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LIGHTWEIGHT COATING MORTARS FOR BUILDINGS RESTORATION

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In this paper, crushed lava-based aggregate was used in mortar mix composition as a full silica sand substitution to improve thermal properties of mortar fulfilling also other physical, mechanical and technical requirements. As a binder, natural hydraulic lime was used. Workability of fresh mortar mixes was characterized by spread diameter. The casted samples were matured for 28 days in a high relative humidity to avoid cracking. For the hardened samples, structural, mechanical, and hygric properties were tested. Thermo-physical properties of the developed mortars were measured as function of moisture content, from the dry to fully water saturated state. The application of lava-based aggregate led to the mortar's increased porosity, improved mechanical strength, lower water absorption, and significantly better thermal performance compared to the control materials with silica aggregate. The newly developed lightweight mortar met the technical, compatibility and functional criteria on rendering mortar and was found well usable for conservation and restoration of historical and heritage masonry and buildings.

Keywords: Thermal performance, Crushed lava aggregate, Natural hydraulic lime, Mechanical properties, Hygric parameters.

1 INTRODUCTION

Buildings often require repairs due to the loss of materials performance. Especially historical and older buildings show deficiencies according to the nowadays' technical standards. Rendering mortars can greatly improve the thermal function of older buildings and thus reduce energy consumption and meet the current technical requirements, and new buildings. Therefore, thermal insulation renders were put on the market. Thermal insulation renders are usually composed of lightweight aggregates, cement, mineral admixtures, and chemical additives affecting mortars workability, adhesion to substrate, etc. Lightweight aggregate can be categorized according to its origin and transformation process (Glória Gomes *et al.* 2019) into i) inorganic (e.g., porous sedimentary rocks, volcanic rocks, expanded glass, expanded clay), and ii) organic (e.g., expanded polystyrene, cork (Panesar and Shindman 2012), (Brás *et al.* 2014), agriculture products – cellulose based aerogel (Baillis *et al.* 2015), Hemp shive (Rahim *et al.* 2016a), flax and straw rape (Rahim *et al.* 2016b), palm date fibers (Ben Mansour *et al.* 2014), (Chikhi *et al.* 2013), other natural fibers (Saghrouni *et al.* 2019), etc. materials. More recently, use of high thermal insulating aggregates, e.g., aerogels, have been intensively researched but their application in building practice is still scarce (Glória Gomes *et al.* 2017).

In restoration and conservation of heritage buildings, materials compatible with those originally applied must be used (Pavlíková *et al.* 2019). In this context one must bear in mind lime was applied in construction of buildings for centuries (Gris *et al.* 2013). Unfortunately, most of the thermal insulation mortars available on the contemporary market are based on Portland cement (PC) or its blends with pozzolanic admixtures. As the usage of PC-based materials in repair works represents serious risk for lime-constructed structures, there is necessary to design and develop novel thermal insulation coating and structural mortars based on air lime or hydraulic lime that enables produce materials of sufficient strength and long-term durability (Zhang *et al.* 2018), (Barbero-Barrera *et al.* 2017). Therefore, new type of thermal insulation mortar based on lava aggregate and natural hydraulic lime as only binder was developed and tested in this work.

2 EXPERIMENTAL TESTS

Within the extensive experimental campaign, new type of thermal insulation mortar (NHL-LA) was designed based on modification of composition of reference mortar with silica aggregate (NHL-Ref) that was fully substituted with crushed lava-based aggregate. With a view to quantify the effect of the application of lava as aggregate, basic structural, mechanical, hygric, and thermo-physical parameters of 28-days cured mortar samples were assessed.

2.1 Materials and Design

Commercial natural hydraulic lime (NHL 3.5, Zement- und Kalkwerke Otterbein GmbH and Co. KG, Germany) was used as an only binder in both reference and modified mortar mixes. The basic physical parameters of NHL were following: specific surface 1,092 m^2/kg, loose bulk density 669 kg/m^3, specific density 2,597 kg/m^3, d_{50} = 53.5 μm, d_{90} = 70.1 μm. Lava granulate (the fine fraction 0/2 mm from Der Naturstein Garten, Hillscheid, Germany) and pure quartz sand (the fine fraction 0/2 mm from Filtrační písky, Ltd., Chlum u Doks, Czech Republic) were used as aggregates. The loose bulk density of silica sand was 1,675 kg/m^3 and that of lava granulate was 1,415 kg/m^3. The dosage of water was adjusted to get the same consistency of both fresh mortar mixes, i.e. their spreading measured in flow table test was 160 ± 5 mm. The composition of examined materials is introduced in Table 1.

