

Jana BOHÁČOVÁ¹, Martin VAVRO², Stanislav STANĚK³**PROPERTIES OF THERMAL INSULATING ALKALI ACTIVATED SYSTEM
RESEARCH AND DEVELOPMENT****VÝVOJ A VÝZKUM VLASTNOSTÍ TEPELNĚ IZOLAČNÍCH ALKALICKY
AKTIVOVANÝCH SYSTÉMŮ****Abstract**

The paper deals with laboratory research and development of alkali activated system with thermal insulation properties, where, such as additive, low density materials are used. The experiment is focused on strength and heat conductivity of prepared substances.

In research five kinds of mixtures were prepared. The values of compressive strength and thermal conductivity of tested admixtures qualitatively correspond to commercially available building material. Results are foundations for next lightweight alkali activated system development and research focused on practical application in building.

Keywords

Lightweight alkali activated system, thermal insulating materials, blast furnace slag, activated water glass, expanded perlite, ekostyren, Liapor, expanded vermiculite.

Abstrakt

Príspevek sa zaoberá laboratorným výzkumom a vývojom alkalicky aktivovaných systémů s tepelně izolačními vlastnostmi, ve kterých je jako plnivo použit materiál s nízkou objemovou hmotností. Experiment je zaměřen na pevnosti a tepelnou vodivost vytvořených hmot.

V rámci výzkumu bylo připraveno pět druhů záměsí. Hodnoty pevnosti v tlaku a součinitele tepelné vodivosti u zkoumaných receptur kvalitativně korespondují s komerčně dostupnými stavebninami. Výsledky jsou základem pro další výzkum a vývoj lehčených alkalicky aktivovaných systémů se zaměřením na praktické využití ve výstavbě.

Klíčová slova

Lehčené alkalicky aktivované systémy, tepelně izolační materiály, vysokopecní granulovaná struska, aktivované vodní sklo, expandovaný perlit, ekostyren, Liapor, expandovaný vermikulit.

¹ Ing. Jana Boháčová, Department of building materials and mining engineering, Faculty of Civil Engineering, VŠB-Technical University of Ostrava, Ludvíka Podéště 1875/17, 708 33 Ostrava - Poruba, phone: (+420) 597 321 968, e-mail: jana.bohacova@vsb.cz.

² Ing. Martin Vavro, Ph.D., Department of building materials and mining engineering, Faculty of Civil Engineering, VŠB-Technical University of Ostrava, Ludvíka Podéště 1875/17, 708 33 Ostrava - Poruba, phone: (+420) 597 321 382, e-mail: martin.vavro@vsb.cz.

³ Ing. Stanislav Staněk, Department of building materials and mining engineering, Faculty of Civil Engineering, VŠB-Technical University of Ostrava, Ludvíka Podéště 1875/17, 708 33 Ostrava - Poruba, phone: (+420) 597 321 968, e-mail: stanislav.stanek.st@vsb.cz.

1 INTRODUCTION

Current development in energy prices and also increasing demands on environmental performance of buildings, force each of us to choose the construction of building, or use in building reconstruction materials and systems, that the heat loss during its use was minimal.

In today's building market we can find a wide range of thermal insulation materials, which are vary in design, depending on properties of their location. Thermal insulation of buildings is performed in five ways, contact system, a system of sandwich walls, ventilated thermal insulating system, using of thermal insulating plaster, or the use of thermal insulating walls [8].

The best insulating materials, whose thermal conductivity ranges from 0,02 to 0,09 W.m⁻¹.K⁻¹, are mainly used in contact or sandwich system, these materials are anchored to the main load-bearing part of the structure. Among the most commonly used insulating materials in this group ranges expanded polystyrene, mineral wool and foam glass [8]. The advantage of these materials is easy workability and formability. Disadvantages are low resistance to mechanical damage, high demands for quality design and also decreased resistance to external influences, or flammability [7].

