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ALKALI-ACTIVATED BUILDING MATERIALS BASED ON BLAST FURNACE SLAG AND NON-STANDARD AGGREGATES

ALKALICKY AKTIVOVANÉ STAVEBNÍ HMOTY NA BÁZI VYSOKOPECNÍ STRUSKY A NESTANDARDNÍHO KAMENIVA

Abstract

This paper deals with alkali activated materials based on fine grained granulated blast furnace slag. Waste aggregates from building materials and building demolition are used as the filler. Its mechanical and durability parameters are tested. Results may contribute to further alkali activated system development and research focused on practical applications in the building industry.

Keywords

Alkali activated materials, blast furnace slag, waste materials, physical and mechanical properties of building materials.

Abstrakt

Příspěvek se zabývá alkalicky aktivovanými materiály na bázi jemně mleté granulované vysokopecní strusky. Současně jsou v těchto hmotách jako plnivo použity odpadní suroviny jak z výroby a úpravy stavebních surovin a hmot, tak také z oblasti demolic staveb. Vytvořený materiál je testován na mechanické a trvanlivostní parametry. Výsledky mohou přispět k dalšímu výzkumu a vývoji alkalicky aktivovaných systémů se zaměřením na praktické využití ve stavebnictví.

Klíčová slova

Alkalicky aktivované materiály, granulovaná vysokopecní struska, odpadní suroviny, fyzikální a mechanické vlastnosti stavebních hmot.

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1 INTRODUCTION

Alkali activated materials, or geopolymers represent a specific group of inorganic cement-free materials. Geopolymers are created by the reaction of latent hydraulic substances or pozzolana (granulated slag, fly ash, metakaolin) with a suitable activator. Soluble compounds of alkali metals, especially sodium and potassium, in particular carbonates, hydroxides or silicates can be used as activators [6]. The product of this activation is a hydraulic binder and, with added water, is suitable for creating composite materials with excellent utility properties [7]. Alkali activated materials can practically serve as alternatives to conventional building materials, particularly to cement concrete, but thanks to its parameters it can be applied in many other fields (eg, restoration, etc.). Its potential is currently used in construction but only sporadically, despite the fact that alkali-activated materials research has been going on since the 1960´s.

An indisputable plus of using alkali-activated materials are its economic and ecological advantages. These materials are important because they can utilize secondary raw materials with latent hydraulic or pozzolanic properties, especially high-volume by-products from metallurgy and energy production. Preparation of alkali-activated binders and composites takes place at normal or slightly elevated temperatures, it does not require prior burning of the preparation at high temperatures (as in the case of Portland clinker), or hardening by sintering at high temperatures and thus reduces the creation of CO_2 from combustion processes and limestone decomposition. The advantage of alkali-activated materials is also the possibility of thein widespread usage as a non-standard filler, that are not normally used in concrete production technology.

This paper presents the basic characteristics of laboratory-prepared alkali-activated composite materials based on finely ground granulated blast furnace slag and recycled or non-standard aggregates.

2 USED MATERIALS

For sample preparations several kinds of raw materials were used. The function of alkali-activated binders is performed by finely ground granulated blast furnace slag. Activation was performed by a solution of water glass, whose silicate module was modified with a 50% sodium hydroxide solution to Ms = 2,0. As a reference filler a standard test sand, that is used for cement strength testing, has been used. The mixture with sand served as a reference batch. In other batches non-standard types of fillers were used. Specifically, recycled brick and concrete, waste from extraction of aggregates and sand-waste from kaolin washing, were used. For all types of binders the granulometry was modified so, that the maximum grain size was about 2mm. Subsequently test mixtures, where a standard sand was replaced with 50 or 100% non-standard aggregates, were prepared. Each batch was tested for mechanical and durability properties. Individual results were compared with the reference sample.

2.1 Blast furnace slag

Blast furnace slag is a by-product of iron metallurgy. During the rapid cooling of hot-liquid matter, granulated blast furnace slag, characterized by latent hydraulic properties is created. For alkaline activation of latent hydraulic substances a significant share of SiO_2 and Al_2O_3 represented in non-crystalline, reactive form is necessary. As with the portland cement, hydrates in alkali-activated materials display binding strength parameters present in C-S-H phases. For properties of hardened alkali-activated materials, it is significant that there is no portlandit ($Ca(OH)_2$), as in the case of Portland cement.

