The application of natural zeolite to cement concrete intended for communications surfaces

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Abstract. The article presents the application of a cement substitute in the form of natural zeolite to cement concrete. The reference mix design intended for communications surfaces and a mix of modified composition taking into consideration zeolite content were prepared. The basic parameters of concrete mix components were specified, including basalt aggregate, cement and zeolite. The influence of the applied zeolite of a grain-size distribution up to 50μm on the obtained parameters of concrete mix and hardened concrete was determined. It was observed that the applied zeolite contributes to the modification of the internal structure of concrete composite and consequently to the increase of the mechanical and physical parameters of hardened concrete tested within diversified standard periods of time. Due to the fact that the resistance of concrete to cyclic freezing and thawing is the determinant of concrete durability, in the case of pavement structure, hardened concretes were subject to a frost resistance assessment. The influence of zeolite content on both internal and external frost resistance of hardened concrete was specified. SEM observations of the internal structure of concretes exposed to the influence of freezing-thawing cycles proved the advantageous changes of zeolite occurrence in concrete mix. A reduction of cement quantity and its replacement thereof with the suggested zeolite allows obtaining a pavement quality concrete of a more favourable internal micro structure and distinguished by higher parameters.

1 Purpose and the scope of research

The article is aimed at the assessment of the suitability of natural zeolite in the composition of cement concrete intended for communications surfaces. The basic properties of basalt aggregate, cement and zeolite were determined. It was assessed whether the applied zeolite influences a change in the parameters of the internal structure of hardened cement concrete, the change of physical and mechanical properties of concrete intended for communications surfaces. The source of natural zeolite formation in nature was the settlement of volcanic ash and then its reaction with lake slats [1].

The included the assessment of basalt aggregate, cement and zeolite parameters. The series labeled B was a basalt aggregate fraction of 2/8mm and 8/16mm. In the case of the

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aggregate the following were determined: volume density (ρ_a) according to [2], absorbability (W) according to [3], abrasion resistance (M_{DE}) according to [4] and crushing resistance (LA) according to [5]. The series labeled C was low-alkali Portland cement (less than 0.6% Na_2O content) and the series Z_{50} was natural zeolite of a grain-size distribution of 50μm. The natural zeolite was dosed, as the substitute of part of cement. The material from the area of eastern Slovakia - Nižný Hrabovec area was analysed.

The influence of the applied natural zeolite on the change of concrete mix parameters was determined. The experiment assumed performing two series of concrete mix. The first series was the so-called reference type of concrete mix the composition of which was in compliance with standard requirements [6]. This concrete mix was indicated as MB, and the results obrtained in the case of this mixture were considered as reference values. The second series included a mixture of a modified composition, in which part of cement (15%) was replaced with natural zeolite. This mixture was indicated as MZ_{50}. The tests included: mix density using a cylinder of 8 dm^3 capacity according to [7], consistency using concrete slump method according to [8] and air contents using manometer method according to [9]

The prepared concrete mix series MB and MZ_{50} after being arranged into (cubic moulds 100x100x100 mm, 150x150x150 mm, cylindrical moulds 150x300 mm and 150x700 mm according to [10]) were subject to standard curing [11] for the assumed research periods (7, 28, 56 and 90 days).

The experiment assumed to perform two series of concrete. The first series was reference concrete (CB), in accordance with the requirements of [6]. The next series included concrete with cement substitute in the form of natural zeolite (series CZ_{50}). Concretes for communications surfaces were analyzed.

The determined concrete parameters included the following: volume density (ρ_o) according to [12], absorbability (N) according to [6], compressive strength (f_{cm}) according to [13], splitting tensile strength (f_{ct}) according to [14], concrete bending strength (f_{cf}) according to [15, 16], stripping strength according to [17], abrasion resistance according to [18], maximum depth of water penetration according to [19] and after diversified curing periods.

The frost resistance of concretes series CB and CZ_{50} was determined for the assumed number of 200 freezing and thawing cycles in water. The evaluation of frost resistance refers to the determination of two parameters. The first parameter is the change of compressive strength of samples subject to freezing and defrosting cycles (ΔR). The second parameter is the change of sample weight after the frost resistance test (ΔG) determined according to [6]. The resistance to scaling for the internal frost resistance of CB and CZ_{50} series concretes has been determined for the assumed number of 56 freezing and thawing cycles in potassium formate. The evaluation of frost resistance refers to the determination of sample weight after frost resistance test (ΔS) determined according to [6].