For insulating of ventilated insulation system, when the insulator is mounted on the carrier structure in free space behind the visual wall, are most commonly used polyurethanes, wool, or cellulose products. The disadvantage of this solution is high cost [7, 8].

In case of insulation with insulating plaster is used so-called thermal-plaster, that in addition to conventional components include insulating particles, mostly expanded perlite and polystyrene. These are used mainly for insulation of complicated facades of historic buildings [8]. The disadvantages are worse thermal insulation properties, surface treatment demands and occasion to follow exactly the technological process of prepared mixture.

Last eventuality of thermal protection is use of structure, that is itself a thermally insulating material. This widely used construction method mainly uses aerated concrete blocks and hollow brick blocks. The advantage of these systems is speed and simplicity of masonry, the disadvantage is low compressive strength and low heat accumulation, worse noise insulating properties and high water absorption [12].

In all mentioned systems is the base of the structure made of traditional building materials, mostly clay bricks, brick blocks and cement-based blocks. Production of these building materials significantly burdens the environment, particularly energy-intensive of firing. A suitable alternative to these materials are alkali-activated systems, also known as geopolymers. These are products of the geopolymerization, that is controlled process of polycondensation of suitable particles. This creates zeolites, alkaline aluminosilicates, aluminosilicates alkaline earth metals, that are highly steady and resistant to external environmental influences and achieve excellent strength parameters [5].

The scope of the research was the development of thermally insulating material based on alkali-activated blast furnace slag, that would suit as strength as thermal insulation properties requirements for use in construction.

2 MATERIALS

In experiment, as feedstock for alkaline activation were used granulated blast furnace slag, water glass and sodium hydroxide. Based on previously conducted studies [1, 2] water glass and 50% NaOH solution were used for activator preparation, activator mixed with blast furnace slag in optimal ratio forms geopolymer.

As a filler with thermal insulating properties for experiment expanded perlite, expanded vermiculite, Liapor and ekostyren were selected.

2.1 Expanded perlite

Expanded perlite (experlite) is a lightweight, granular material, produced by thermal modification of raw perlite. Perlite, acid rock of volcanic origin, is essentially amorphous aluminum silicate, in comparison with other volcanic glasses has different amounts of chemically bound water. During heat treatment at temperatures 900 - 1300°C leads to expansion of perlite, white hollow spheres of various sizes are formed and increase in the volume of the original rock is about five times. Expanded perlite has excellent thermal and noise insulation properties, is nonflammable, nontoxic, chemically inert. Volume is steady, material has excellent sorption properties and very low density, in range from 70 to 100 kg.m⁻³ [4, 11].

In the experiment experlite EP 180 in grain size 0-2 mm, density of 95 kg.m⁻³, and coefficient of thermal conductivity of 0,049 W.m⁻¹.K⁻¹ was used.

2.2 Expanded vermiculite

Expanded vermiculite is made of hydrated laminar magnesium-aluminum-iron silicate, vermiculite. Exposed to temperatures around 1000°C leads to expansion of scales due to conversion of interlaminar water in vapor and to subsequent eight to twenty times enlarge of original volume. Density of resulted material ranges from 60 to 200 kg.m⁻³. Expanded vermiculite is absorbent, has low thermal conductivity, is fireproof, resistant to microorganisms and molds [4].

In the experiment expanded vermiculite in grain size 1,4 - 6 mm, density of 80 kg.m⁻³ and the coefficient of heat conductivity of 0,065 W.m⁻¹.K⁻¹ was used.

2.3 Liapor

Liapor is a lightweight aggregate of spherical shape, arised by expansion of natural clay. The process takes place in rotary kilns at temperatures from 1100 to 1200°C. Final product is almost spherical grained, has uniform internal structure and closed surface. Liapor amongs to ceramic aggregates, its major advantage is minimal water absorption, durability, safety, excellent thermal insulation and low density that depends on fraction and ranges from 300 to 500 kg. m⁻³ [9].

