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Development of Thermal Insulation Materials Based On Silicate Using Non-Traditional Binders and Fillers

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Abstract**—**When insulation and rehabilitation of structures is important to use quality building materials with high utility value. One potentially interesting and promising groups of construction materials in this area are advanced, thermally insulating plaster silicate based. With the present trend reduction of energy consumption of building structures and reducing CO_2 emissions to be developed capillary-active materials that are characterized by their low density, low thermal conductivity while maintaining good mechanical properties.

The paper describes the results of research activities aimed at the development of thermal insulating and rehabilitation material ongoing at the Technical University in Brno, Faculty of Civil Engineering. The achieved results of this development will be the basis for subsequent experimental analysis of the influence of thermal and moisture loads developed on these materials.

Keywords**—**Insulation materials, rehabilitation materials, lightweight aggregate, fly ash, slag, hemp fibers, glass fibers, metakaolin.

I. Introduction

REDUCTION of energetic demands of current and new structures is crucial from the point of environment and sustainable development. Currently, this problem is especially important with respect to negative aspects of global warming and the European Parliament and Council directive 2010/21/EU (which is implemented in their national laws and regulations of the various states of the EU), further, Energy Climate package „20-20-20“, adopted by European Parliament and Council in 2008, legalized in June 2009.

Paper is devoted of development of advanced silicate materials (plasters), which are currently increasingly demanded for renovation of external cladding of building constructions or solution of inner insulation of buildings.

II. Draft of Test Mixtures

Based on the literature search and the experience gained from previously conducted research work in the development of silicate, thermal insulation plaster was designed to test a total of 10 recipes using both classical and alternative binders and fillers [1]-[6].

Individual test recipe of thermal insulation and renovation plasters were composed of the following components:

- *Lightweight aggregate* based on foam glass: fractions 1-2, 0.5-1, 0.25-0.5 mm,
- *Expanded perlite* EP-150, fraction 0.315-2.5,
- *Lime hydrate* DL 80-S,
- *Finely ground limestone* 7/V,
- *Cement* CEM I 42.5 R,
- *Blast furnace finely ground granulated slag*,
- *Metakaolin* Mephisto K05,
- *Activated power plant fly ash*,
- *Chemical additives* and *chemical admixtures* (methylceluloze, polymer dispersions and aeration additive),
- *Water* from the water supply system,
- *Hemp fibres CANABEST*,
- *Glass fibres* Cem-FIL, Anti-Crack HD, OCV Reinforcements.

The detailed composition is given in Table I.

TABLE I
COMPOSITION OF TESTING MIXTURES AT 100 KG DRY MIX [IN KG]

Mixture	1	2	3	4	5
Aggregate 0.25-0.5	3.37	-	3.37	2.71	3.37
Aggregate 0.5-1	23.58	23.58	23.58	22.86	23.58
Aggregate 1-2	38.63	38.63	38.63	37.87	38.63
Perlite 0.315-2.5	-	3.37	-	2.14	-
Lime hydrate	3.25	3.25	3.25	6.29	3.25
Limestone	13.48	13.48	13.48	13.49	13.48
CEM I 42.5 R	15.73	15.73	-	8.46	-
Metakaolin	-	-	15.73	4.23	-
Fly ash	-	-	-	-	15.73
Additive	1.96	1.96	1.96	1.96	1.96
Water	52.18	37.25	67.20	44.29	47.44
Mixture	**6**	**7**	**8**	**9**	**10**
Aggregate 0.25-0.5	2.71	3.37	2.97	2.75	2.73
Aggregate 0.5-1	22.86	23.58	23.59	22.46	22.30
Aggregate 1-2	37.87	38.63	38.55	37.70	38.14
Perlite 0.315-2.5	2.14	-	3.19	2.17	2.16
Lime hydrate	9.49	3.25	10.14	6.38	6.33
Limestone	13.49	13.48	13.77	13.68	13.58
CEM I 42.5 R	4.74	-	-	-	-
Slag	-	15.73	5.80	12.87	12.78
Fly ash	4.74	-	-	-	-
Additive	1.96	1.96	1.99	1.99	1.97
Water	45.36	46.53	48.55	44.57	42.45
Hemp fibres	-	-	1.45	1.45	-
Glass fibres	-	-	-	-	0.72

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Mixture 1 was reported as a reference. For recipe 2 was the finest fraction of lightweight aggregate replaced Perlite fraction of 0.315 to 2.5. In test mixtures 3, 5 and 7 were used alternative binders, as a substitute for cement, in particular they were metakaolin, fly ash and finely ground slag. On the basis of the initially detected results, particularly the mechanical properties were designed test formulas 4 and 6, wherein the alternative binders supplemented cement in recipe 4 was a ratio metakaolin: cement 1:2, for formulation 6 was the proportion of fly ash and cement 1:1. Recipes 8, 9 and 10 were designed to determine the effects of cannabis and fiberglass particular mechanical but also thermal insulation properties. Water was dosed individually to the desired flow value 140 mm. [7]-[9]

III. Determination of Properties of Mortars in Fresh State

When preparing test samples were each successively dosed ingredients. In the first phase were mixed dry ingredients and then was added to the first batch mixing water, which corresponded to 90 % of the expected amount of water, followed by stirring. After maturing min. 180 seconds was performed determining consistency and treated with a second dose of water that has been chosen with regard to the desired consistency (flow value 140 mm) and the batches were vortexed again.