In this experiment, finely ground granulated blast furnace slag SMŠ 380, a standard product of Kotouč Štramberk, s.r.o., was used.

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2.2 Activator

For blast furnace slag activation sodium water glass from the company Kittfort was used. Before using the activator, a silicate module (ratio SiO_2/Na_2O) of water glass was modified to a value of 2,0. To modify the silicate module, a solution of 50% sodium hydroxide was used.

2.3 Recycled brick

Recycled brick was prepared for the experiment in the laboratory, by crushing three pieces of solid brick in a laboratory jaw crusher. Used bricks came from two sources - two pieces are "new" bricks, purchased commercially, the third piece came from a house in Frýdlant nad Ostravicí. Before crushing, the compressive strength of each sample was determined. The strength values are given in Tab. 1. After this process, the recycled aggregate was sieved to a maximum grain size of 2 mm.

Tab. 1: Compressive strength

Sample	**Compressive strength [MPa]**
Brick from demolition	29,9
„new brick 1“	26,9
„new brick 2“	26,1

2.4 Recycled concrete

Recycled concrete was prepared by crushing a few pieces of concrete block after pressure testing in the Laboratory of Building Materials at the Faculty of Civil Engineering, Technical University of Ostrava. All specimens used were represented by plain simply cement concrete with strength class C30/37 after 28 days of setting. After crushing, the recycled aggregate was sieved to a maximum grain size of 2 mm.

2.5 Waste aggregate

Waste aggregate is represented by an aggregate fraction of 0/4 with a high content of filler generated in the process of stone crushing. The waste aggregate specimen used in represented petrographic greywacke taken from the Bohučovice quarry near Hradec nad Moravicí. Before material application, its granulometry was adapted so that the grains over 2 mm were removed.

2.6 Waste sand from kaolin washing

Waste (or "secondary") sand is a small aggregate with a grain size 0-4 mm, that is generated by kaolin washing. In terms of mineralogical composition this sand consists mainly of quartz, feldspar, mica (muscovite> biotite), residual kaolinite, a small amount of limonite (goethite), anatase and unspecified carbonate. It is only rarely used as a natural material these days, and is usually deposited at the surface of mined areas. This sand's grain size was also adjusted by removing grains over 2 mm.

3 MIX RECIPES AND TESTING OF PROPERTIES

For the purpose of testing alkali-activated materials in the laboratory a total of nine batches containing recycled and waste aggregates were prepared; preparations are listed in Tab. 2. The preparation labeled Z1 is the reference compound with 100% quartz sand as the type of the filler. For mixtures Z1A - Z1D 50% of the sand filler was replaced with non-standard test aggregate, and mixtures Z1E - Z1H include only non-standard aggregates as a filler. For most tests, a standardized testing procedure for mortars and concretes were used. The test specimen dimension was 40x40x160mm [1]. Because of the varying density of quartz sand and waste materials used, the aggregate doses were measured by volume. Fresh barches-were adjusted to an equal consistency of 200 mm, measured by slumping [2].

Tab. 2: Preparation of alkali-activated mixtures

Sample	Slag [g]	Quartz sand [g]	Activator [ml]	Recycled brick [g]	Recycled concrete [g]	Waste aggregate [g]	Waste sand[g]
Z1	450	1350	127	-	-	-	-
Z1A	450	675	127	482	-	-	-
Z1B	450	675	127	-	597	-	-
Z1C	450	675	127	-	-	580	-
Z1D	450	675	127	-	-	-	603
Z1E	225	-	127	964	-	-	-
Z1F	225	-	127	-	1195	-	-
Z1G	225	-	127	-	-	1160	-
Z1H	225	-	127	-	-	-	1206

Prepared samples were tested for compressive and flexural strengths after 7 and 28 days [3]. Durability tests were composed of a frost resistance test and a water and chemical de-icing agents resistance test [4, 5]. Their resistance to acids was also tested. In this test, samples after 28 days of setting were immersed for 7 days in a 3% solution of hydrochloric acid. Subsequently, the specimens tested the compressive and flexural strength. Finally, the specimens also tested for resistance to high temperatures. Samples were burned in a furnace chamber at a temperature of 800° C for 2 hours. After that, samples were tested for compressive and flexural strengths.