Fresh mixtures were casted into prismatic molds having size of 40 mm × 40 mm × 160 mm and cubic molds of 100 mm side. The samples were cured for 28 days at T = (22 ± 2) °C and RH = (80 ± 5) %.

Table 1. Mortars' composition (kg/m^3).

	Substance			
Material	**Natural hydraulic lime**	**Sand**	**Lava granulate**	**Water**
NHL-Ref	410.0	1,394.7	-	307.7
NHL-LA	482.5	-	1,385	386.0

2.2 Structural Properties

In basic characterization experiments, specific density, bulk density, and open porosity were measured for 28-days samples. For these tests, 5 samples were used. First, the samples were dried in a vacuum drier at 60 °C. The specific density ρ_s (kg/m^3) was measured by Pycnomatic ATC (Thermo Scientific), an automated helium pycnometer.

The dry bulk density ρ_b (kg/m^3) was tested in compliance to EN 1015-10 (1999). The total open porosity ψ (%) was then determined from the bulk density and specific density data.

2.3 Mechanical Parameters

The strength tests (flexural strength f_f (MPa), compressive strength f_c (MPA)) were conducted in accordance with the standard EN 1015-11 (1999). For each mortar mixture, 5 standard prisms with the dimensions of 40 mm × 40 mm × 160 mm were measured.

The dynamic elastic modulus E_d (GPa) of dry samples was assessed by the use of the pulse ultrasonic device DIO 562 (Starmans Electronic).

2.4 Water Transport Characteristics

The water absorption coefficient A_w (kg/(m^2·s$^{1/2}$)) was measured in compliance with the EN 1015-18 (2002). The 1-D water transport was ensured by the insulation of all lateral sides of the specimens (5 for each material) with epoxy resin. In free water intake test, the particular specimens were immersed approx. 2-5 mm in water and the increase in mass change was continuously monitored by precise laboratory scales controlled by computer. In this way, continuous contact of specimens with water reservoir was reached. From the measured water absorption coefficient, and the capillary moisture content value w_{cap} (kg/m^3), the apparent moisture diffusivity κ (m^2/s) was calculated (Kumaran 1999).

2.5 Thermal Performance of Mortars

Mortar's heat transport and storage parameters as thermal conductivity λ (W/(m·K)) and volumetric heat capacity C_v (J/(m^3·K)) were obtained by an apparatus ISOMET 2114 (Applied Precision, Bratislava, Slovakia). The measurement was done at T = (23 ± 2) °C. As moisture presence significantly deteriorates thermal insulation function of porous building materials, the ISOMET tests were conducted first for dried samples and then in dependence on moisture content of the particular mortar samples up to their full saturation. For the measurement, 5 samples of both control and lava containing mortars were examined.

3 RESULTS AND DISCUSSION

Structural properties of 28 days hardened coating mortars are summarized in Table 2. The usage of lava granules greatly increased mortar's porosity in comparison with the control material. Accordingly, the bulk density of the newly developed mortar was lower. The observed higher porosity is promising for the intended use of tested material for repair applications, where porosity > 40% is often recommended due to the attainment of water evaporation (Fusade *et al.* 2019).

Table 2. Structural parameters of studied mortars.

Mortar	**Bulk density (kg/m^3)**	**Specific density (kg/m^3)**	**Total open porosity (%)**
NHL-Ref	1,781	2,587	31.1
NHL-LA	1,716	2,840	39.6

The experimentally assessed values of the tested mechanical parameters are presented in Table 3. The substation of silica sand with lava-based aggregate led to the improvement of all tested mechanical characteristics what is highly beneficial for the practical use of a newly developed light-weight mortar. According to the compressive strength values, the NHL-R plasters can be categorized into class CS I (EN 998-1 2016) and plaster NHL-LA into class CS II.

