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Thermal Insulating Silicate Materials Suitable for Thermal Insulation and Rehabilitation Structures

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***Abstract*—**Problems insulation of building structures is often closely connected with the problem of moisture remediation. In the case of historic buildings or if only part of the redevelopment of envelope of structures, it is not possible to apply the classical external thermal insulation composite systems. This application is mostly effective thermal insulation plasters with high porosity and controlled capillary properties which assures improvement of thermal properties construction, its diffusion openness towards the external environment and suitable treatment capillary properties of preventing the penetration of liquid moisture and salts thereof toward the outer surface of the structure.

With respect to the current trend of reducing the energy consumption of building structures and reduce the production of CO_2 is necessary to develop capillary-active materials characterized by their low density, low thermal conductivity while maintaining good mechanical properties. The aim of researchers at the Faculty of Civil Engineering, Brno University of Technology is the development and study of hygrothermal behaviour of optimal materials for thermal insulation and rehabilitation of building structures with the possible use of alternative, less energy demanding binders in comparison with conventional, frequently used binder, which represents cement.

The paper describes the evaluation of research activities aimed at the development of thermal insulation and repair materials using lightweight aggregate and alternative binders such as metakaolin and finely ground fly ash.

***Keywords*—**Thermal insulating plasters, rehabilitation materials, thermal conductivity, lightweight aggregate, alternative binders.

I. INTRODUCTION

DURING the reconstruction and rehabilitation of envelopes of building structures are increasing demands on the thermal insulation properties of the materials used, especially when it concerns the reconstruction of objects loaded with increased humidity. In these cases it is necessary to use particular materials with high open porosity, low thermal conductivity and good mechanical properties.

The paper describes the results of research in the area of development of lightweight thermal insulation plasters with lightweight aggregates based on volcanic glass and using alternative raw resources, which represent metakaolin and finely ground fly ash.

Already from previous research works concerning the development of thermal insulating materials and remediation has been found that the use of metakaolin as a substitute for cement in the lightweight thermal insulating plasters based on lightweight aggregate and hydrated lime can achieve significant improvement in mechanical properties, while maintaining very good thermal insulation properties. Metakaolin is disadvantageous in terms of its very high price, which is markedly higher than the price of cement, therefore we tried to replace metakaolin and other hydraulic or latent hydraulic binder. Suitable substitution was chosen finely ground fly ash, which has in combination with hydrated lime comparable properties as metakaolin, but its purchase price in comparison with metakaolin is the substantially lower [1]–[5].

One of the objectives of development plaster mixtures intended for the rehabilitation and insulation of buildings was to achieve the best possible ratio of thermal and mechanical properties. For use of these materials in practice defined basic requirements of the above key parameters developed materials:

- The requirement for the maximum value of the thermal conductivity in dry state:

$$\lambda_{10,dry,max} = 0.08\ \mathrm{W.m^{-1}.K^{-1}};$$

- The requirement of a minimum compressive strength:

$$f_{c,min} = 0.5\ \mathrm{N.mm^{-2}};$$

- Request the density of hardened mortar in interval:

$$\rho_v = 250\text{–}500\ \mathrm{kg.m^{-3}};$$

- The requirement of high porosity:

$$P > 70\ \%.$$

These parameters should predetermine the use of the material in the insulation of building structures associated with the remediation of moisture.

II. TEST MIXTURES AND PRODUCTION OF TEST SAMPLES

During the development of thermal insulation plasters using metakaolin and finely ground fly ash was proposed a total of 6 test mixtures. The basis of all test batches were lightweight porous aggregate based on expanded volcanic glass obsidian and hydrated lime. The quantity of hydraulic/latent hydraulic binder was chosen uniformly 50 kg per 1 m^3 test mixes [6], [7].

The individual test mixtures were designed in order to monitor the influence of the type and quantity of binder used

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on the final properties developed materials in hardened state. Water was dosed individually for every batch in such a manner as to achieve consistency flow value according to EN 1015-3 in the range 140–150 mm. Composition individual recipes, including dosing sub-components per 1 m^3 of mixture was as follows:

