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Investigation of the Effectiveness of Siloxane Hydrophobic Injection for Renovation of Damp Brick Masonry

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***Abstract*—**Experimental investigation of the effect of hydrophobic injection on siloxane basis on the properties of old-fashioned type of ceramic brick is presented in the paper. At the experimental testing, the matrix density, total open porosity, pore size distribution, sorptivity, water absorption coefficient, sorption and desorption isotherms are measured for the original, as well as the hydrophobic-injection treated brick. On the basis of measured data, the functionality of the hydrophobic injection for the moisture ingress prevention into the studied ceramic brick is assessed.

***Keywords*—**Brick masonry, siloxane hydrophobic injection, moisture ingress, functionality testing.

I. Introduction

BRICK masonry usually suffers from moisture coming from several sources. In case of older brick buildings, where the horizontal water-proofing layer is usually missing, the moisture intakes especially from the subsoil. Other significant sources of moisture in building structures are the faults of eaves, water pipelines and improper construction design.

Water in all its phases significantly decreases mechanical properties of masonry materials. Furthermore, in damp conditions porous building materials are susceptible to frost damage, because of the volume changes accompanying the phase conversion of water from the liquid into the solid phase. Water can deteriorate building materials and structure surfaces also by acid decomposition reactions. Typical example is sulphur dioxide that dissolves in water and partly forms sulphurous acid and sulphur trioxide that forms acid as well. Both acids decompose lime and lime-mixed binders in coatings and mortars.

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Moist or damp buildings have been in several studies attributed to the negative health effects [1]. Due to the excessive moisture, several biological processes are evoked leading to the biological growth ranging from bacteria, algae, and fungi to moss [2]. Another serious problem for the functionality of building materials and buildings represents the decrease of thermal insulation function of materials with increasing moisture content. Since the thermal conductivity of water is approximately 0.60 W/mK at 20°C [3], which is more than 20 times higher than of the air, the thermal conductivity of damp material rapidly increases [4].

Since the negative effects of moisture presence in building materials and structures are quite obvious, there is necessary to prevent moisture ingress into the buildings for their whole service life. In case of the damp brick masonry, there are several methods that can be applied for its reconstruction and renovation. Among them, the use of injection substances is the most popular method for barring the liquid moisture transport from the subsoil. In this paper, the experimental investigation of the effectiveness of hydrophobic siloxane injection is presented in order to access its applicability at restoration of brick masonry.

II. Studied Materials and Samples

The siloxane injection was applied into the old-fashioned type of ceramic brick produced by the brick factory Zlínské cihelny Ltd., Czech Republic. This brick was chosen in consideration of its composition and appearance that are very close to the original historical bricks that were one of the most often used building material in the Central European territory over the last centuries. The brick is poorly burnt, inhomogeneous, and its colour varies from bright red to greyish. The original brick size is 290 mm x 145 mm x 65 mm. Within the samples' preparation, the brick was cut in halves and into the each part, a 100 mm deep hole of 20 mm diameter was bored. The prepared holes were then filled by siloxane injection Aquafin SMK. In this way, the free-flow injection was performed. For sample preparation see Fig. 1.

14 days after injection penetration the particular samples were cut from the treated brick halves, whereas the visibly injection saturated parts of the brick were chosen for experimental testing.

Siloxane injection Aquafin FMK is product of company Schomburg Čechy a Morava, Ltd. For its application, the water dilution is necessary at the rate of 1:11. Within the application of this hydrophobic substance, fast penetration was observed what is beneficial for its practical use in reconstruction works.

Fig. 1 Ceramic brick filled by siloxane injection

III. Experimental methods

At the experimental testing, measurements of matrix density, total open porosity, pore size distribution, water absorption coefficient, sorptivity, sorption and desorption isotherms were done for the penetrated brick samples as well as for the reference material. All the experiments were realised in the air-conditioned laboratory at constant temperature 23 ± 1˚C and relative humidity 30 ± 5%.

A. Matrix Density

The matrix density was measured by helium pycnometry using apparatus Pycnomatic ATC (Thermo). It applies well known technique of helium displacement to measure the real density of solid substances. Since helium is inert element and has a very small atom, it can penetrate even extremely narrow pores in a solid [5]. 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.