The testing mixtures were set properties in the fresh state. These were:

- Determination of bulk density of fresh mortar (according to EN 1015-6),
- Determination of consistence of fresh mortar (according to EN 1015-3),
- Determination of air content of fresh mortar (according to EN 1015-7).

The results of measurements of properties in fresh state are given in the following Table II [9], [10]:

TABLE II
Overview of Test Mixtures Properties in Fresh State

Mixture	Flow value [mm]	Bulk density [kg.m^{-3}]	Content of air [%]
1	140	570	40
2	140	518	31
3	140	576	29
4	140	550	37
5	140	540	35
6	140	580	36
7	140	534	24
8	120	530	34
9	140	520	40
10	140	530	39

As is evident from the results, the highest density of fresh samples showed mixture 6 (cement:fly ash = 1:1) and mixture 3 with metakaolin. Air content in fresh mortar move at all test samples in the range of 24-40%.

Fig. 1 Determination of Flow value

Then testing samples were prepared for testing of physical, mechanical and thermal insulating properties:

- 18 blocks with dimensions of 40 mm x 40 mm x 160 mm,
- 3 plates with dimensions of 300 mm x 300 mm x 50 mm.

IV. Determination of Properties of Mortars in Hardened State

Samples were hardened after demoulding, stored in a laboratory environment at 21 ± 2°C and relative humidity of 45 ± 5%. The test samples were in regular intervals 14 and 28 days made the determination of selected physical and mechanical properties. [11]-[14] The test specimens were hardened state, the following tests and measurements:

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

The results of these properties are given in the following tables and figures.

TABLE III
Overview of Test Mixtures Bulk Density in Hardened State

Mixture	1	2	3	4	5	6	7	8	9	10
Bulk density of hardened mortar [kg.m^{-3}]										
- 14 days	445	416	409	400	385	419	353	386	366	398
- 28 days	432	396	379	394	354	404	338	372	363	386

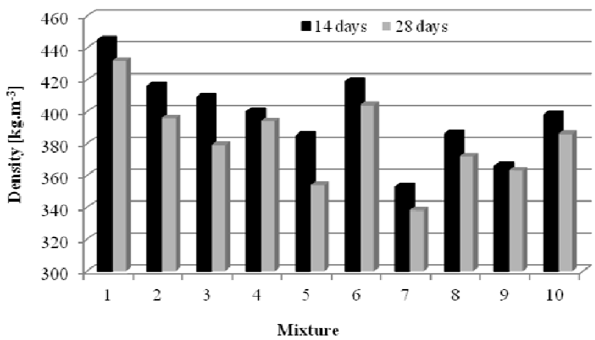

Fig. 2 Overview of bulk density in hardened state

As can be seen from the measured values of bulk density (in 28 days) of the mixtures ranged from 338 to 432 kg.m^{-3}. The using of alternative binders with a high specific surface area was in all cases to reduce the density.

In the next step, it was made determination of thermal insulating properties of the test samples. Measurements of thermal conductivity were performed using stationary plate method in accordance with ISO 8301 for mean temperature +10°C and a temperature gradient of 10 K.

Fig. 3 Apparatus Holometrix 2300 for determination of thermal conductivity

TABLE IV
OVERVIEW OF TEST MIXTURES THERMAL CONDUCTIVITY

Mixture	Thermal conductivity [W.m^{-1}.K^{-1}] in 14 days	in 28 days	In dried state
1	0.1005	0.0955	0.0943
2	0.1176	0.1046	0.0996
3	0.1343	0.0920	0.0837
4	0.1042	0.0984	0.0962
5	0.1046	0.0983	0.0895
6	0.1109	0.1080	0.0944
7	0.0920	0.0929	0.0845
8	0.1167	0.0985	0.0820
9	0.0919	0.0910	0.0877
10	0.0947	0.0916	0.0944

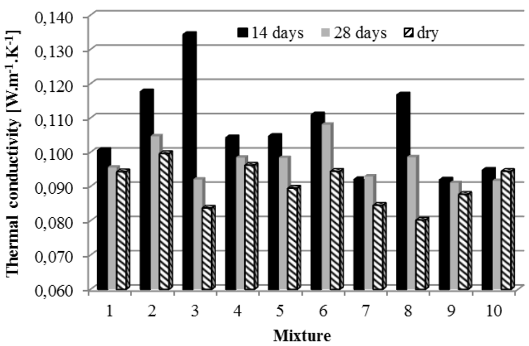

Fig. 4 Overview of values of thermal conductivity

In determination of thermal conductivity for the test mixtures, it was found that replacing cement with alternative binders to improve thermal properties of all specimens. The lowest value of thermal conductivity in dried state was determinated by mixture 8 with hemp fibres.