- *Mixture 1 (reference)*: 97.4 kg lightweight aggregate, 150 kg lime hydrate, 50 kg cement, aeration and other additives in a total amount 1.65 kg, 330 kg water;
- *Mixture 2:* 97.4 kg lightweight aggregate, 150 kg lime hydrate, 50 kg fly ash, aeration and other additives in a total amount 1.65 kg, 373 kg water;
- *Mixture 3:* 97.4 kg lightweight aggregate, 150 kg lime hydrate, 50 kg alternative binders- metakaolin and fly ash in the ratio 1:3, aeration and other additives in a total amount 1.65 kg, 353 kg water;
- *Mixture 4:* 97.4 kg lightweight aggregate, 150 kg lime hydrate, 50 kg alternative binders- metakaolin and fly ash in the ratio 3:1, aeration and other additives in a total amount 1.65 kg, 360 kg water;
- *Mixture 5:* 97.4 kg lightweight aggregate, 150 kg lime hydrate, 50 kg metakaolin, aeration and other additives in a total amount 1.65 kg, 425 kg water;
- *Mixture 6:* 97.4 kg lightweight aggregate, 150 kg lime hydrate, 50 kg alternative binders- metakaolin and fly ash in the ratio 1:1, aeration and other additives in a total amount 1.65 kg, 375 kg water.

Fig. 1 Demonstration aggregates derived from volcanic glass

Production of test specimens for the determination of the monitored parameters was carried out with the aid of Filamos M50 mixer with forced circulation, the total volume of trial mixes were chosen optimally to the type of mixer used was a 15 l. In all cases was carried out immediately after mixing, the determination of the properties of the fresh mortar.

Of the test mixtures were prepared test specimens the following forms:

- Cuboids: 40 mm x 40 mm x 160 mm - for the determination of mechanical properties, density, thermal conductivity and absorption capillary coefficient;
- Plates: 300 mm x 300 mm x 50 mm - for the determination of the thermal conductivity at steady state.

Fig. 2 Part of the test forms filled after mixing

III. RESULTS OF TEST MEASUREMENTS

The test samples were assayed for physical and rheological properties in the fresh state:

- Determination of bulk density of fresh mortar (according to EN 1015-6) [8],
- Determination of consistence of fresh mortar (according to EN 1015-3) [9],

The results of measurements of properties in fresh state are given in the following Table I.

TABLE I
OVERVIEW OF TEST MIXTURES PROPERTIES IN FRESH STATE

Mixture	Flow value [mm]	Bulk density [kg.m^{-3}]
1	140	820
2	140	859
3	140	820
4	140	771
5	140	810
6	140	700

From the survey of test mixtures and the values listed in Table I, it is apparent that due to the increased specific surface area in metakaolin is required, in the case of mixture 5 with metakaolin, a higher amount of water to achieve the same consistency than the other mixtures, where it was used cement, fly ash or a combination of fly ash and metakaolin.

Further, it was conducted to determine the physical and mechanical properties in the hardened state. They were:

- Determination of bulk density of hardened mortar (according to EN 1015-10) [10],
- Determination of mechanical properties of hardened mortar (according to EN 1015-11) [11],
- Determination of thermal conductivity by stationary plate method (according to EN 12667 and ISO 8301) [12],
- Determination of capillary absorption coefficient of hardened mortar (according to EN 1015-18) [13].

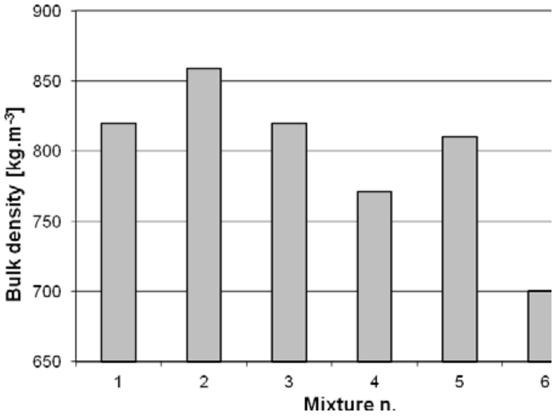

Fig. 3 Overview of bulk density in fresh state

Fig. 4 Apparatus for determine of mechanical and thermal insulating properties

The results of measurements and tests carried out on test specimens of hardened state are given in Table II.

