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Lime-based plasters with combined expanded clay-silica aggregate: Microstructure, texture and engineering properties

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ABSTRACT

Plasters containing lightweight aggregates are mostly characteristic by low bulk density and low thermal conductivity but these favorable properties are often achieved at the expense of mechanical strength. In this paper, lightweight lime-based plasters are designed which have good thermal and mechanical properties at the same time. As their supposed applications include the renovation of surface layers of historical buildings, burnt clay shale is used as pozzolanic admixture to lime. The volumetric ratio of silica sand and expanded clay aggregate (ECA) is varied over a wide range to analyze the effect of ECA on microstructure, texture, and mechanical, thermal and hygric parameters of investigated plasters. The microstructural studies show a more compact interfacial transition zone between the basic lime-pozzolan matrix and ECA, as compared with silica sand, which is the most important factor affecting the properties of studied plasters. Apparently, the surface roughness of ECA grains at first makes possible easier formation of hydration products and later it can support the growth of calcite crystals and CSH amorphous phases. The textural analysis together with the measurement of basic physical properties reveals, as the second principal factor, a substantial increase of open porosity with the increasing ECA dosage; the added pores are mostly within the range of 10 nm to 1 μm. The assessment of the wide range of engineering properties of designed plasters leads to the identification of the lime-pozzolan plaster with the volumetric ratio of 1: 1 between silica sand and ECA as the most appropriate solution. The thermal conductivity of this plaster is two times lower than of the lime-pozzolan plaster with silica aggregates, while the changes in compressive and bending strengths are only marginal. The favorable hygric properties can be considered as another asset. Faster water vapor transport, together with the higher water vapor adsorption capability, can decrease a risk of water condensation and moderate the effects of both exterior and interior climate, the relatively slow liquid water transport is a limiting factor for rainwater penetration. The economical parameters of the plaster with the best functional properties are also very good. According to the current situation on the Czech market, the price increase is only 3%, as compared with the reference mix.

1. Introduction

Current requirements on building materials are increasingly demanding and contemporary plasters are not an exception. They cannot serve as a protection against surrounding environment with an aesthetic role only; some other demands are arising, such as acoustic and thermal insulation, or fire resistance. The improvement of thermal performance can be achieved mainly by lightening. There are several ways how to lighten a plaster, such as introducing air or gas into a mixture, increasing the water to plaster ratio, or using carbonated water [1]. However, the most common method is incorporation of lightweight solids in blended mortars or cement renders.

The application of lightweight aggregates in lime- and cement-based matrices was studied by many investigators in the past. The possibilities of adding perlite and vermiculite in mixed-binder

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mortars were examined by Silva et al. [2]. They observed mechanical strength decrease with the increasing amount of lightweight aggregates. Torres et al. [3] focused their study on mechanical properties and hygric characteristics of lightweight cement mortars with expanded perlite, expanded glass, hollow micro-spheres and expanded polystyrene. The utilization of all studied aggregates led to the bulk density fall, mechanical strength deterioration and sorptivity growth. The greatest changes were achieved when expanded polystyrene was used, followed by expanded perlite. The results most similar to the reference mortar were obtained when expanded glass and hollow micro-spheres were employed. Zach et al. [4] focused their work on evaluating a possibility of using expanded obsidian as aggregate substitution in thermal insulation plasters. Expanded obsidian, when combined with lime hydrate, showed a good ratio of thermal characteristics to mechanical properties.

Among the organic natural materials, cork was the most frequently used as lightweight aggregate. Its utilization was studied by Brás et al. [5] who replaced silica sand in lime-based and cement-based mortars by cork granulate. They reported a positive effect of cork on the thermal insulating ability, a decrease of water vapor permeability (in the case of lime mortars) and decrease of mechanical strengths. Another representative of natural mortar-ligthweighting materials is hemp shive, which was studied by Mazhoud et al. [6]. They aimed their study at hygric and thermal properties of hemp-lime plasters and observed good hygroscopic properties, high water vapor permeability and low thermal conductivity. Similar results were obtained by Barreca and Fichrea [7] when olive stone was used as an alternative component in blended mortars. With an increasing amount of olive stone, the bulk density was lowered, the water absorption increased, while the thermal conductivity decreased.

Waste materials were also a subject of investigations related to plasters lightening. Corinaldesi et al. [8] used waste polyethylene terephthalate, pulverized glass fiber reinforced plastic and wood waste at the preparation of cement-based and lime-based plasters. The bulk density decreased, which was accompanied by the mechanical strength fall and thermal conductivity decrease.