4 TEST RESULTS

Individual tests were always performed on three specimen and arithmetic averages were calculated for partial results. The results of strength parameters, frost resistance, salts and acid resistance and strength after firing are presented in Tab. 3 and 4 and in Fig. 1 to 5.

Tab. 3: Compressive and flexural strengths after 7 and 28 days

Sample	Flexural strength after 7 days [MPa]	Flexural strength after 28 days [MPa]	Compressive strength after 7 days[MPa]	Compressive strength after 28 days[MPa]
Z1	8,1	9,9	62,3	87,8
Z1A	4,9	7,5	35,5	52,0
Z1B	5,8	7,4	43,8	72,7
Z1C	5,2	5,5	33,9	50,5
Z1D	7,4	6,9	49,3	69,7
Z1E	2,7	5,0	8,5	41,7
Z1F	5,1	5,2	27,6	40,7
Z1G	6,4	6,1	23,5	38,5
Z1H	6,1	7,1	35,0	55,2

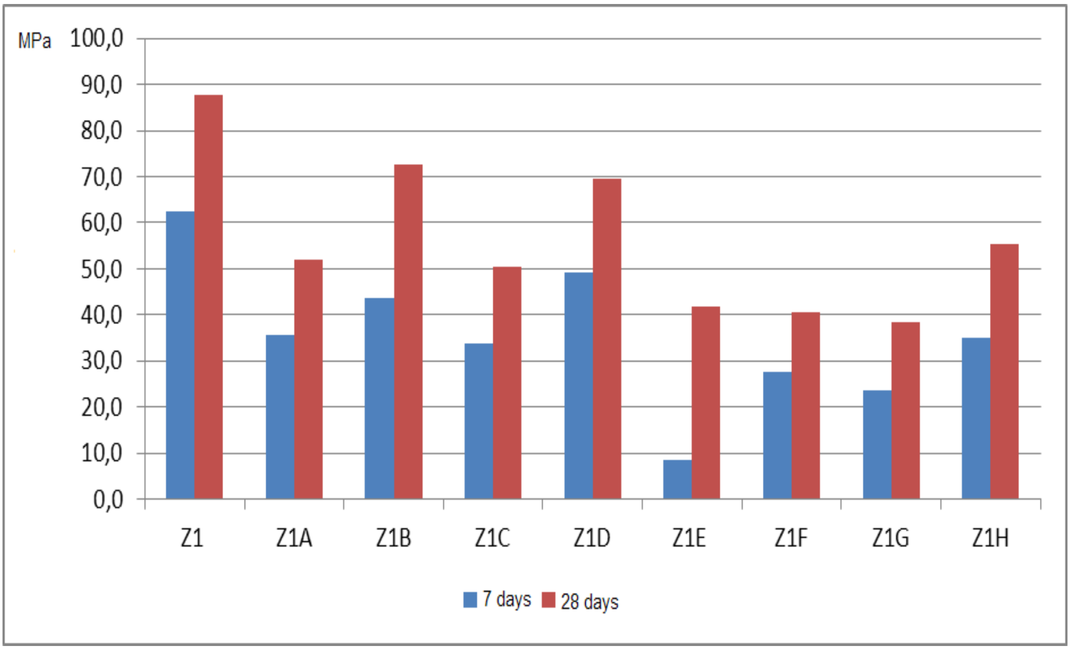

Fig. 1: Development of compressive strength versus time

The results presented in Tab. 3 and in Fig. 1 indicate that the highest compressive strength after 28 days was achieved, quite logically, by the reference compound Z1. The value of the reference mixture strength reached nearly 90 MPa. It should be noted, that even some samples of mixtures with a 50% content of non-standard aggregates (Z1B with recycled concrete and Z1D with waste sand from kaolin washing) or even mixtures with 100% content of non-standard fillers (Z1H with waste sand from kaolin washing) exceeded the value of 50 MPa compressive strength.