In order to assess the impact of the used natural zeolite on the changes of the internal structure, concretes of series CB and CZ_{50} were subject to observations in a scanning electron microscope (SEM). The preparation of samples and the interpretation of the obtained results were in compliance with those described in literature works (20, 21). Fresh fractures were prepared using concretes CB and CZ_{50}. The preparation surface was observed by means of a scanning electron microscope SEM and each time it was more than1.0 cm^2. The magnification ranged from 200x to 100000x.

2 Materials

According to the obtained results it was proved that the grain-sized distribution of the analyzed basalt aggregate ranged from 2 mm to 8 mm and from 8 mm to 16 mm - Fig. 1a.

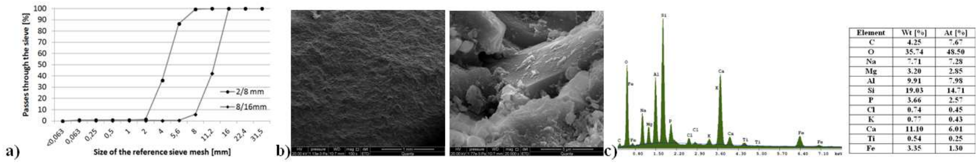

Fig. 1. Characterization of the tested basalt aggregate, a) grain-size distribution, b) SEM image of basalt grain, c) image of chemical microanalysis.

Based on the observations conducted by means of a Quanta Feg 250 Scanning Electron Microscope it was proved that the fraction of basalt grit contains quarto crystals of a conchoidal fracture. The grains are of an irregular, angular and sharp shape - Fig. 1b.

Based on the chemical microanalysis of the analysed porphyry grit, the occurrence of the following elements, i.e. oxygen, silicon, calcium, aluminum and sodium was proved (Fig. 1c). An aggregate grading composition of mix series MB was selected according to the guidelines of [6] taking into consideration limit curves of good grain size distribution (Fig. 2).

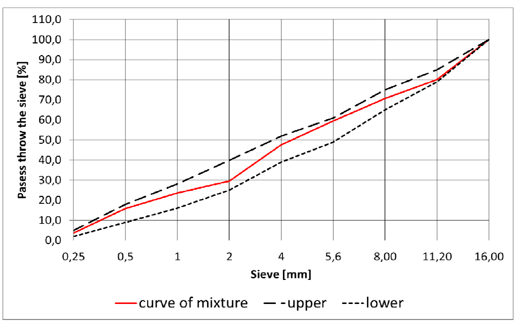

Fig. 2. Designed aggregate mixture curve, together with limit curves (lower and upper)

Quantity selection of the remaining components (Table 1) was based on experimental methods maintaining the consistency of reference mix at S1 level and taking into consideration the exposure class XF4, with the air amount between 4,5-5,5%.

Table 1. Compositions of the designed mixes of the following series MB and MZ_{50}.

components	density	MB	MZ_{50}
	kg/dm³	**kg/m³**	**kg/m³**
CEM I 42.5N MSR/NA	3.10	370	314.5
Natural zeolite	2.30	-	55.5
Fine aggregate 0/2mm	2.66	598	598
Basalt 2/8mm	3.16	864	864
Basalt 8/16mm	3.16	753	753
Water	1.00	148	148
Plasticizer	1.14	2.6	2.6
Aerating agent	1.00	1.7	1.7

3 Results

3.1 Assessment of the influence of natural zeolite on the parameters of concrete mixes

According to the obtained laboratory test results (Table 2) it was proved that the air content in mixes with zeolite is non-compliant with the standard requirements [6]. In the case of MZ_{50} mix, the air content was the lowest at 3.5%. Significant diversification was proved in the case of volume density. The mix of MZ_{50} series was distinguished by the highest parameter, while the mix of the MB series was distinguished by the lowest parameter. The difference was 3%. Based on the obtained results, no significant influence of the natural zeolite on the concrete mix consistency was proved. In the case of all analyzed mixes, the consistency defined in experimental test corresponded to S1 class.

