-, water- and salt solution transport parameters. Also, two typical experiments for demonstrating the dehumidification and desalination potential of hydrophilic mineral wool are described.

2 Experimental methods

2.1 Basic material parameters

As fundamental physical material characteristics, bulk density ρ_b [kgm^{-3}], vacuum saturation moisture content w_{sat} [kgm^{-3}], porosity [Vol.-%] and matrix density ρ_m [kgm^{-3}] were determined. They were obtained using the gravimetric method and the water vacuum saturation method. The vacuum saturation moisture content was calculated according to the equation

$$w_{sat} = \rho_w \frac{m_{sat} - m_0}{m_{sat} - m_a} = \rho_w \psi \,, \tag{1}$$

where ρ_w is the water density [kg m^{-3}], m_0, m_{sat} and m_a are the mass of dry sample, water- saturated sample and mass of the immersed water - saturated sample [kg], respectively, and ψ is the open porosity, which is defined as the ratio of the volume of open pores in material to its total volume. Matrix density was calculated as

$$\rho_{mat} = \frac{m_0}{V(1-\psi)}, \tag{2}$$

where V is sample volume [m^3].

The measurement of basic parameters took place in a conditioned laboratory at the temperature of 22±1 ˚C and 25-30% relative humidity. Each result represents the average value from four to five measured values.

2.2 Water vapour-, water- and salt solution transport parameters

Two versions of the common cup method were employed in the measurements of the water vapor diffusion coefficient [1]. In the first one the sealed cup containing silica gel (5% relative humidity) was placed in a controlled climatic

chamber with 97% relative humidity and weighed periodically. In the second one the cup containing the saturated solution of K_2SO_4 (97% relative humidity) was placed in 25% relative humidity environment. The measurements were done at 20°C in a period of one week. The steady state values of mass gain or loss were determined by linear regression for the last three readings.

The water vapor diffusion coefficient D [m^2s^{-1}] was calculated from the measured data according to the equation

$$D = \frac{\Delta m \cdot d \cdot R \cdot T}{S \cdot \tau \cdot M \cdot \Delta p_p}, \tag{3}$$

where Δm the amount of water vapor diffused through the sample [kg], d the sample thickness [m], S the specimen surface [m^2], τ the period of time corresponding to the transport of mass of water vapor Δm [s], Δp_p the difference between partial water vapor pressure in the air under and above specific specimen surface [Pa], R the universal gas constant, M the molar mass of water, T the absolute temperature [K].

On the basis of the diffusion coefficient D, the water vapor diffusion resistance factor μ was determined,

$$\mu = \frac{D_a}{D}, \tag{4}$$

where D_a is the diffusion coefficient of water vapor in the air.

The water and salt solution sorptivity was measured using a standard experimental setup. The specimen was water and vapor-proof insulated on four lateral sides and the face side was immersed 1-2 mm in the water or salt solution. The automatic balance allowed recording the increase of mass. The water absorption coefficient A [$kgm^{-2}s^{-1/2}$] was then calculated using the formula

$$i = A \cdot \sqrt{t}, \tag{5}$$

where i is the cumulative water or salt solution absorption [kg/m^2], t is the time from the beginning of the suction experiment. The water or salt solution absorption coefficient was then employed for the calculation of the apparent moisture diffusivity in the form [2]

$$\kappa_{app} \approx \left(\frac{A}{w_c - w_0} \right)^2, \tag{6}$$

where w_c is the saturated moisture content [kgm^{-3}] and w_0 the initial moisture content [kgm^{-3}].

In the experimental work, the following samples for each material and fiber orientation were used: water vapor diffusion coefficient – 9 cylinders with the diameter 105 mm and thickness 20 mm, water sorptivity - 5 specimens 50 x 50 x 25-50 mm according the thickness of the layer cut from the insulation board.