B. Total Open Porosity and Pore Size Distribution

The porosity measurements were performed on dried samples using apparatuses Pascal 140 and 440 (Thermo) working on mercury intrusion principle [6]. The physical basis of this measurement results from the assumption that the non-reactive and non-wetting liquid (in our case mercury) will not penetrate pores until sufficient pressure is applied to force its entrance. As narrow pores must be filled up, such high pressure must be applied [7]. The relationship between the applied pressure and the pore size into which the mercury will intrude is then given by the Washburn equation [8].

C. Water Sorptivity and Water Absorption Coefficient

Water sorptivity and water absorption coefficient measurement was done using a free water intake experiment. It is the simplest technique for the characterization of the ability of porous materials to absorb water and transport it by capillary forces, thus for describing liquid water transport.

The sorptivity S (m/s$^{1/2}$) is defined [8] as

$$I = S \cdot t^{\frac{1}{2}}, \quad (1)$$

where I (m) is the cumulative absorption of water and t (s) the corresponding time of water absorption.

Equation (1) is a simplification of the general expression for the cumulative mass of water in terms of the square-root-of-time rule that is commonly employed in the diffusion theory, which is obtained by dividing the original equation

$$i = A \cdot t^{\frac{1}{2}} \quad (2)$$

by the density of water ρ_w (kg/m^3). In Equation (2), i (kg/m^2) is the cumulative mass of water and A (kg/m^{2}s$^{1/2}$) the water absorption coefficient. A combination of (1) and (2) leads to

$$A = S \cdot \rho_w . \quad (3)$$

The experimental setup applied in this paper for water absorption coefficient and water sorptivity measurement was quite common. The specimens of plate form were water- and vapor-proof insulated on all lateral sides using epoxy resin. Then, the particular specimens were fixed on automatic balance and immersed 1–2 mm in the water. Constant water level in the tank was achieved using a Mariotte bottle with two capillary tubes. One of them, with inner diameter of 2 mm, was immersed under water, while the other, with inner diameter of 5 mm, was above water level. Using automatic balance allowed recording the increase of sample mass. From the plotted relationships between the cumulative mass of water and square root of time, water absorption coefficient was accessed as a slope of the linear part of this dependence.

D. Sorption and Desorption Isotherms

Apparatus DVS-Advantage (Surface Measurement Systems Ltd.) was used for measurement of sorption and desorption isotherms of studied materials. The instrument measures the uptake and loss of vapour gravimetrically using highly precise balances having resolution 10 μg. The vapour partial pressure around the sample is generated by mixing the saturated and dry carrier gas streams using electronic mass flow controllers. The humidity range of the instrument is 0 – 98% with accuracy ± 0.5% at temperatures 5 – 60°C. In this way, the temperature dependence of vapour adsorption/desorption can be measured as well.

The studied samples were first dried in the vacuum drier at 60°C. Then, the particular samples of the researched materials were put in the climatic chamber of the DVS-Advantage instrument and hung on the automatic balances in the special steel tube. The experiments were performed at 20°C. The samples were exposed to the following partial pressure profile: 0; 10; 20; 30; 40; 50; 60; 70; 80; 90 and 98% relative humidity. For each sample, one full sorption cycle was measured. During the experiments, the DVS-Advantage instrument was running in dm/dt mode (mass variation over time variation) to decide when equilibrium was reached. A fixed dm/dt value of 0.0000% / min was selected for all relative humidity segments. This criterion permits the DVS software to automatically determine when equilibrium has been reached and complete a relative humidity step. When the rate of change of mass fell below this threshold over a determined period of time, the relative humidity set point proceeded to the next programmed level.

IV. Results an Discussion

Matrix density measured by helium pycnometer is presented in Table I. We can see that the application of siloxane hydrophobic injection led to a slight decrease of matrix density of the treated brick in comparison with reference material.

