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Properties of hydrophobised lightweight mortars with expanded cork

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HIGHLIGHTS

- We focused on the assessment of the durability of hydrophobized mortars with cork.
- The frost resistance is linear dependent on the strength properties of the mortars.
- Adhesive properties (SFE) bear a close relationship to the frost resistance.
- Sand improved the frost resistance of mortars, in comparison to lime addition.

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ABSTRACT

The article evaluates the efficiency of surface hydrophobisation based on organosilicon compounds. The subject of the study involved expanded cork mortars produced from *Quercus Suber* oak. Surface hydrophobisation was carried out by means of: a solution of methyl-silicone resin with high VOC content, aqueous emulsion from methyl-silicone resin in potassium hydroxide and low-molecular alkyl-alkoxy-silane in an organic solvent. The basic mechanical and physical parameters were investigated in this paper. The following parameters were studied: compression strength, tensile strength, density, open and total porosity, absorbability, water vapour diffusion capacity, vapour-permeability, capillary water absorption coefficient, frost resistance, resistance to sodium sulphate corrosion, surface free energy (SFE), thermal conductivity coefficient. The contact zone, micro-structure, and decomposition of polysiloxane gel in the mortars were presented on the basis of a scanning electron microscope (SEM) research. The mortar characterized by the greatest porosity exhibits the highest absorptivity. The mortar with sand is the tightest; its absorptivity is almost three times lower than the one of a mortar without sand. The mortar C2S with sand has the highest resistance. All considered samples exhibited good resistance to salt crystallization after 15 cycles. The mortars subjected to hydrophobisation showed virtually no damages following the frost resistance test, whereas the mortar samples with 20% cork and lime content were badly damaged and suffered a 14% weight loss. The contact angle and SFE determine the wetting and adhesion properties of mortars. The latter can be modified by means of cork and sand additions.

1. Introduction

Following the trends of energy efficient building construction, traditional mortars are substituted with lightweight, heat-insulating alternatives, in which the typical aggregate, i.e. sand, is replaced with, for instance: expanded perlite [1,2], waste perlite power [3], silica fume and fly ash [4], recycled Styrofoam granules [5,6], pozzolanic [2], cork granules [7], polyurethane foam [8], blast furnace slag [9], ceramsite [10], wood waste [11], pumice [12,13], and many others.

Numerous studies have been conducted pertaining to the impact of proportions and thermal properties of aggregates exerted on mortars. A comprehensive study investigating prospective sewage sludge management in a sintered ceramic material, including a lightweight aggregate, was presented in [14,15]. Paper [13] proved that pumice aggregate mortar is characterized by a greater compressive strength than Portland cement mortar when exposed to cycles of freezing and thawing. The applied pumice aggregate increased the resistance to salt attack. Mortars are supplemented with lightweight additives which improve the thermal properties thus mitigating condensation and heat transfer through

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thermal bridges, the impact of which is especially apparent in the eastern and northern Europe.

High thermal, acoustic and vibration insulation of cork, as well as its durability and resistance are increasingly often applied in civil engineering. Cork may be found in granular form, used for instance as a plaster and concrete additive to improve their thermal insulation. On the other hand, cork material in the form of spent boards can be reused by being ground into granules.

The bark tissue of *Quercus Suber* oak used for cork production comprises microcells, the shape of which resembles tetradecahedrons connected with capillaries. The interior of these polyhedrons is filled with a gas characterized by properties similar to air. As many as 40 million tetradecahedron microcells are found in 1 cm^3 of cork mass. The main components of cork include: suberin – about 45%, lignins – 27%, cellulose and polysaccharides – 12%, tannin – 6%, wax – 5%, other substances – 5% [16]. The gas mixture in microcells constitutes as much as 90% of its volume; hence, the weight of cork amounts to approximately 250 kg/m^3. Its mass constitutes one-fifth of the weight of water. Taking into account the low absorptivity of cork, reaching about 20%, this material can be considered almost unsinkable. Cork is characterized by a low thermal conductivity coefficient λ of about 0.038 W/(m·K) and high specific heat value. Cork belongs to the group of flame retardant materials, with Euroclass E fire rating. While burning, it produces no toxic compounds which would be detrimental to people. Owing to suberin which constitutes up to 45% of its mass, this material inhibits the infiltration of liquids and gases, boasting a chemical and biological resistance. That feature mainly results from the content of tannins and lack of proteins.

Studies on a lightweight thermal insulating mortar based on recycled cork were described in the articles by Moreira et al. [17], and Bras et al. [16]. Experimental results [17] prove that expanded cork reduces the density, compression strength and thermal conductivity of mortars. The mortars with expanded cork used as a lightweight filling material are characterized by a higher vapour-permeability and are more efficient in avoiding undesirable vapour condensation inside a wall. On the other hand, the studies carried out by Bras, Leal and Faria [16] present a comparison of traditional cement mortars with the cement mortars supplemented with cork or Styrofoam granules. This paper analyzed the mixtures in which sand was substituted with cork, amounting to 0–80% of mass. The experiment confirmed the findings of Moreira et al. The comparison of lightweight mortars based on cork and Styrofoam encouraged further analyses. In the case of mortars with cork granules, increasing the quantity of cork leads to a linear drop in thermal conductivity. This drop is greater in the case of cork mortars, than with Styrofoam ones. Cork-based mixtures can lower the thermal conductivity coefficient to 75%, whereas Styrofoam is capable of reducing this value to 60% [16]. It was also shown that the mortars with cork granules addition are much more stable and less prone to temperature changes per kilogram of substance. A traditional mortar with Styrofoam addition is more susceptible to temperature changes. In the case of mortars with Styrofoam, the water absorption coefficient is almost constant and is not very sensitive to the amount of Styrofoam substituting sand. Cork granules are characterized by a different relation. When 60% of aggregate is substituted, the absorption coefficient is much lower than in the case of mortars with Styrofoam, which is beneficial to the moisture conditions inside a building [3]. The above-mentioned studies present certain advantages of cork mortars over traditional ones, also with Styrofoam addition. Undoubtedly, they have a positive influence on the indoor environment. However, these mortars are characterized by high absorptivity and low resistance to corrosion, especially frost. Therefore, applying hydrophobic protection onto these mortars seems justified.