2.3 Drying experiment

Water transport from porous building material saturated with water through different kinds of hydrophilic mineral wool materials was investigated. In the experiments brick, sandstone or autoclaved aerated concrete (AAC) samples with dimensions 60x60x30(65) mm were water and water vapour proof insulated with epoxy resin on four lateral and one frontal sides (one side remained uninsulated), and these samples were immersed into water until they were entirely saturated with water. Then dried samples of hydrophilic mineral wool were prepared and insulated with silicon rubber on four lateral sides. Next step was connecting the brick, sandstone or AAC samples and hydrophilic mineral wool samples uninsulated sides together in order not to prevent evaporation from one uninsulated side of the mineral wool sample to the laboratory environment (21 ± 1°C, 20 % relative humidity). The junction between brick, sandstone or AAC and mineral wool was insulated from the outside with sanitary silicone. The brick or sandstone samples and mineral wool samples were mechanically stuck together with a simple construction (see Fig. 1).

Figure 1: Drying experiment.

Two saturated brick, sandstone or AAC samples were not equipped with mineral wool layer and were left drying from their one uninsulated front side as reference samples for the sake of drying velocity comparison. The fiber orientation in mineral wool samples was perpendicular to moisture transport

direction (except for PRG, which fiber orientation was parallel to moisture transport direction). This experiment performance respects fiber orientation in supplied insulation boards in order to simulate moisture transport within these boards applied on the masonry. All samples were periodically weighted and weight losses caused by drying were recorded. Time dependent history of moisture content in the porous material samples was calculated from these data.

2.4 Desalination experiment

Salt solution transport from porous building material (brick, sandstone) to a water saturated hydrophilic mineral wool layer DR was studied in this experiment. The porous building material samples were water and water vapour proof insulated on five sides with epoxy resin (one side remained uninsulated) and put into desiccator with 1-M sodium chloride solution in order to saturate them with the solution. Afterwards, hydrophilic mineral wool samples were prepared and water and water vapour proof insulated with silicone rubber on four lateral sides and left for one day in sealed desiccator filled with distilled water. Then the porous building material samples and mineral wool DR samples were stuck together in the same way as at the drying experiment (see Fig. 2).

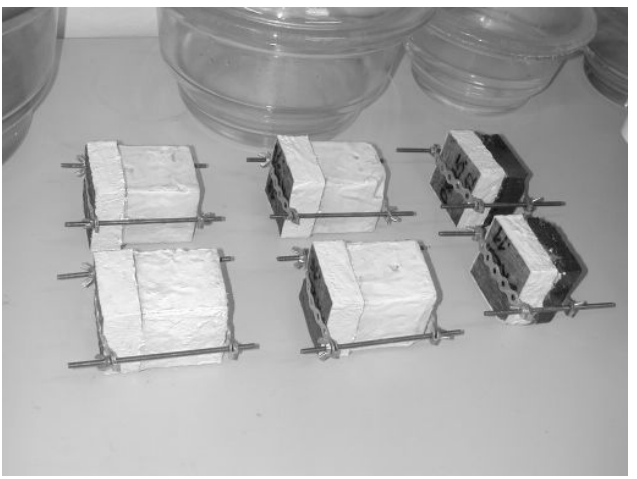

Figure 2: Desalination experiment.

After chosen time (1 hour, 1 day, 1 week) the appropriate couples of hydrophilic mineral wool samples were separated from porous building material samples and dried out at 100 °C. Finally, the chloride ions concentration in distilled water leach from these samples in mg/l was measured. The desalination experiments differed from each other as for the porous building material type (brick or sandstone) and thickness (30, 60, 120 mm) and the mineral wool sample thickness (25, 50, 100 mm).

3 Hydrophilic mineral wool materials

Several hydrophilic mineral wool materials manufactured by Rockwool CZ and potentially applicable for desalination purposes were analyzed. The first of them was two-layered material DD consisting of soft low-density layer DDS and hard high-density layer DDH. The second was ultra-low-density board PRG and the last one the high-density board DR which was designed specifically for ultra-fast water transport. All materials had the fiber orientation parallel to the board surface, except for the PRG boards which had the fibers parallel to the water flow.