TABLE I
Matrix Density of Researched Materials

Material	Matrix density (kg/m^3)
Reference brick	2743
Brick treated with siloxane injection	2693

Results of total open porosity measurements are given in Table II. We can see that the application of siloxane injection did not affect the total open porosity of the ceramic brick. This finding is in agreement with the data given by the Aquafin SMK producer, since the material was designed as hydrophobic injection without capillary filling effect.

TABLE II
Total Open Porosity of Researched Materials

Material	Porosity (%)
Reference brick	23.4
Brick treated with siloxane injection	23.7

Results of pore size distribution analysis are presented in Figs. 2 - 4.

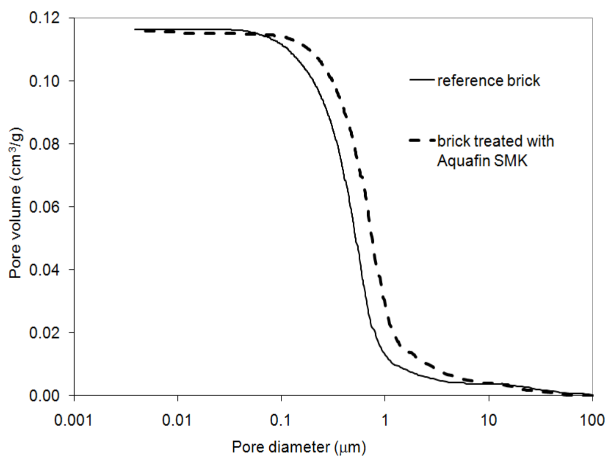

Fig. 2 Pore size distribution - cumulative curve

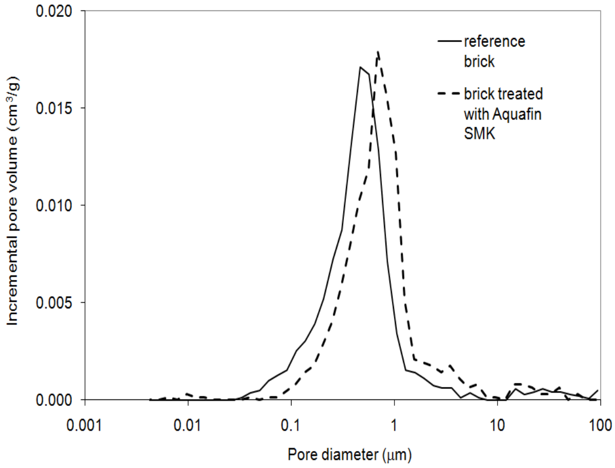

Fig. 3 Pore size distribution curve

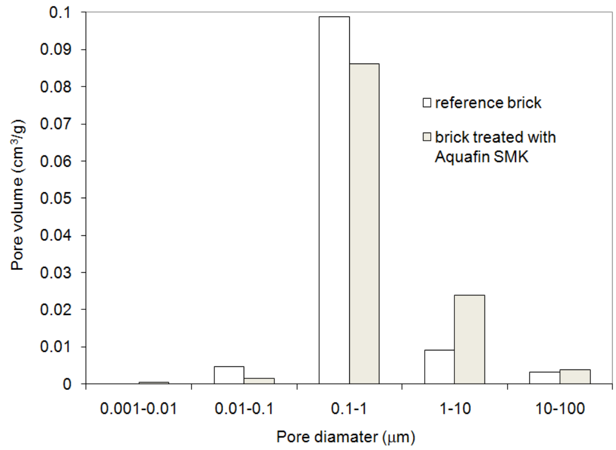

Fig. 4 Pore size distribution - histogram

The pore size distribution data did not show any significant decrease of the volume of capillary pores transporting the liquid water which was in a good agreement with the helium pycnometry measurements.

Data obtained in the free water intake experiment are given in Fig. 5. Looking at the data one can see a very substantial slowing down of moisture transport in material provided by siloxane injection. The differences in measured curves of the same material can be assigned to the inhomogeneity of the brick structure and distribution of applied injection.

Water absorption coefficient and water sorptivity determined on the basis of data given in Fig. 5 are introduced in Table III where the average values of researched parameters are presented. The obtained results confirmed expected reduction of both studied liquid water transport properties that reached for the treated brick values typical for high performance concrete that is usually considered as water proof material.