In all cases presented above the lightening of plasters by lightweight aggregates (no matter of which kind) led predictably to lowering of bulk density, which was accompanied by a desired improvement of thermal insulating capability. This was always achieved at the expense of mechanical strength. However, it should be noted that sometimes this solution was necessary, e.g., for the compatibility with historical buildings.

Expanded clay aggregate (ECA) has been successfully used as a component of lightweight concrete mixtures in the past. Experimental results showed that it was responsible for densification or, more specifically, achievement of less porous structure and higher micro-hardness of interfacial transition zone in concrete than in the case of other lightweight aggregates [9,10]. In the case of aggregate with higher water absorption the internal curing affected positively the hydration processes of cement. Concrete containing ECA was even reported to show faster strength development in the first 28 days than those with normal aggregates [11]. The application of ECA also led to lower shrinkage and tensile creep and to the improvement of frost resistance of concrete [12].

On the other hand, it should be noted that in lightweight cement-based composites the weakest constituent was not the cement matrix or the interfacial transition zone as in the case of ordinary concrete but the ECA [13]. In other words, final mechanical characteristics of such concrete were mostly influenced by the mechanical behavior of the lightweight ceramic aggregate. It could be affected in a limited way only, e.g., by the bulk density of ceramic, the outer shell thickness, the macroporosity, or the broken grains percentage in ECA. Nevertheless, in the case of denser ceramic aggregate the final compressive strength could reach similar values as in the case of ordinary aggregate [14].

The application of lime as the main binder in lightweight composites containing ECA was not reported yet in common literature sources. In the very few cases when in such a composite lime was used as a part of mixed cement-lime binder, its role was only complementary [15,16]. However, lime composites are known to exhibit generally lower strength values than cement-based materials. Therefore, the mechanical properties of ECA should not play such a decisive role in the lime-based matrix. The decrease of bulk density caused by the ECA application might then lead to the achievement of desired thermal properties of the composite without a significant mechanical strength deterioration.

In this paper, lime-based plasters lightened by ECA are studied. As their supposed applications include the renovation of surface layers of historical buildings, burnt clay shale is utilized as the pozzolanic admixture replacing cement. Taking into account the price of ECA which is (per kg) currently on the Czech market almost four times higher than silica sand, the combined expanded clay-silica aggregate is used. In the experimental work, the microstructure of the designed plasters is investigated at first, with a particular attention to the interfacial transition zone between the lime-pozzolan matrix and the two different types of aggregate. The texture and basic physical characteristics are analyzed as well. Then, a wide set of mechanical, thermal and hygric parameters is determined as a function of silica sand/expanded clay ratio and the links between the microstructure, texture and material properties are analyzed. Finally, the most suitable solution is identified, based on the assessment of both functional and economical factors.

2. Materials and mix design

Hydrated lime CL 90-S (Mokrá plant of Carmeuse Czech Republic) was used as the main binder in all studied plasters. Burnt clay shale Mefisto L05 (České lupkové závody) was added as a supplementary cementitious material with good pozzolanic properties [17] which was supposed to improve the mechanical characteristics. Natural silica sand (the fine fraction 0/4 mm from Sklopísek Střeleč) and expanded clay (Lias Vintířov) were used as aggregates. The ECA was produced using clay from the Sokolov basin. It was expanded in a rotary kiln at the temperature of 1150 °C, using granules with a desired dimension. According to the information of the producer, the final product had spherical grains and its internal porosity system was uniform, while the surface of spheres was sintered. Basic properties of the applied ECA, as given by the producer [18], are presented in Table 1. The oxide composition of all raw materials, which was determined by the X-ray fluorescence method (XRF), is given in Table 2. The phase composition obtained by the X-ray diffraction analysis (XRD) is presented in Table 3. The granulometry of aggregates and binders is shown in Figs. 1 and 2, respectively.

The composition of the analyzed plasters is presented in Table 4.

Table 1
Properties of the expanded clay aggregate.

Property	Value
Fraction [mm]	0/4
Loose bulk density [kg m^{-3}]	575
Particle bulk density [kg m^{-3}]	1025
Thermal conductivity [W $m^{-1}K^{-1}$]	0.12
Water absorption [% by mass]	5
Flammability (DIN 4102)	A1
Crush resistance [MPa]	3.8