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Increased water repellence of ceramic buildings by hydrophobisation using high concentration of organic solvents

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ABSTRACT

One of the methods used to reduce the impact of water on building objects is hydrophobisation. This article presents the analysis of the efficiency of hydrophobising preparations based on silica-organic compounds with a high concentration of organic solvents due to their increased hydrophobic potential, compared to water based preparations. The testing materials were ceramic bricks.

The following parameters were tested: water drop absorption coefficient, contact angle and surface free energy, surface water absorptivity, water vapour diffusion ability, water vapour permeability, thermal conductivity coefficient, as well as silicon resin distribution in the micro-structure of a ceramic brick. Based on the obtained results, the efficiency of hydrophobisation using the high volatile organic compounds (VOCs) content emulsion was analysed. The surface free energy (SFE) of the impregnated samples was 4.5–5.2 times smaller than in the case of the standard samples, which indicated a very good hydrophobicity of the bricks using the high VOC content emulsion.

1. Introduction

Implementation of the regulations pursuant to EU directive 2006/32/WE3 of 17th May 2006, imposed an obligation on Poland to undertake adequate actions which are aimed at reducing the final energy consumption in the buildings started from 1st January 2008. The final energy consumption in Polish households is mainly focused on heating the buildings, making up from 31% to 71% of the energy consumption [1]. The data included in literature indicate that Poland's final energy demand for central heating [2] is approximately 41.5%. The effects of fuel consumption during the operation of the buildings and due to environmental pollution caused by the CO_2 emissions have been discussed in literature [3].

A significant factor which causes an increase in energy consumption is related to damage arising directly or indirectly from moisture present in the external walls [4]. Too much moisture has a negative effect on people's health and this is the reason of the overestimated heat consumption due to an increase in the thermal conductivity of the external envelopes. Moisture is one of the main factors influencing not only the quality of air, heat comfort and energy consumption, but also the durability of the building materials. In the case of upgrading the energy performance of a building being in operation, a significant factor which can reduce economic viability is related to the damage arising directly or indirectly from moisture present in the external walls. The major objective to improve the heating parameters of building objects is to minimise the value of the thermal conductivity coefficient λ [W/mK], which is directly associated with a decrease in heat exchange through the external partitions of the building.

Wall dampness is caused by interstitial condensation [5], where water is transported as a result of capillary action. This relates in particular to the basement walls, where water is drawn in by capillary action and it significantly influences the heat transfer, increasing the thermal conductivity of the porous materials by four to six times. This has been confirmed in the research [6,7]. Consequently, this may result in the development of biological and chemical corrosion, as well as higher costs of operating the building [8,9].

Construction durability is significantly dependant on waterproof protection performed in a proper way. One of the innovative solutions is to apply a polymer based impregnate to change a wall from highly water absorbent to water repellent [10,11]. In this case, the best way to protect a building against the impact of rainwater is by hydrophobisation [12–15]. Hydrophobisation is used to protect the building objects, exposed to periodical rainwater, against

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moisture [13–17]. The purpose of hydrophobising treatment is to make the material surface hydrophobic. It is associated with an increase in the boundary surface tension between water and the material impregnated with a suitable preparation. The objects exposed to a hydrostatic pressure cannot be protected in this way. Hydrophobisation is also applied to protect walls against weathering, and façade stains, as well as to increase wall durability against abrasion.

Nowadays, organosilicone compounds and polymers are used for hydrophobisation [18–27]. Silicones are the most effective and safest preparations used for the hydrophobising process. Potassium alkyl-silicates, alkoxy-silanes, hydrated siloxanes and siloxanes in hydroxide form are used as silicone hydrophobisers. Potassium alkyl-silicates are the only ones available in the shape of a strongly alkaline (pH 14) aqueous solution [28]. Other compounds are soluble in organic solvents.

Controversial compounds of hydrophobising preparations are organic solvents. Volatile organic compounds (VOC) contained in hydrocarbon preparations can be toxic, carcinogenic or mutagenic [29–34]. The most important legal act regulating the emission of VOC in the European Union is the Council's directive 2004/42/EC [35] regarding the limitation of VOC emission due to application of organic solvents in some paints and lacquers. It restricts the content of VOC in products used for decorative and renovative painting. For the purpose of the renovation and conservation of a building, some individual licences for the sale and use of specific quantities of products which do not meet the established VOC limits established in the directive can be granted by EU member states [35].

Solvent impregnates with a high VOC content play a significant role in hydrophobising preparations, and, due to high effectiveness, their use is preferred in comparison with water preparations [36–42].

Water-proof impregnation is efficient only if a critical depth of agent penetration is obtained. Penetration depends on the following factors: duration of the contact between the silane and the material surface, the chemical reactivity of the applied silanes, type of solvent, and the viscosity of the solution [43].