In experiment were used three different aggregate fractions of Liapor see Tab. 1.

Tab. 1: Properties of the aggregate Liapor [10]

Material name	Fraction [mm]	Density [kg.m ⁻³]	Coefficient of heat conductivity [W.m ⁻¹ .K ⁻¹]
Liapor 1-4/500	0/4	500	0,11
Liapor 4-8/450	4/8	450	0,11
Liapor 8-16/275	8/16	275	0,09

2.4 Ekostyren

Ekostyren is a specially modified polystyrene chippings. Ekostyren is only minimally porous, well resistant to acids and alkaline solutions, is volume steady and has low density, that is around 30 kg.m⁻³ [6].

In the experiment ekostyren with density of 30 kg.m⁻³ and thermal conductivity coefficient of 0,035 W.m⁻¹.K⁻¹ was used.

3 MATERIALS PREPARATION

Alkali-activated systems are currently widely studied among groups of materials. In construction practice geopolymers are not almost used and there are no standards for testing. Therefore, all specimens were prepared and subsequently tested according to standards for testing of cements and mortars.

Because of the significant differences in used fillers (different water absorption, granulometry, density) was already at the beginning of the research clear, that is not possible to unify all the mixtures under any of the parameters, so they cannot be on the basis of the results compared among themselves. Therefore, the aim of this experiment was to find for each of the materials ideal ratio between the binder and filler component, to obtain the best balance between strength parameters and the thermal insulating properties, with regard to the workability for eventual industrial use.

As the basis for preparation of batch has been used tested recipe of alkali-activated granulated blast furnace slag (GVS), where was as a filler standard sand used. The composition of the reference mixture is shown in Tab. 2 [2].

Tab. 2: The composition of the reference mixture

Material	GVS [g]	Activator [ml]	Water [g]	Standard sand [g]
Quantity	450	118,6	90	1350

In the first phase of the experiment batches by reference mixture were prepared. Filler was due to its low density dosed by volume. Based on measurements it was found that 1350g of standard sand corresponds to the reference volume of 800ml. Consequently, mixtures were prepared containing always 800ml of thermally insulating material such as filler, GVS and activator according to the reference batch, and we measured the amount of water needed for proper workability of mixtures.

During the experimental work was number of individual ingredients adjusted according to specified requirements. Based on comparison of results of strength parameters, consistency and workability of the mixtures, the extent given of research are purposely not mentioned, was selected for further tests in total five mixtures. For each of lightweight materials was selected one batch, with the exception of Liapor. Two different mixtures with Liapor were prepared, a mixture containing only filler fraction 4/8 and another one, consisted of fractions 1/4 and 8/16 in volume ratio of 40:60.

The final composition of mixtures are listed in Tab. 3.

Tab. 3: Composition of mixtures

Sample	GVS [g]	Activator [ml]	Water [g]	Filler volume [ml]
Liapor 4/8	450	118,6	80	1300
Liapor 1/4+8/16	300	79,0	50	400 + 600
Vermiculite	585	154,0	300	1300
Experlite	585	154,0	220	1300
Ekostyren	450	118,6	90	800

For mechanical properties testing of these mixtures were prepared specimens with dimensions (160 x 40 x 40) mm. Samples were put in the wet cabinet and after 7 and 28 days of ripening in moist conditions were for compressive strengths tested according to ČSN EN 196-1 [3]. Flexural strengths were not investigated. For all batches density in wet and in dry condition were determined. Determination of thermal conductivity coefficient was done.

4 TEST RESULTS

Tests of compressive strength after 7 and 28 days of ripening were always performed on six specimens, arithmetic average of obtained values was measured. Also density of wet and dry samples was determined. The results are shown in Tab. 4. Graphical representation of strength increase is in Fig. 1.