In the next stage, it was made determination of the mechanical properties (flexural strength and compressive strength at times 14 and 28 days) of the test mixtures. The results are given in the following tables and figures.

TABLE V
OVERVIEW OF TEST MIXTURES MECHANICAL PROPERTIES

Mixture	Flexural strength [N.mm^{-2}] 14 days	Flexural strength 28 days	Compressive strength [N.mm^{-2}] 14 days	Compressive strength 28 days
1	0.76	0.99	1.49	2.27
2	0.54	0.59	1.11	1.25
3	0.22	0.26	0.31	0.37
4	0.63	0.67	1.62	1.67
5	0.30	0.23	0.38	0.23
6	0.44	0.80	0.90	1.59
7	0.18	0.25	0.14	0.10
8	0.47	0.53	0.75	0.88
9	0.52	0.56	0.63	0.67
10	0.57	0.65	0.93	1.00

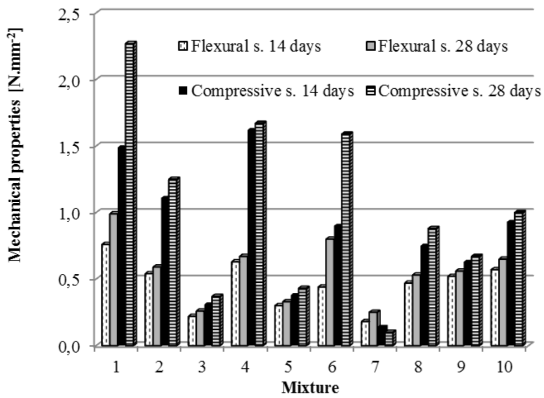

Fig. 5 Overview of results of mechanical properties at times 14 and 28 days

As can be seen from the measured values for all mixtures with an alternative binder deteriorated mechanical properties, in both flexural strength and compressive strength with too. Values of flexural strength (at time 28 days) of the testing mixtures ranged from 0.23 to 0.99 N.mm^{-2}. Values of compressive strength (at time 28 days) of the testing mixtures ranged from 0.10 to 2.27 N.mm^{-2}.

To improve the mechanical properties has been increasing the dose of hydrated lime at the expense of alternative latent hydraulic binder.

Capillary absorption coefficients were determinated at the end of experimental works. Measurements were performed according to the methodology for both classical and for restoration plasters.

TABLE VI
OVERVIEW OF CAPILLARY ABSORPTION COEFFICIENT VALUES

Mixture	1	2	3	4	5	6	7	8	9	10
Capillary absorption coefficient [Classic - kg.m^{-2}.min$^{-0.5}$;Restoration - kg.m^{-2}]										
Classic	0.15	0.45	0.78	0.23	0.37	0.12	0.81	0.09	0.07	0.18
Restoration	5.42	7.40	19.5	5.76	9.40	3.76	15.0	2.05	3.25	5.09

Alternative substitute for cement binders were in many cases an increase in the coefficient of capillary absorption. The largest increase occurred in the case of mixture 3 containing metakaolin.

V. Conclusion

The aim of the development of thermal insulation plasters - based on lightweight aggregate, which could be used for the maintenance and insulation of buildings, was to find the optimum recipe of capillary-active in achieving the best possible balance between thermal insulation and mechanical properties. With this development renders were chosen other alternatives binders (metakaolin, finely ground slag, fly ash) than is currently the most widely used binder - Portland cement because of not only economic but also in terms of environmental friendliness .

Based on the results of measurements on samples of the proposed formulas developed plasters can be concluded that the use of alternative binders in comparison with the reference one recipe a decrease in the volume weight of the mortar in the hardened condition and also to improve the thermal insulation properties. The lowest values of thermal conductivity in the dry state were achieved in 8 recipes (0.0802 $W.m^{-1}.K^{-1}$), 3 (0.0837 $W.m^{-1}.K^{-1}$), 7 (0.0845 $W.m^{-1}.K^{-1}$). Unfortunately, almost all recipes, except the recipe 4, worsening of mechanical properties, which is closely associated with a reduction in the bulk density. Mixture 4, which was used as an alternative metakaolin binder ratio of cement: Metakaolin was equal to 2:1, had very good mechanical properties after 28 days, when the flexural strength of the hardened mortar was 0.67 $N.mm^{-2}$ and a compressive strength of 1.67 $N.mm^{-2}$. Use of fibers in order to improve the mechanical and thermal insulation properties, either hemp or glass, did not contribute to a significant increase of the mechanical properties. In formulas 8 and 9, however, were achieved good heat insulating properties when the thermal conductivity in the dry state was lower as 0.900 $W.m^{-1}.K^{-1}$ compared to a reference recipe.

In the present case it was found that mixtures 2, 3, 5, 7 developed strongly absorbing and capillary-active, it can be assumed their excellent performance in conjunction with capillary active internal thermal insulation system. Developed insulating plaster can be used for example for insulation lining the windows or to create transitions between insulated and uninsulated parts of the structure.

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