The impact of organosilicon-based hydrophobic preparations on the heat insulating mortars with expanded cork was investigated in this work. Hydrophobisation of construction materials is usually conducted by means of organosilicon compounds. Siloxane bonds Si–O–Si and carbon-silicon bonds Si–C–Si constitute the basis for organosilicon polymers [11]. High efficiency of mortar and lightweight concrete hydrophobisation was obtained in the studies of Frattolillo et al. [18], Tittarelli [19], Suchorab et al. [20], Barnat-Hunek et al. [10]. The authors conducted the assessment of surface hydrophobisation for protection against moisture, freezing-thawing cycles, and crystallization of sulphate salts.

2. Materials and methods

2.1. Materials

The initial preparations involved devising the composition of three expanded cork mixtures. The mortar compositions (percentage) are shown in Table 1. The mortar samples bear the following markings: C1L denotes the mortars with 10% of cork aggregate and hydrated lime; C2L stands for the mortars including 20% of cork aggregate and hydrated lime; C2S corresponds to the mortars comprising 20% of cork aggregate, quartz sand and no hydrated lime; C2L.1/C1L.1/C2S.1 denote the mortars subjected to surface hydrophobisation by means of a solution comprising methyl silicone resin; C2L.2/C1L.2/C2S.2 are mortars that underwent surface hydrophobisation with an aqueous emulsion of methyl silicone resin and organic solvents used as an additive; finally, C2L.3/C1L.3/C2S.3 correspond to the mortars that were surface-hydrophobised by means of low-molecular alkyl-alkoxy-silane.

1. The methyl silicone resin and water solvents
2. Methyl silicone resin and organic solvents
3. Alkyl-alkoxy-silane.

While devising the composition of mortars, attention was drawn to the impact of various cork amounts: 20% and 10%. In principle, this impact is obvious. On the basis of studies [16,17] it was proven that increasing the amount of cork, the resistance parameters of mortars will deteriorate, whereas the parameters related to thermal insulation, porosity, and absorptivity will improve. The work also demonstrated the impact of binder, i.e. lime and another fine aggregate, i.e. sand, on the properties of mortars. The mortar marked as C2L contains no sand, whereas in the C2S mortar, sand was substituted with lime.

Portland Cement CEM I 32.5R is characterized by the specific surface equalling 3985 cm^2/g, binding time amounts to 75 min, loss on ignition reaches 5.0% by weight, volume stability is lower than 10 mm, the compressive strength after 2 days is greater than 10 MPa, and exceeds 32.5 MPa following 28 days. CEM I 32.5R was devised in line with the Polish standards, i.e. EN 197-1:2011 [21] and PN-B-19707:2013-10 [22]. The apparent density of utilized hydrated lime equalled 405 kg/m^3, thus conforming to the EN 459-1:2015-06 standard [23]. Its composition comprised the following compounds: CaO – 95.5%, CO_2 – 2.1%, MgO – 0.5%, SO_3 – 0.1%, free water – 1.5%. The quartz sand employed in the study was composed of:95.3% SiO_2, 1.9% Al_2O_3, 0.7% Fe_2O_3, 0.35% CaO. The mortars comprised cork granules with the size of 0.5/1 mm and 1/2 mm. The density of 0.5/1 mm fraction amounted to 60 kg/m^3, whereas the one characterizing the 1/2 mm fraction equaled 70 kg/m^3. The thermal conductivity coefficient of cork granules amounted to 0.04 W/mK and 0.036 W/mk, respectively, humidity – up to 6%, absorptivity – 0.5 kg/m^2, fire rating – Euroclass E. The mineral composition of cork was as follows: suberin – 45%, lignin – 25%, cellulose – 13%, extractables – 10%, ash – 2%, and others – 5%. A plasticizing-reinforcing admixture in the form of ethylene vinyl acetate copolymer was added to the mortars in the amount of 0.15%. This additive improves numerous parameters of mortars, including: compression strength, workability, water retention in the adhesive, mixture flexibility, adhesion to all construction substrates. Simultaneously, it lowers the evaporation rate.

Classification of preparations was carried out on the basis of studies found in the literature [24,25] as well as the authors' own studies [10,26,27]. The hardened mortars were surface-hydrophobised with three preparations differing in respect to the solvent, viscosity, surface tension, particle size, etc. These factors are deter-

Table 1
Percentage composition of mortars.

Components	C2L	C1L	C2S
Expanded cork 0.5/2 mm	20	10	20
Hydrated lime	25	30	–
Quartz sand 0/2 mm	–	–	30
Portland Cement I 32.5R	25	30	30
Ethylene vinyl acetate copolymer	0.15	0.15	0.15
Water	29.85	29.85	19.85