Tab. 4: Compressive strengths after 7 and 28 days and the average density

Sample	Compressive strengths after 7 days [MPa]	Compressive strengths after 28 days [MPa]	Density wet sample [kg.m ⁻³]	Density dry sample [kg.m ⁻³]
Liapor 4/8	13,3	23,4	1250	1150
Liapor 1/4+8/16	3,3	7,1	860	810
Vermiculite	5,9	17,1	1570	1130
Experlite	20,3	21,7	1380	1070
Ekostyren	5,5	5,5	880	840

The results show that the highest compressive strength after 28 days was achieved for samples with Liapor 4/8 and experlite, where average values ranged above 20 MPa. In case of sample with ekostyren strength after 7 days did not increase. Compressive strengths of all proposed mixtures after 28 days are comparable to commercially available thermal insulating structural elements type of aerated concrete blocks.

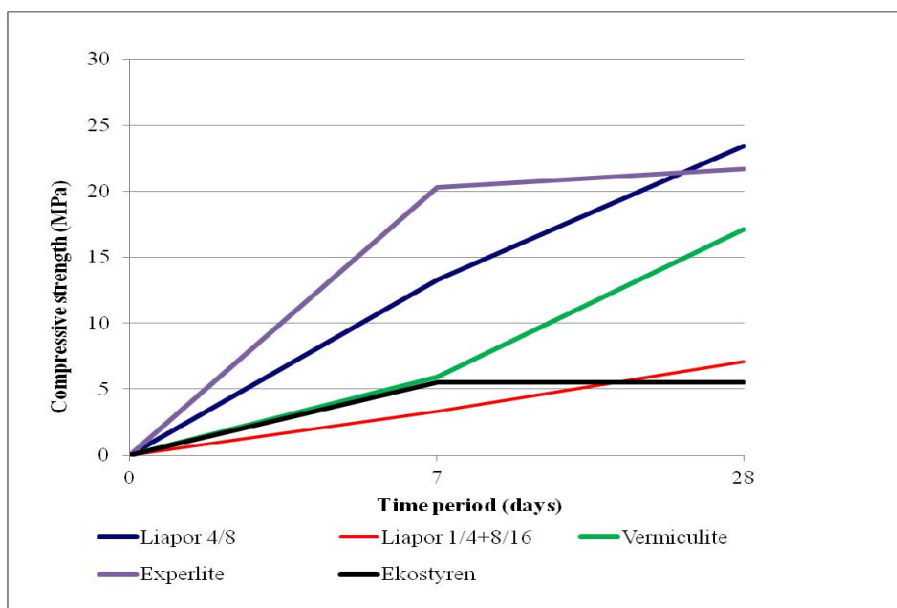


Fig. 1: Graphical representation of compressive strength increase

As a result of drying of the specimens was the greatest decrease of density values identified with samples containing highly absorbing fillers, namely batch of vermiculite and experlite. The lowest density was found in a mixture with Liapor 1/4 + 8/16 and ekostyren see Fig. 2.