4 Experimental results and discussion

The results of basic material parameter measurements are presented in Table 1. The matrix density of studied materials is within possible production range. Porosity of all materials is higher than 90 %, which is typical for this type of material, the matrix density corresponds with typical values for basalt.

Table 1: Basic material parameters.

Material	Bulk density	Porosity	Matrix density
	[kg/m^3]	[Vol.-%]	[kg/m^3]
DDS	90	96.4	2540
DDH	210	91.9	2540
PRG	60	96.5	2697
DR	164	93.1	2644

Table 2 presents water vapour properties of studied materials. All materials exhibit quite similar values of water vapour diffusion resistance factor. It is obvious, that bulk density for this type of material does not affect diffusion resistance in a significant way.

Water and salt solution transport properties are presented in Table 3. Highest values are reached by material DR, which was specially designed for very fast liquid moisture transport.

The example of the course of the drying process of porous building material samples through a hydrophilic mineral wool layer is presented in Fig. 3 for AAC. The fastest drying occurs for samples without hydrophilic mineral wool layer which is obviously caused by the diffusion resistance of mineral wool being

approximately two to four times higher that diffusion resistance of the air. Among the experimental setups with mineral wool layers the fastest drying was observed for DDH. The other hydrophilic mineral wool materials exhibited very similar drying rates.

Table 2: Water vapour diffusion properties.

Material	Water vapour diffusion coefficient			Water vapour diffusion resistance factor		
	97/25%	5/25%	5/87%	97/25 %	5/25%	5/87 %
	D [m^2s^{-1}]			μ [-]		
DDS	1.2 E-5	6.25 E-6	6.2 E-6	1.9	3.7	3.8
DDH	1.4 E-5	6.3 E-6	7.3 E-5	1.8	3.9	3.2
PRG	1.6 E-5	5.5 E-6	5.3 E-6	1.4	4.2	4.3
DR	1.3 E-5	7.0 E-6	7.2 E-6	1.8	3.3	3.2

Table 3: Water and salt solution transport parameters.

Material	Water absorption coefficient A [kg $m^{-2}s^{-1/2}$]					
	water	0,1 M NaCl	0,2 M NaCl	0,5 M NaCl	0,8 M NaCl	1 M NaCl
DDH	5.66	5.86	5.50	5.80	5.13	5.23
DDS	3.63	2.38	2.63	1.91	1.43	1.28
PRG	3.70	3.60	3.41	3.22	3.44	3.36
DR	5.13	-	-	4.91	-	5.43

Figure 4 presents results of the desalination experiment: time dependent NaCl transport process from ordinary brick into hydrophilic mineral wool. It is evident, that while thickness of joined mineral wool samples remains the same, the smaller is the brick sample thickness the higher is the amount of transported NaCl solution into mineral wool samples within the same time intervals.