Table 2. Parameters of mixtures of the following series MB and MZ_{50}.

mix	Density	Consistency	Air contents
	kg/m^3	**mm**	**%**
MB	2493	20 - S1	5.5
MZ_{50}	2569	0 - S1	3.5

3.2 Assessment of the influence of natural zeolite on the selected physical and mechanical parameters of hardened concrete

During scientific research, the amount of the required samples was determined using students' T-distribution assuming the significance level of 0.05. The minimum essential number of samples ranged between 4 and 5, depending on the type of the conducted test. In case of such assumptions, 6 samples were selected, which, each time, were intended for the laboratory tests.

According to the obtained experimental test results (Fig. 3a) it was proved that the natural zeolite significantly influences volume density of hardened concrete. Concretes of the CZ_{50} series were distinguished by a higher volume density, while concretes of the CB series of a lower volume density. The examined feature is also strictly dependent on the length of curing period. The diversification of the examined feature in the case of the CZ_{50} and CB concrete type was approx. 72, 74, 85 and 79 kg/m^3 after 7, 28, 56 and 90 days accordingly.

According to the obtained experimental test results (Fig. 3b) it was proved that the natural zeolite did not significantly change the absorbability of hardened concrete. It was proved that absorbability of the concrete series CB and CZ_{50} does not exceed 3.2%. It should be emphasised that all of the analyzed concrete types complied with the requirements of [6] standard with regard to absorbability.

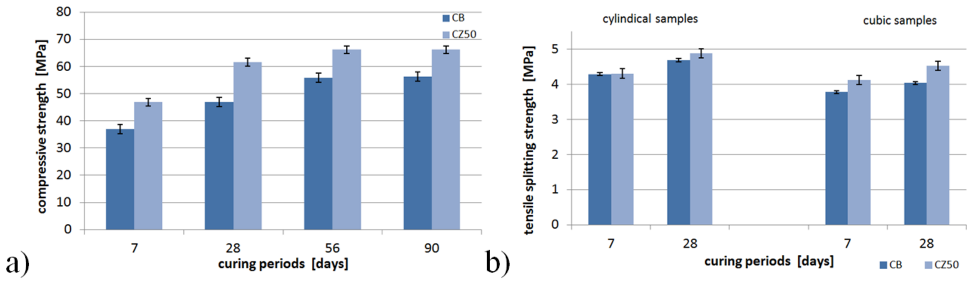

Fig. 3. Average hardened concrete density (a) and absorbability (b) of series CB and CZ_{50} during diversified curing periods.

The favourable influence of zeolite on the reduction of water penetration depth by 12 mm was proved, which was not referred to in the increase of hardened concrete resistance to the influence of freezing and thawing cycles. In the case of concrete of the CZ_{50} series, the comparable decrease of resistance (ΔR) and sample mass (ΔG) was proved after 200 cycles of frost resistance test, in regard to concrete of CB series - Table 3.

Table 3. Parameters of concrete series CB and CZ_{50}.

concrete	Maximum depth of water penetration, [mm]		Concrete frost resistance test, [%]		Mass of exfoliated material, [g]	Abrasion resistance, [$cm^3/50cm^2$]	
	$\overline{X}$	**σ**	**ΔR**	**ΔG**	**ΔS**	$\overline{X}$	**σ**
CB	56	6	2.15	0.05	0.00	10.2	0.3
CZ_{50}	40	8	3.20	0.02	0.00	10.9	0.4

According to the analysis of the obtained test results it was proved that concrete of the CZ_{50} series is distinguished by favourable mechanical parameters. Compared to the CB concrete series, concrete of the CZ_{50} series, has higher resistance parameters and is distinguished by comparable absorbability. The results obtained after the frost resistance test (Table 3) are also the confirmation thereof.

3.3 Assessment of the influence of natural zeolite on the microstructure of hardened concrete

According to the conducted SEM observations it was proved that the natural zeolite contributes to the change of internal structure of cement matrix (Fig. 4, 5).