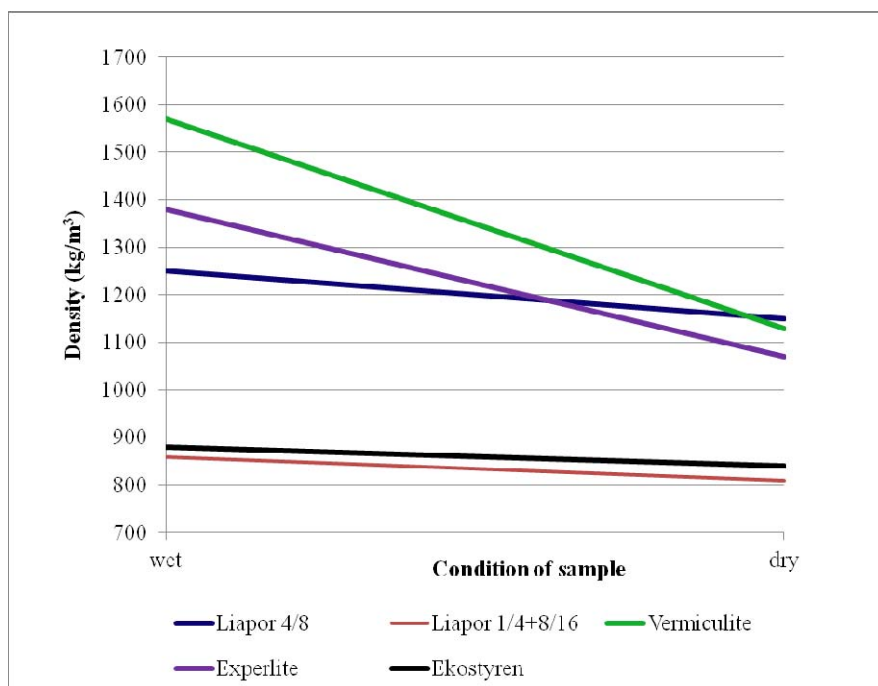


Fig. 2: Density decrease after drying of samples

The most important step of this research was to verify the thermal insulation properties of created materials, namely the thermal conductivity (λ). For this purpose a specially test specimens were prepared, and these samples were put in the wet cabinet and for 28 days. Subsequently samples were dried at 105°C, the surface was smoothed and then thermal conductivity coefficient was measured. This parameter was determined at the Department of geomaterials research laboratory of the Institute of Geonics AV ČR, v.v.i. in Ostrava. Measurements were performed by ISOMET 2104, by Mrs. Anežka Dušková. For each sample five individual measurements were performed, arithmetic average was calculated out of obtained values. The results are given in Tab. 5.

Tab. 5: Thermal conductivity of test specimens

Sample	Liapor 4/8	Liapor 1/4 + 8/16	Vermiculite	Experlite	Ekostyren
λ [W.m ⁻¹ .K ⁻¹]	0,237	0,165	0,306	0,219	0,123

λ values for all the batches ranged from 0,1 to 0,3 W.m⁻¹.K⁻¹, that ranks prepared mixtures among the materials with good thermal insulation properties, a mixture of ekostyren even approaches a group of highly thermally insulating material (in λ ranging from 0,03 to 0,1 W.m⁻¹.K⁻¹).

Fig. 3-12 show specimen prepared for thermal conductivity determination. On the left there is always a wet specimen, on the right there is a dry sample after surface treatment.



Fig. 3 and 4: Look of samples filled with Liapor 4/8



Fig. 5 and 6: Look of samples filled with Liapor 1/4 + 8/16



Fig. 7 and 8: Look of samples filled with vermiculite



Fig. 9 and 10: Look of samples filled with experlite



Fig. 11 and 12: Look of samples filled with ekostyren

5 CONCLUSION

Results of laboratory tests show that alternative binders may very well be applied in production of heat-insulating building materials.

Alkali-activated slag achieve above-average strength parameters, geopolymers are resistant to aggressive substances, frost resistant, fireproof and excellent compactibility, rapidly solidify and harden, so it is ideal system for usage in production of prefabricated building materials [1, 2].

Using lightweight aggregate in these systems were prepared materials with low thermal conductivity. Reduction of density leads to deterioration of strength properties, due to use of alkali-activated slag are strengths in comparison with commercial products sufficient. Currently selected mixtures are durability tested, frost resistance and salt and de-icing agents resistance is determined.

In conclusion, we have to say that the possibility of lightening of the material has not yet been exhausted and in further research it is possible to reduce density due to higher share of filler, and to enhance thermal insulation properties.

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Reviewers:

Ing. Vlasta Ondrejka Harbuláková, PhD., Department of Environmental Engineering, Faculty of Civil Engineering, Technical University of Košice.

Doc. Ing. Jiří Brožovský, CSc., Department of building materials and components, Faculty of Civil Engineering, Brno University of Technology.