During testing of the resistance to the influence of positive and negative temperature test specimens were exposed to a total of 100 cycles of freezing according to ČSN 72 2452 [4]. Results listed in Tab. 4 and Fig. 2 show that samples made from modified batches with some non-standard aggregates increased strength values in comparison to the values before freezing.

Tab. 4: Compressive and flexural strengths after 100 cycles of freezing

Sample	**Flexural strength [MPa]**	**Compressive strength [MPa]**
Z1	11,5	97,4
Z1A	7,2	45,0
Z1B	9,5	61,1
Z1C	9,3	56,2
Z1D	9,3	72,2
Z1E	6,4	42,5
Z1F	0,8	24,3
Z1G	4,3	33,0
Z1H	7,8	57,1

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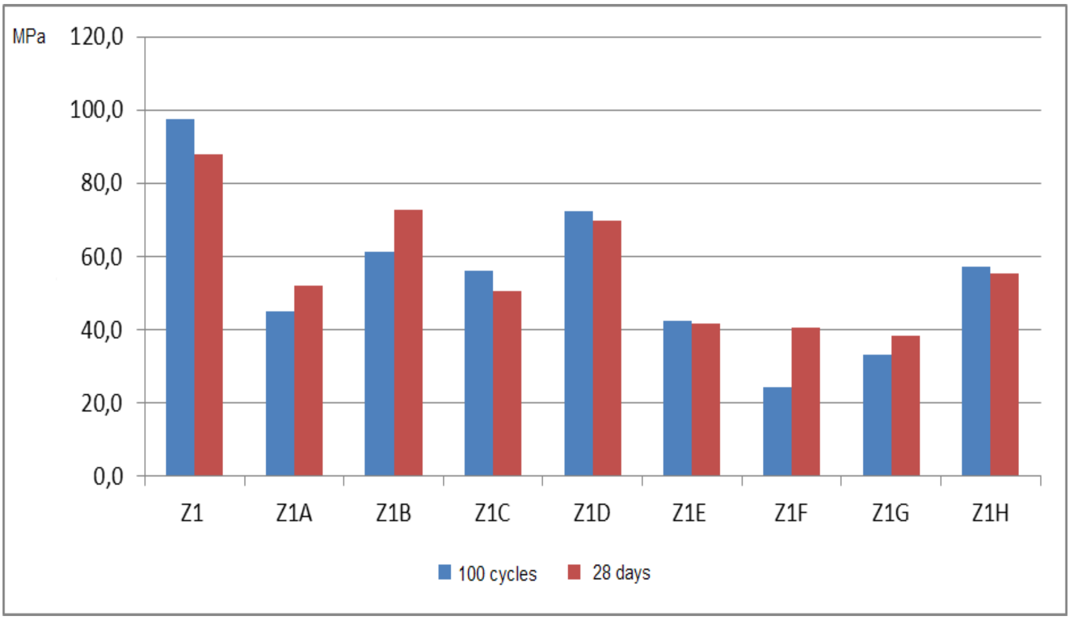

Fig. 2: Compressive strength after 100 freezing cycles compared with the strength after 28 days

The test of water and chemical de-icing agents resistance was performed according to the procedure in ČSN 73 1326 [5]. The results in Fig. 3 show that the reference compound, as well as most blends of modified mixtures, achieved maximum waste value of 4% of the original weight of the specimen after 100 freezing cycles. The exceptions are mixtures Z1E (with 100% content of recycled brick) and Z1G (with 100% content of waste aggregate), where the amount of waste exceeded 10%.