Table 3. Mechanical parameters of studied mortars.

Mortar	**Flexural strength (MPa)**	**Compressive strength (MPa)**	**Young's modulus (GPa)**
NHL-Ref	0.8	1.2	4.3
NHL-LA	1.0	2.6	5.2

Mortars' liquid water transport properties are introduced in Table 4. As capillary water absorption was > 0.30 kg/(m^2·$s^{1/2}$), the both studied materials were found applicable as repair mortars. The capillary water absorption of both plasters was categorized into class W1 (EN 998-1 2016). On analogous moisture imbibition reported, e.g., Pavlíková *et al.* 2019, who studied moisture transport in air lime mortars enriched with wood-based biomass ash admixing. Also Fusade *et al.* (2019) received for hydraulic lime mortars water absorption coefficient values in the range 0.3-0.379 kg/(m^2·$s^{1/2}$).

Table 4. Mortars' hygric properties.

Mortar	A_w (kg/(m^2·$s^{1/2}$))	w_{cap} (kg/m^3)	κ × 10^{-6} (m^2/s)
NHL-Ref	0.33	218	2.30
NHL-LA	0.32	272	1.38

The data of thermo-physical parameters is presented in Figures 1 and 2. The thermal conductivity value was significantly reduced by use of lava granulate due to its large porosity and limited pores connectivity. Moreover, the newly developed hydraulic mortar exhibited much lower effect of moisture presence on the thermal conductivity contrary to its high porosity.

The differences in C_v values measured for NHL-Ref and NHL-LA mortars were very small similarly as the dependence of the heat storage capacity on moisture. This finding is very promising for intended application of the developed mortar with lava-based aggregate on moist masonry.

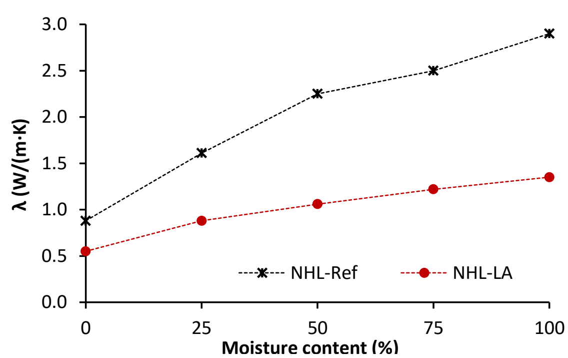

Figure 1. Mortars' moisture dependent thermal conductivity.

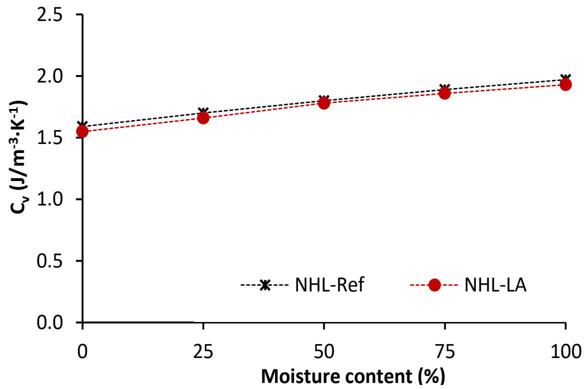

Figure 2. Mortars' moisture dependent heat storage capacity.

4 CONCLUSIONS

Crushed lava-based aggregate was researched as a full substitution of silica sand in formulation of hydraulic lime-based mortar mix. The mortar with lava aggregate showed sufficient mechanical strength (class CS II) and high water absorption (class W I) what is favorable for its usage in repair applications, where high water absorptivity will enable water evaporation from damp masonry materials, such as bricks and wall stones. In this respect, the interconnectivity between porous systems of mortar and substrate (bricks, stone blocks, etc.) will be of the particular importance. Moreover, mortars with lava had low thermal conductivity and its limited dependence on moisture pointed out to its applicability for both rendering and walling purposes even in restoration and conservation of historical masonry.

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