The effect of alkaline activated reservoir sediments used as a binder in concrete on its compressive strength

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Abstract
Sediment as the product of erosion processes is found in every water body and reduces the storage capacity and the lifetime of water reservoirs. The quantity of sediment which affects downstream areas and also their quality complicate sediment management. Dredged sediments are on the borderline of soils, water and waste. The favourite dredged material management options are natural options. Beneficial re-use is a way to encourage the use of dredged material as a potential resource and not as a waste. Sediments are regarded as a suitable raw material in construction industry. This paper is focused on the study of the effect of sodium hydroxide as a pozzolanic activator of sediments from Ruzin reservoir (Slovakia) used as a binder in concrete on the compressive strength of hardened concrete. Reservoir sediments are mechano-chemically and chemically activated with the addition of solid sodium hydroxide into milling process. Hardened mixtures containing 40% of binder replacement by activated sediments were tested for compressive strengths after 28, 90 and 365 days of curing. The results show that sodium hydroxide is not an effective pozzolanic activator for sediments.

Keywords: Sodium hydroxide, sediment, compressive strength, pozzolanic activator

1. Introduction

The use of river, reservoir and harbour sediments as a major or minor material in the building industry is currently a common matter in various studies. Sediments can be used as a raw material for lightweight aggregate production (e.g. Chen et al., 2012), in the production of bricks and ceramics (e.g. Torres et al., 2009). They can be also used in concrete in the form of coarse-grained sediments (particles > 0.063 mm) as a filler replacement (Junakova & Balintova, 2014). An unconventional idea is the use of fine-grained particles as a binder in concrete, however, with the limitation that sediments do not have significant pozzolanic properties (Junakova & Junak, 2017). The advantage of reuse of sediments as an alternative raw material in construction industry saves natural resources and on the other hand solves environmental and water management problems caused by silting (Junakova & Balintova, 2013).

The study is aimed at assessing the effect of reservoir sediments' alkaline activation in order to use them as a binder in concrete on the development of compressive strengths of sediment-based concrete.

2. Material and methods

To assess the suitability of reservoir bottom sediments reuse as a binder in the production of concrete, composite sediment samples were taken from the Ružín water reservoir (Slovakia, GPS N48.82732°, E21.07823°).

The basic physico-chemical parameters (as grain size, mineralogical and chemical composition) were analyzed in sediments. Also the biomass fly ash (FA), used in the composites to increase the CaO content of the mixture, was analyzed. Particle size distribution was conducted using a Mastersizer 2000 with wet sample dispersion (Malvern Instruments, UK). To determine crystalline minerals, the X-ray powder diffraction (XRD) method with Bruker D2 Phaser instrument (Bruker, Germany) was used. To analyze sediments' chemical composition the X-ray fluorescence spectrometry using SPECTRO iQ II (Ametek, Germany) was applied.

Due to the physico-chemical properties of reservoir sediments, fine-grained sediments (fraction < 0.063 mm) were modified by mechanical and mechano-chemical activation and used as a 40% cement replacement. Mechanical activation of the sediments by their dry milling was carried out in a laboratory vibrating mill (type VM4) for 3 minutes with respect to the coarse-grained texture of the original (taken) sediments from Ružín. The aim of the experiments was to optimize the composition of the prepared mixture in order to increase the strength characteristics of the prepared composites. Therefore, in addition to grinding, the sediment from Ružín was activated in other ways. Due to the low CaO content of the sediment sample, fly ash (FA) from a local biomass incinerator was added to the dry milling process in ratio 1:1 (sediment : fly ash). Mechano-chemical activation of sediment consisted of adding granulated NaOH as a chemical activator of pozzolanic properties to a mixture of sediment or sediment and fly ash. The choice of NaOH as an activator was based on literature (Abdullah et al., 2012).

For the preparation of composites (SRM0-SRM4), Portland cement (CEM I 42.5) and natural aggregates of 0/4 mm and 4/8 mm were used as raw material in the experiments. The SRM1 mixture contained coarse-grained sediment as a 40% cement replacement, which was milled for 3 minutes. The SRM2 mixture was prepared using sediment milled for 3 minutes in a mill together with granulated NaOH in ratio 2/1 (sediment/NaOH). The SRM3 mixture was prepared using sediment ground for 3 minutes in a mill together FA in ration 1:1 (sediment:FA). The SRM4 mixture contained sediment milled for 3 minutes in a laboratory vibrating mill together with FA and granulated NaOH (sediment:FA:NaOH = 1:1:1). Also control mixture (SM0) without sediment was prepared. The criteria of the standard STN EN 206 (2017) were taken into account when designing the recipe (Tab. 1).

Table 1. Mixture composition for 1 m^3

Mixture composition	Kg
CEM I 42,5 N	350
Aggregate 0/4 mm	1123
Aggregate 4/8 mm	717
Water/cement ratio	0.55

After 28, 90 and 180 days, the samples were subjected to a compressive strength test using ELE ADR 2000 (ELE International Ltd, GB).

3. Results and discussion

The analysis of physico-chemical parameters of sediments shows that sediments taken from Ružín reservoir contain 56% of particles below 50 μm. The fine-grained texture of the sediments similar to cement particle size was achieved by milling them for 3 minutes while the proportion of particles smaller than 50 μm increases to 94%. Mineralogical analysis shows that sediments contain quartz, muscovite, nontronite and albite, which confirms the presence of silicates. The mineralogical composition of the fly ash from biomass combustion shows that the fly ash contains carbonates (calcite), hydroxides (portlandite) and sulfates (arkanite). The results of the XRF analysis show that the main constituents of the sediments are SiO_2 and Al_2O_3 and Fe_2O_3, the presence of which is essential in the production of Portland cement. Fly ash contains CaO as main component.
The strength characteristics of prepared composites based on sediment as binders after 28, 90 and 180 days of curing are shown in Tab. 2.

Table 2. Compressive strengths of prepared sediment-based composites as binders and control mixture

Mixture	Compressive strength (MPa)		
	28 days	90 days	180 days
SM0	38.3	47.2	48.0
SRM1	20.3	20.7	21.9
SRM2	4.6	6.1	10.8
SRM3	22.7	22.0	23.9
SRM4	8.4	10.3	10.7

The results of testing the compressive strength of composites based on partial binder substitution by activated secondary raw materials have shown that the use of sediment as a partial cement substitute in concrete causes a reduction in the compressive strengths.
When comparing the strength of composites without using NaOH as the activator and using it (SRM1 vs SRM2, SRM3 vs SRM4), it is evident that the addition of NaOH has a negative impact on strength development. Significantly lower values of compressive strengths of SRM2 and SRM4 mixtures compared to others indicate that the degree of conversion to C-S-H gels in the composite is probably too low due to the high concentration of hydroxyl ions in the system, which causes a shift in the hydration process of C3S and C2S (Abdullah et al., 2012). As indicated in (Luna et al., 2006), C-S-H gels can be formed from precipitated Ca $(OH)_2$ at a pH of about 12.4. The pH of the fresh mixture was measured at 13.8 therefore the process of hydration of the mixture was only partial (Juenger and Jennings, 2001).
In conclusion, it can be summarized that mechano-chemical activation of sediment using NaOH as activator of pozzolanic properties (in a concentration of 5M solution) has a negative effect on the development of composite compressive strengths, probably due to the high pH of the fresh mixture (about 13.8).

Acknowledgement
This research has been supported by the Slovak Grant Agency for Science (Grant No. 1/0419/19).

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