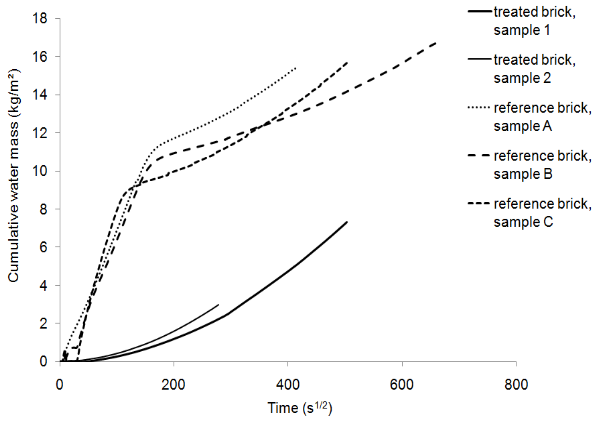

Fig. 5 Results of water intake experiment

TABLE III
WATER ABSORPTION COEFFICIENT AND SORPTIVITY

Material	Water absorption coefficient ($kg/m^2s^{1/2}$)	Sorptivity ($m/s^{1/2}$)
Reference brick	0.08	8.18×10^{-5}
Brick treated with siloxane injection	0.0015	2.00×10^{-6}

Sorption and desorption isotherms measured by the dynamic vapour sorption device are displayed in Figures 6 and 7. We can see that the application of the hydrophobic injection led to the reduction of brick water vapour sorption capacity in comparison with the reference ceramic brick. This finding is beneficial from the practical point of view, since not only overhygroscopic moisture but also adsorbed moisture can in some building structures cause problems, as for their functionality and durability.

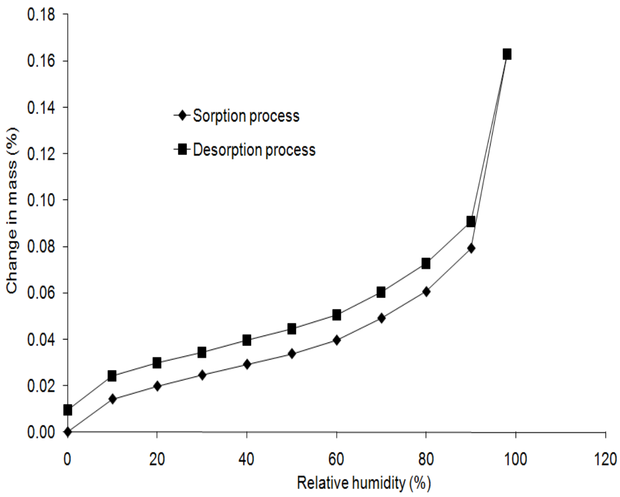

Fig. 6 Sorption and desorption isotherms of reference brick

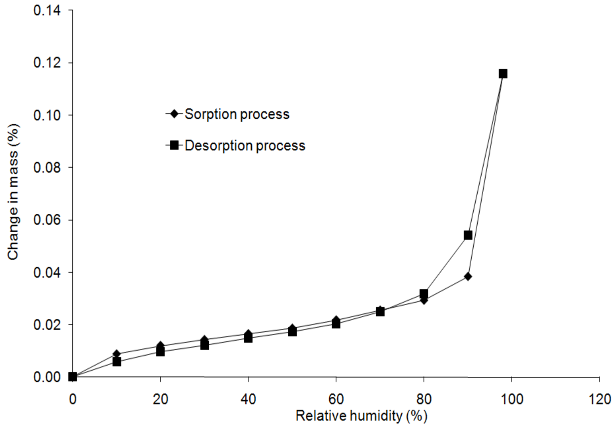

Fig. 7 Sorption and desorption isotherms of treated brick

V. CONCLUSION

The experiments presented in this paper showed a high effectiveness of the researched hydrophobic siloxane based injection at the slowing down of liquid moisture ingress into the analyzed ceramic brick. The obtained findings represent valuable information for building practice, where the studied injection Aquafin SMK can be recommended for the reconstruction of brick masonry.

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