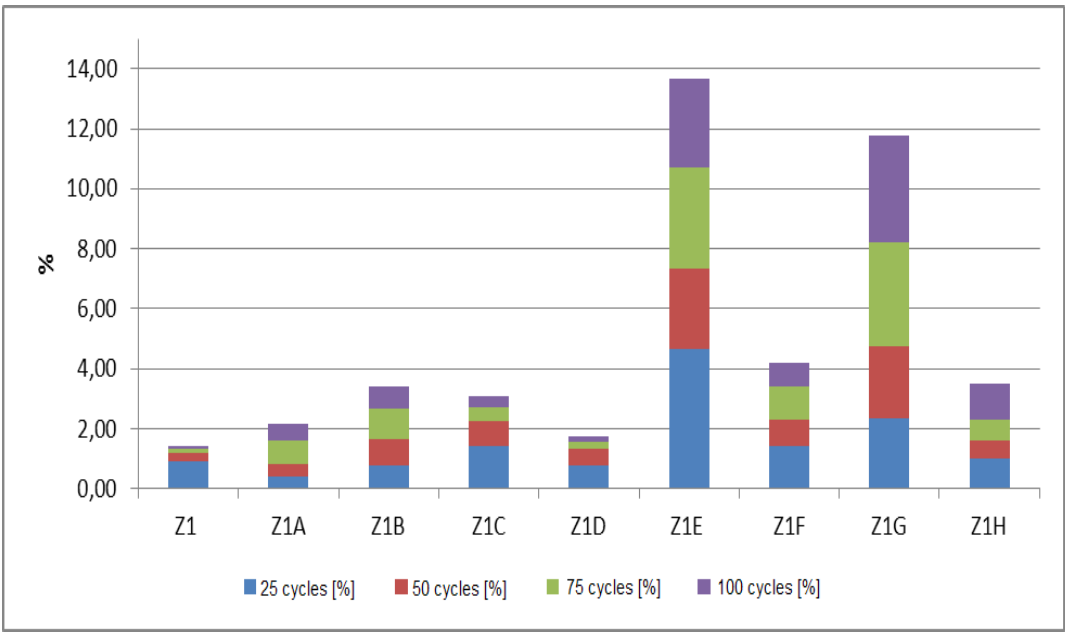

Fig. 3: Weight of waste from the surface of the specimens in % of the weight of original sample after 25, 50, 75 and 100 cycles of testing water and chemical de-icing agents resistance

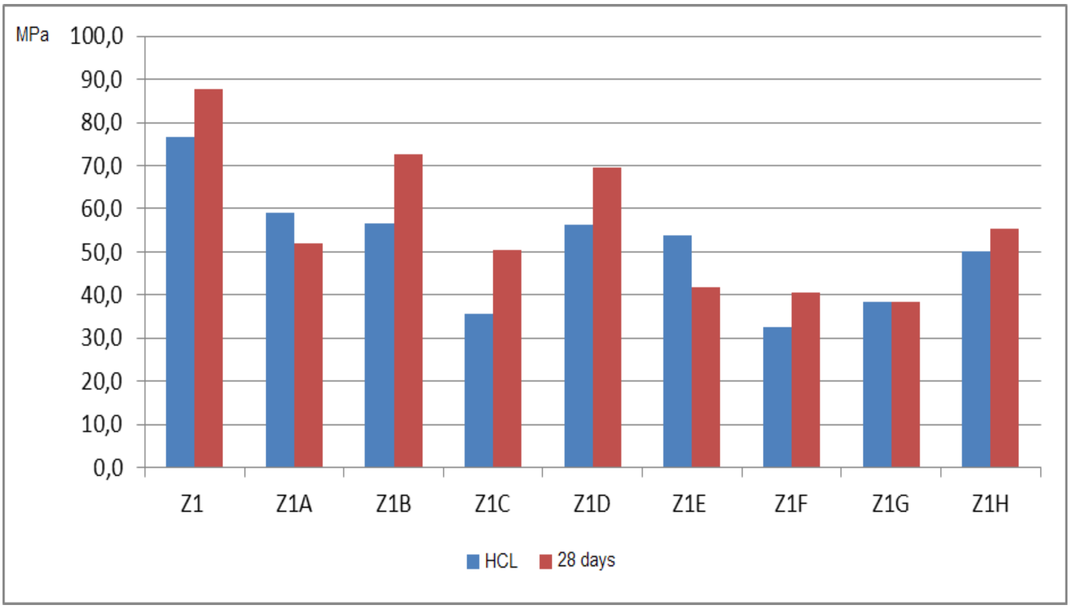

Fig. 4: Compressive strength after exposure to 3% HCl solution in comparison with the strength after 28 days