TABLE II
PROPERTIES OF TEST MIXTURES IN HARDENED STATE

Mixture	1	2	3	4	5	6
Bulk density of hardened mortar after 28 days [kg.m^{-3}]						
	406	427	391	358	369	334
Thermal conductivity in dry state [W.m^{-1}.K^{-1}]						
	0.0921	0.0879	0.0848	0.0750	0.0883	0.0824
Flexural strength after 28 days[N.mm^{-2}]						
	0.31	0.54	0.47	0.52	0.34	0.24
Compressive strength after 28 days[N.mm^{-2}]						
	0.37	0.94	0.85	1.10	0.80	0.56
Capillary absorption coefficient [kg.m^{-2}]						
	31.17	26.04	29.55	30.68	19.03	23.92

As seen from the measured values, test mixtures exhibited for identical quantities of the hydraulic/latent hydraulic binder significantly different mechanical properties. Featured properties showed mixture 5, where it was used as a binder metakaolin. The worst characteristics showed recipe no. 2 with the addition of fly ash.

The measured values were evaluated and have been verified depending on the thermal insulation properties of density and amount of modal binders.

Between density and thermal conductivity have been demonstrated weak correlation (correlation coefficient 0.62) while increasing density increased too thermal conductivity for test mixtures.

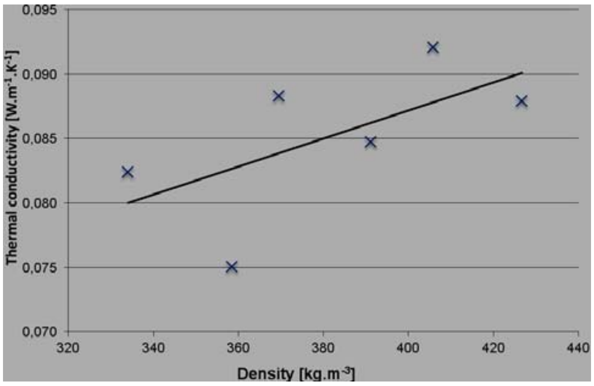

Fig. 5 Dependence of thermal conductivity in dry state on bulk density

Further, was also verified dependence of the compressive strength after 28 days on density. In Fig. 6 is further captured dependence of the compressive strength on the amount of binder (separately for each species binders). In this case, however, is not established between these properties is no correlation.

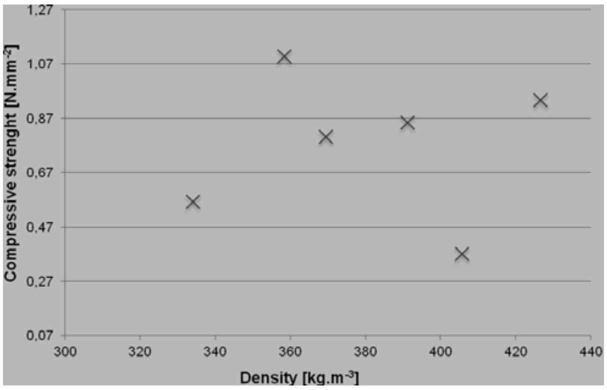

Fig. 6 Dependence of compressive strength on bulk density

For comparison, the properties of the individual recipe was chosen ratio of thermal insulation and mechanical properties $c_{fc/\lambda.}$[s.K.mm^{-2}]. Calculated values for the ratio of mechanical and heat insulating properties are shown in Table III.

TABLE III
OVERVIEW OF VALUES OF $c_{FC/\lambda}$ OF TEST MIXTURES

Mixture	$c_{fc/\lambda}$ [s.K.mm^{-2}]
1	4.0
2	10.7
3	10.1
4	14.6
5	9.1
6	6.8

From the viewpoint of thermal insulation and mechanical properties therefore appear as the best mixture no. 4, where it was used metakaolin and ash, in a ratio of 3:1.

IV. CONCLUSION

Based on the measurements it was found that the thermal insulating plaster mixtures based on lightweight aggregates of volcanic glass and hydrated lime show a very good ratio of thermal insulation and mechanical properties, especially when the binder used as metakaolin or fly ash (or combination both).

In the case of the use of fly ash was shown that is suitable alternative substitute for metakaolin, wherein as the most suitable, on the basis of measurements, appears partial substitute of metakaolin ash, in a ratio of 3:1.

We can conclude that the developed materials have very good properties, which predetermine their use in the area of rehabilitation of historic buildings. In this case, the materials were developed internally hydrophobic, which is evident from the measured values of the capillary absorption coefficient listed in Table II. If the developed materials should be used as the plaster remediation, according to specification WTA, it would be necessary to reduce the capillary activity renders appropriate waterproofing additives and uses a higher amount of binder to achieve the desired compressive strength of 1.5 N.mm^{-2}.

Due to the high open porosity and low density materials are developed plasters without any further adjustments significant potential for the remediation and insulation building structures.

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