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Possibilities of using of alkali-activated mortars in aggressive environment

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Abstract

In the article the incipient experimental works about using of alkali-activated mortars in an aggressive environment are introduced. Several types of mortars with different composition were prepared and examined. Observed properties of alkali-activated mortars were: resistance of cement concrete's surface to water and defrosting chemicals, resistance against crack formation and development, adhesion to the concrete base and frost resistance. The purpose of this experiment was to propose a mixture of alkali-activated material that would be suitable for application in the form of a screed for concrete and other materials. The pilot tests were performed with several mixtures with different combinations of initial materials. They were also tested in different mixing ratios, depending on the rheological properties of the respective individual mixtures.

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Keywords: Alkali - activated materials; durability; resistance; mortars

1. Introduction

Binders based on alkali-activation of suitable constituents are stable materials with proven physical and mechanical and chemical properties. These are able to overcome the commonly used Portland cement in many different properties (e.g. compressive strength, chemical resistance, temperature resistance) [1,2]. The main advantages of alkali-activated materials seem to be low energy intensity, great resistance against chemical aggressive substances, high strength, long-term durability and high temperature resistance.

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Alkali-activated material is between classic hydrated inorganic binders and glassy and ceramic materials. For alkali-activated materials, various input materials were studied, like albite, kaolinite and other types of aluminosilicate materials. Alkali-activation can also transform many waste materials like fly ash, slag and metakaoline to full valued materials with high strength and high resistance to fire, acids and bacteria. Alkali-activated materials are compounds of aluminium and silicium; Si-O-Al-O bond is the building element of chemical chains. Geochemical synthesis takes place through oligomers (dimmers and trimers), which form the structure of one unit of three dimensional macromolecular structure. Portland cement is an essential construction material. However, high production of Portland cement causes pollution of the environment. Therefore, cementitious materials with lower energy consumption (and lower production of CO_2) attract attention to geopolymerous cement worldwide.

Geopolymer cement is chemically defined as (K-Ca)(Si-O-Al-O-Si-O-) poly (sialate-siloxo), also called alkali-activated cement [1].

Production of geopolymer cement requires temperatures no higher than 750 °C, the chemical process of geopolymerizaiton itself produces no CO_2 and fuel consumption is minimal. Therefore, emissions are decreased by up to 80 – 90 %.

Alkali activation of aluminosilicates proceeds in three steps. Each of them can act in various ways which result in different final products. Geopolymer's formation is very fast and all steps take place substantially simultaneously. The first phase is dissolution of aluminosilicate glass with a strong alkaline substance, which promotes the formation of zeolite precursors of dissolved particles (nuclei). Free ions are reoriented and form clusters (small molecules). After nuclei reach a critical size, crystal growth begins. These small molecules present in the solution can combine and create larger molecules which collide in an amorphous gel with minor crystalline phases. The resulting two-dimensional to three-dimensional geopolymer has the formula: $Mn\ [-(Si\text{-}O)_z - Al\text{-}O]_n \cdot wH_2O$ and is similar to zeolitic precursors. The crystalline zeolite growth of nuclei is very slow. [1,3,4,5,6]

Factors affecting the properties of alkali-activated materials:

- nature of the precursor
- $SiO_2 : Al_2O_3$: CaO (MgO) ratio in the solution
- aggregate's properties and composition
- conditions of hydrothermal process (e.g. temperature)

The above-described properties of the alkali-activated materials in combination with good adhesion predispose this material for use as a protection of concrete structures against aggressive environment and high temperatures. Based on this features, the idea of laboratory experiments with alkali-activated materials – and their application as a coating for concrete – originated.

2. Materials and methods

2.1. Materials

Basic components of proposed mixtures were water glass, metakaoline (with additives), micronized limestone, slag and fly ash. Fine quartz sand was used as a filler and fine polypropylene fibers were used as dispersed reinforcement. The composition of each mixture can be seen in Table 1.

List of materials:

- Metakaoline - Baucis L110, produced by calcination of natural kaolin at 600 – 800 °C. Kaolin was mined in Nové Strašecí; chemical composition is shown in Table 2.
- Micronized limestone – produced by grinding and subsequent milling of crystalline limestone (marble) with a density of 2 572 kg/m^3 from Zblovice location.
- Slag – fine milled blast furnace slag Štramberk of Třinecké železárny with a specific gravity of 2 810 kg/m^3 and surface area 380 m^2/kg.

- Fly ash - Dětmarovice power plant fly ash is a product of classical high temperature combustion of coal.
- Quartz sand - fraction 0 - 1 mm.
- Water glass - Baucis L110, sodium water glass with silicate module of 1.474 and density of 1 388 kg/m^3, the chemical composition is shown in Table 3.
- Fibers - Fibrin 615 produced by KrampeHarex (length 6 mm, diameter 5µm, melting point 150 – 160 °C).

Table 1. Mixture's composition (*g/l*).

Materials / Mixture	A	B	C	D
Metakaoline	770	330	330	330
Micronized limestone	-	440	-	-
Slag	-	-	440	-
Fly-ash	-	-	-	440
Quartz sand	1 100	1 100	1 100	1 100
Water glass	330	330	330	330
Water	82	82	82	82
Fibers	2	2	2	2

Table 2. The chemical composition of the metakaoline Baucis L 110 [7].