Fig. 4 presents the results of testing samples to the effect of exposure to a 3% HCl solution. The results show that for most materials, the strength compared to strength before testing in acid decreased, but if the batch contains 50% or 100% recycled brick (mixes Z1A and Z1E) the strength increased. In the case of the mixture Z1E, the rate was increased by even more than 20% of its original strength.

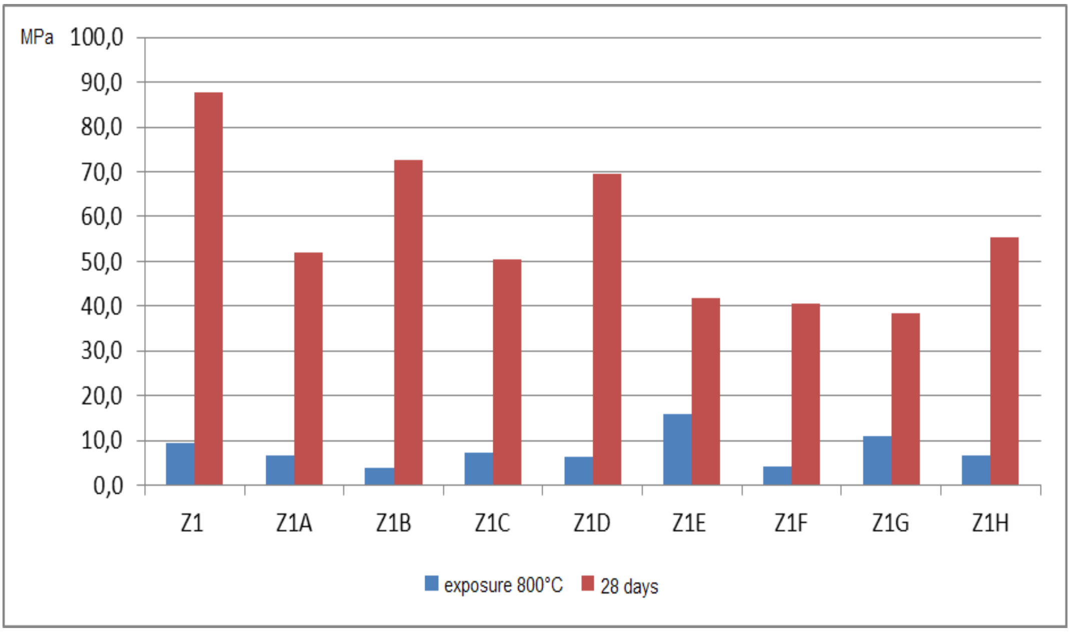

Fig. 5: Compressive strength after exposure to 800°C compared to the strength after 28 days

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Fig. 5 displays the comparison of the compressive strength after 28 days of samples of each mixture with the strength after subsequent firing at 800°C with isothermal pauses of 2 hours. The strength of all tested samples significantly decreased after exposure to high temperatures. The lowest drop was found in Z1E mixture that contained 100% recycled brick as a filler. This can be probably attributed to the fact that brick is a material with a thermal history and therefore the reaction of alkali-activated system with the filler is different than with other fillers.

4 CONCLUSION

The results of this experimental study of selected properties of alkali-activated materials containing non-standard aggregates suggest that the use of fillers based on waste and recycled materials in these systems is very perspective. We managed to create mixtures which, despite the content of 50% or 100% alternative aggregate of total filler, reach strengths higher than 50 MPa, are resistant to frost, water and chemical de-icing agents and their mechanical properties are not reduced by effects of acidic environments.

The importance of identified results and conclusions of this phase of laboratory research is particularly important also in terms of the fact that some of the tested fillers (eg, acidic sands from kaolin washing) are not applicable in concrete and mortar technology based on Portland cement.

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