Water preparations, if exposed to a long lasting impact of corrosive factors such as moisture, frost and salinity, do not constitute an effective protection against corrosion. Sometimes, water preparations expand the loamy minerals contained in building materials. This narrows the diameters of the capillaries and thus prevents the penetration of any hydrophobising preparation into the material structure, and thus it makes the hydrophobisation inefficient [40,43]. Due to low efficiency of the hydrophobisation with water-soluble preparations, it is strongly recommended to repeat the procedure every year or every few years [12,43].

The recent research proves that the deepest penetration in the structure of porous materials is possible in the case of hydrophobic preparations based on the low-molecular oligomers of alkyl-alkoxides and the poorest penetration is typical for a polymer, water-soluble preparations which have an effect on their efficiency [36,39,40,43].

The purpose of the research presented in this paper is to evaluate the use of hydrophobising preparations based on organosilicone compounds for the impregnation of ceramic building materials. Surface hydrophobisation using solvent substances was analysed. The efficiency of the three preparations that differed in the grade of their hydrolytic polycondensation, viscosity and concentration were verified, considering the fact that they were the factors which determined the final result of a hydrophobising process.

The experiments were conducted based on the Recommendations Technical Approvals [44], European Standards [45–48] and RILEM 25-PEM Recommendations [49]. The following laboratory tests were performed: the basic physical properties, water drop absorption, contact angle and surface free energy, surface water absorptivity, water vapour diffusion ability and permeability, silicon resin distribution in the micro-structure of a ceramic bricks and thermal conductivity.

On the basis of the obtained results, a detailed analysis of the hydrophobisation efficiency using silica-organic hydrocarbon compounds was carried out.

The paper analysed the effectiveness of three organosilicone agents recommended for ceramic building materials.

2. Materials, samples and test programme

2.1. Details of materials and sample specifications

The subject of the surface hydrophobisation were ceramic bricks. Determination of apparent density, density, open and total porosity was performed according to EN 1936:2010 [45]. Six measurements were assumed to bring about conclusive results of the research.

The results were as follows: apparent density $\rho_b = 1.68\,\mathrm{g/cm^3}$, density $\rho_r = 2.52\,\mathrm{g/cm^3}$, open porosity $P_o = 20.33\%$, total porosity $P = 33.33\%$, total volume of the open pores $V = 0.578\,\mathrm{cm^3/g}$.

The following preparations were selected for the laboratory tests:

- A1 methyl silicone resin (MESI) are macromolecular compounds with three-dimensional-grid $R{-}O{-}Si{-}[O{-}Si]_n{-}O{-}Si{-}R$, where: R – methyl derivative
- A2 silicone dispersion solution in an organic solvent $R{-}Si{-}O{-}Si{-}R$where: R means the derivative, e.g. $-H$, $-CH_3$, $-C_2H_5$
- A3 alkyl-alkoxy-silane oligomers $R_n{-}Si{-}(OR')_{4-n}$, where: R_n – alkyl-alkoxy-silane derivative.

$$\underset{\text{Alkiloalkoksysiloxane}}{R-Si(OR\prime)_3} \xrightarrow[-R\prime OH]{\text{Evaporation}\uparrow + H_2O} \underset{\text{Silicone resin}}{R-SiO_{3/2}}$$

Alkyl-alkoxy-silanes are reactive compounds of silicone and organic nonpolar functional groups $R{-}Si{-}(OR')_3$. Efficiency of impregnation is determined mostly by the chemical composition of monomers: alkoxy groups (OR′) determine the reactivity of compound and alkyl groups (R) define the hydrophobic efficiency of the impregnated material [50].

The characteristics of the preparations used in the examination are set out in Table 1. The viscosity coefficient η was determined using the time of the flow measurement [50]. Surface tension was estimated using the method of liquid rise in the capillary [51]. The research was conducted at a temperature of 22.5 °C. Five measurements were assumed to bring about conclusive effects.

The rise in velocity of the preparations in the building material depends on surface tension and the viscosity ratio σ/η. The highest value of surface tension and solution viscosity, thus of the rise in velocity of the preparation, is obtained by preparation A2. On the other hand, the lowest one is that of the alkyl-alkoxy-silanes oligomer in A3. The lowest values of viscosity, surface tension, density and concentration of a chemically active substance are shown by the organic solvent based on methyl silicone resin in A1, which guarantees good results of hydrophobisation.

Bricks were sliced into three equal parts. Then, the samples were dried at 70 ± 5 °C until the solid mass was obtained. Two samples were impregnated with a hydrophobising agent and the third one – the standard one, was used for comparative purposes. Two layers of the preparation were applied, using a brush. The impregnation was conducted on two surfaces, which were designated for the examination of absorptivity and determining the water drop absorption