Loss on drying (105 °C)	Loss on ignition (1 005 °C)	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	TiO_2 (%)	CaO (%)	MgO (%)	K_2O (%)	Na_2O (%)
0.34	2.79	43.50	26.54	0.69	1.13	18.32	5.60	0.16	0.30

Table 3. The chemical composition of the water glass Baucis L 110 [7].

SiO_2 (%)	K_2O (%)	Na_2O (%)	H_2O (%)
27.8	0.2	17.7	54.3

2.2. Mixture requirements

The alkali-activated mixture was designed in first experimental steps of research. Mixture's main component was metakaoline activated by water-glass. Several different types of mixtures with variating ratio of main components and microfillers was examined in the beginning of experiment.

Primary demands for the mixture were:

- simple preparation via rotary agitator
- appropriate rheological properties, possibility to apply by steel trowel
- hardening without special attendance
- appropriate adhesion to the concrete base (ČSN 73 2577) [7]
- determination of wear resistance - Böhme (ČSN EN 13 892-3) [8]
- resistance to water and defrosting and resistance to chemicals (ČSN 73 1326/Z1) [9]
- test for frost resistance (ČSN 73 2579) [10]

3. Results and discussion

Within laboratory experiments different variants of alkali-activated materials in the form of fine-grained screed were examined. These different mixtures variants were applied to the concrete paving and tested for selected demands in first stages of experiment (Fig. 1). Some of the mixtures were even colored with pigments as shown in Fig. 2.

a

b

Fig. 1. Details of examined samples (a - author´s photo) test of adhesion to the base - mixture B, (b - author´s photo) surface after resistance to water and defrosting chemicals to ČSN 73 1326/Z1, after 100 freeze-thaw cycles - mixture C.

Fig. 2. Detail of colored sample - surface after test of resistance to water and defrosting chemicals according to ČSN 73 1326/Z1, after 100 freeze-thaw cycles (author´s photo) - mixture B with pigments.

Table 4. Results of selected properties on samples of mixtures - average values.

Selected property / Mixture	A	B	C	D
Resistance to water and defrosting chemicals after 100 freeze-thaw cycles (g/m^2)	1 450	1 120	120	dissolution
Test of adhesion to the base before frost (*MPa*)	1.9	2.2	1.6	2.4
Test of adhesion to the base after frost (100 freeze-thaw cycles) (*MPa*)	1.7	2.1	1.8	2.3

Table 5. Results of selected properties on samples of the best mixture - Mixture B (guaranteed values).

Selected property	Values
Resistance to water and defrosting chemicals after 100 freeze-thaw cycles	max. 1 200 g/m^2
Test of adhesion to the base	min. 1.5 MPa
Test of adhesion to the base before frost	2.2 MPa
Test of adhesion to the base after frost (100 freeze-thaw cycles)	2.1 MPa

For the first mix design and its application, problems in the form of cracks in the surface occurred (Figure 3a). By modifying the composition (mixing ratio and use of additives) we were able to reduce the surface’s cracking achieve a flawless surface (Figure 3b).

a b

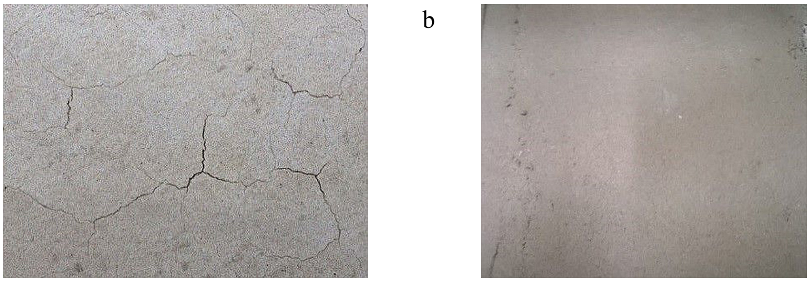

Fig. 3. Details of surface of samples (a - author´s photo) with cracks, (b - author´s photo) without cracks.

4. Conclusions

Several mixtures were proposed and examined with respect to demanded parameters within lab testing. Some of these demands were examined by testing (frost resistance test, adhesion to the base test, resistance to water and defrosting chemicals). Regarding adhesion to the substrate and a screed's adhesion after 100 freeze-thaw cycles, all testes specimens achieved satisfactory results. The best adhesion to the concrete's surface was achieved with mixture D – results were 2.4 MPa before freezing and 2.3 MPa after 100 freeze-thaw cycles. For other mixtures, the values of adhesive strength were slightly lower. Mixture C's adhesion was actually higher after 100 freeze-thaw cycles than before them. Testing of resistance to water and defrosting chemicals yielded considerably worse results. Absolutely best results were achieved with a mixture C (120 g/m^2 after 100 freeze-thaw cycles), while with mixture D, sample's complete disintegration occurred. Observing the development of cracks, the undeniably best results were achieved with mixture B – surface was without any cracks whatsoever. Almost crack-free has been also achieved with a mixture D. For other mixtures (A, C), some surface cracking always appeared.

Goals dedicated for further research are limitations of crack development in case of application on specific concrete element and improvement of resistance to water and defrosting chemicals.

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