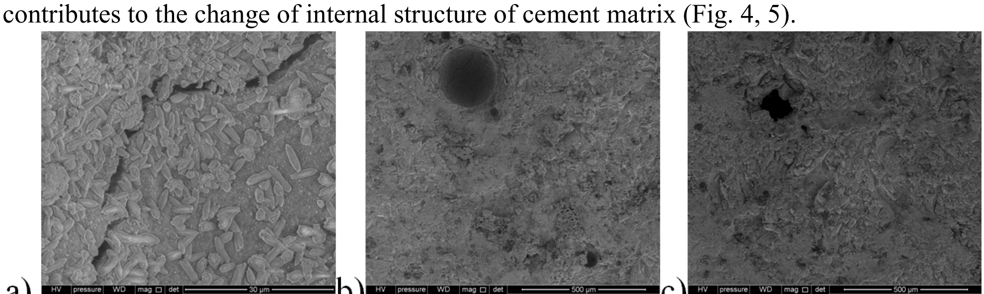

Fig. 4. Internal structure of cement concrete series CB: a) air pores, b) cement matrix, c) contact areas between cement matrix and aggregate grains.

The internal walls of air voids undergo cracking of a width up to 2-3µm. Crystallization in granular-fibrous form occurs (Fig. 4a). The internal structure of concrete of the CB series is distinguished by non-continuous contact areas between the aggregate grains and the cement matrix (Fig. 4c). The cement matrix, in the case of concrete of the CB series, is consistent. The diameters of the air voids are up to 240µm (Fig. 4b).

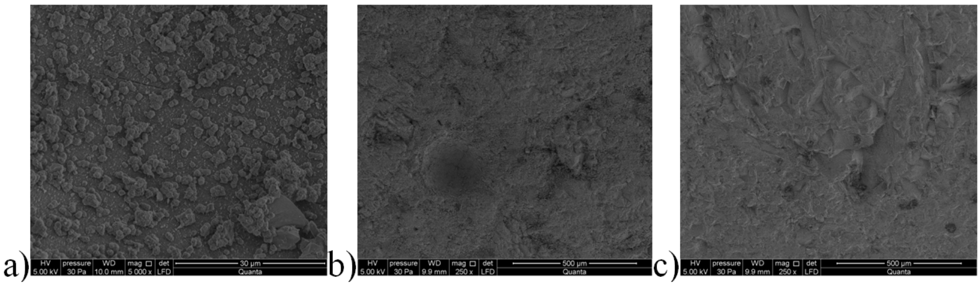

Fig. 5. Internal structure of cement concrete series CZ_{50}: a) air pores, b) cement matrix, c) contact areas between cement matrix and aggregate grains.

The cement matrix, in the case of concrete of the CZ_{50} series, is consistent and the crystallization of hydrated calcium silicate occurs in grained form (Fig. 5b). The crystallization of ettringite, with the length of single crystals of which is up to 43µm, occurs in the cement matrix. The internal structure of concrete of the CZ_{50} series is distinguished by continuous contact areas between the aggregate grains and the cement matrix (Fig. 5c). The internal walls of air voids undergo cracking of a width up to 2-4µm and crystallization in granular form occurs (Fig. 5a).

4 Conclusions

According to the conducted laboratory tests, the following conclusions have been reached:
- natural zeolite composition contains oxygen, sulfur, aluminum, potassium, carbon, sodium, calcium, magnesium;
- application of zeolite to the mix influences the increase of mechanical parameters (compressive strength and splitting tensile strength) and performance parameters of concrete (abrasion resistance and stripping resistance) and as a consequence the opportunity to extend the operation time and structure durability.
- natural zeolite used in concrete mix contribute to the increase of concrete ultimate compressive strength after standard curing period by 16% and stabilization of growth after an extended period of up to 90 days at a level of 15%;
- natural zeolite used in concrete mix contribute to the increase of concrete's ultimate stripping strength after a standard curing period by 47%, which is very important in the case of airport pavements because the pull-off test is based on the concept that the tensile stress is related to the mortar's tensile adhesion strength;
- natural zeolite used in concrete mixes does not significantly affect the change of concrete bending strength and concrete resistance to the influence of freezing and thawing cycles;
- applied natural zeolite favourably affect the changes of the internal structure of concrete composite (contact areas between aggregate grains and cement matrix, crystallization of cement matrix and air void);

It is possible to clearly reduce the amount of cement used and CZ_{50} concrete is distinguished by more favourable parameters with respect to performance characteristics. The higher abrasion resistance of CZ_{50} concrete, together with its higher stripping strength prove the increased resistance of this concrete to the destructive influence of vehicular traffic.

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