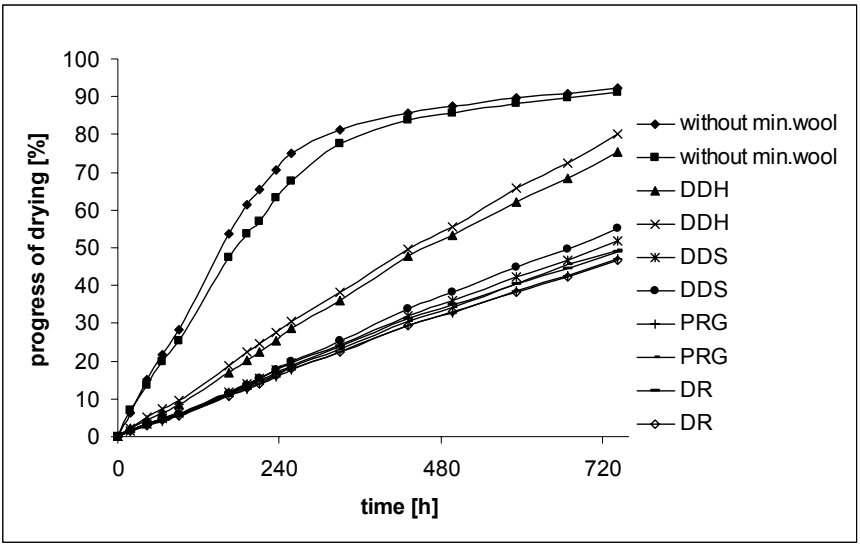

Figure 3: Drying of AAC specimens through hydrophilic mineral wool layer.

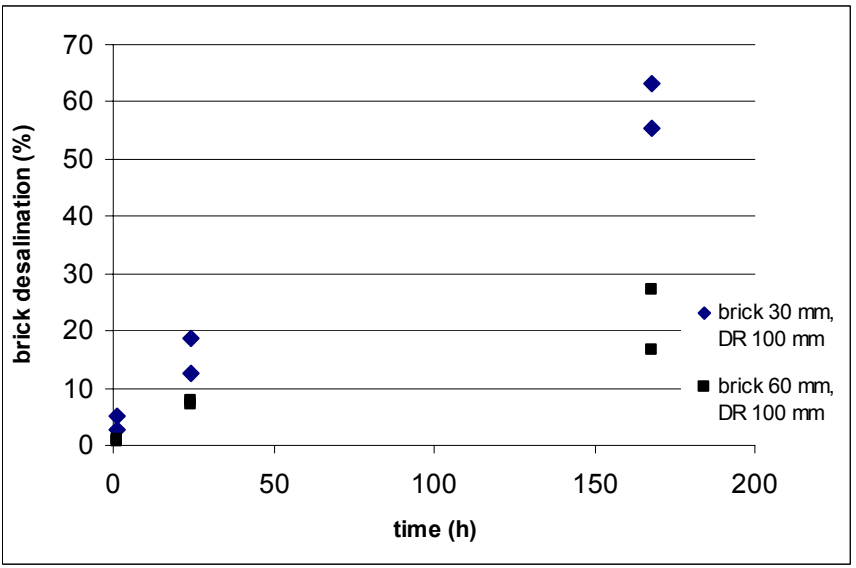

Figure 4: NaCl solution transport from brick specimen into hydrophilic mineral wool layer.

5 Conclusions

Experimental work presented in this paper confirmed that hydrophilic mineral wool possesses good prerequisites for utilization in the building industry in cases where fast moisture and salt transport is required. Liquid moisture and salt solution transport in this type of material is significantly faster than in most other building materials, water vapour diffusion resistance factor differs from ordinary mineral wool only in the range of measurement error.

As for the presumed application purpose, hydrophilic mineral wool cannot be used for simultaneous drying and salt transport, but only for one purpose in selected time, i.e., either for water transport or for salt transport. This is a consequence of the fact that for moisture removal from a porous building material the hydrophilic mineral wool layer has to be dry, but it has to be water saturated for the purpose of desalination use. The hydrophilic mineral wool utilization for desalination is also restricted to the seasons without frost.

On the other hand, it is possible to use this material for drying purposes also in winter period, because it can protect historic masonry from frost in the form of exterior thermal insulation, and thus continue in the water removal from the masonry also in these quite unfavourable conditions. However, in the subsequent summer period it is more appropriate to remove the insulation boards from the drying structure because natural drying of the masonry depends on outside temperature and in summer it is faster with an open material surface than through hydrophilic mineral wool layer.

Acknowledgement

This research was supported by the Ministry of Education, Youth and Sports of Czech Republic, under project No MSM: 6840770031.

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