IOP Conf. Series: Materials Science and Engineering **385** (2018) 012023 doi:10.1088/1757-899X/385/1/012023

The effect of sediment treatment on strength and water absorption capacity of sediment based concrete

N Junakova and J Junak

Institute of Environmental Engineering, Faculty of Civil Engineering, Technical University of Kosice, Vysokoskolska 4, Kosice 04200, Slovakia

Abstract. The paper presents the possibility of the Ružín (Slovakia) reservoir sediments' reuse as a 40% replacement of Portland cement in concrete. Treatment of sediments consists of sediment dry milling, adding of fly ash from local biomass incinerator plant into the dry milling process due to the low CaO sediment content and sediment's mechano-chemical activation using sodium hydroxide in the form of solid and solution as a chemical activator of pozzolanic properties. The results show the possibility of sediment reuse in building materials. However, treatment of sediments with the addition of fly ash doesn't significantly affect the development of compressive strength. Sodium hydroxide is not an effective pozzolanic activator for sediments. The absorptivity of composites increases with the fly ash and sodium hydroxide addition. Also the NaOH application form (as a solid or solution) influences the total absorption water capacity. Pouring the mixture with 5M NaOH increases the absorptivity of the hardened composites.

1. Introduction

River and reservoir sediment is a naturally occurring element in many water bodies. They are significant environmental, socioeconomic and geomorphological source. Most of them originate through erosion processes and are further transported in a hydrographic network [1]. The transported particles silt watercourses, settle in water reservoirs, where they cause different environmental [2-3] and water management problems [4]. Worldwide, reservoir sedimentation occurs at a rate of about 0.8 percent per year [5]. Most of the existing reservoirs in the world could be completely silted up in 200 to 300 years from now, with large reaches of river system permanently lost [5]. The sediment extraction is an essential part of maintaining the flow and functionality of watercourses and water structures. But the problem is how to manage with the extracted sediments [6,7]. Because sediments refer to the conglomerate of organic and inorganic materials that can be carried away by water [8], the sediment grain size classes ranging from rock to clay can be applied for a lot of different purposes [9]. Due to the perpetual availability of the sediments from the reservoirs and their properties, conversion of dredged sediments into secondary raw material as lightweight aggregate [10-12] or bricks and tiles [13-15] creates a permanent disposal solution that is cost predictable over the long-term and cost competitive with alternative options [16]. An unconventional idea not only in the world but also in the Slovak Republic in the sustainable management of river and bottom sediments is the use of sediments and remediation products as a secondary raw material in the production of concrete [7,17-19].

In this paper, the possibility of the Ružín (Slovakia) reservoir sediments' reuse as a partial replacement of binder in concrete is discussed. The compressive strength and water absorption capacity of sediment based composites are studied.

IOP Conf. Series: Materials Science and Engineering **385** (2018) 012023 doi:10.1088/1757-899X/385/1/012023

2. Material and methods

A laboratory-scale study was performed using the sediments extracted from the Ružín reservoir, located in the east of Slovakia. Based on the initial physico-chemical analysis of sediments (particle size distribution, mineralogical and chemical composition) [19], they were used as a partial (40%) cement replacement in concrete. The choice of 40% binder (Portland cement) substitution with sediments resulted from the literature [20]. Pontikes and Snellings [20] state, that supplementary cementitious materials containing less CaO can be blended into cements only up to 40% total weight without significant loss in binding properties.

The blended concrete specimens were prepared with modified sediments (fraction below 0.063 mm) as a binder as follows. With respect to the coarse-grained texture of the original (extracted) sediments from Ružín, mechanical modification of the sediments by dry milling in a laboratory vibrating mill for 3 minutes was performed. Due to the low CaO content in the sediment, fly ash from local biomass incinerator plant was added into the dry milling process in a ratio of 1:1 (sediment : fly ash). Finally, mechano-chemical activation of the sediment consisted of sodium hydroxide addition as a chemical activator of pozzolanic properties [20-21] into the sediment, and sediment and fly ash mixture. Granulated NaOH was added to a dry milling process at the weight ratio of 2.6:1 (sediment : NaOH); and 1:1:0.8 (sediment : fly ash : NaOH) to achieve 5 M NaOH solution. Sodium hydroxide activator was also used in the form of a pre-prepared 5M solution, which was added into the blended mixture instead of water. Portland cement (CEM I 42.5 N) and two different fractions of natural aggregates (0-4 mm and 4-8 mm) were used as other raw materials. Table 1 shows the compositions of the studied mixtures. A precise mixing procedure was followed according to standard STN EN 206 [22]. Control mixture (SM0) was also made only with Portland cement to compare the effect of sediment as a binder replacement on compressive strength. Double set of mixtures were prepared.

Table 1. Composition of mixtures.

Mixture	Binder (kg/m^3)		Filler-Natural Aggregate (kg/m^3)		Water (kg/m^3)
	CEM I	Sediment	Fraction 0-4 mm	Fraction 4-8 mm	
Control SM0	350	-	1123	717	193
SRM1	210	140 (milled)	1123	717	193
SRM2	210	140 (milled with NaOH)	1123	717	193
SRM3	210	140 (milled with FA)	1123	717	193
SRM4	210	140 (milled with FA and NaOH)	1123	717	193
SRM5	210	140 (milled and poured with NaOH)	1123	717	193
SRM6	210	140 (milled with FA and poured with NaOH)	1123	717	193

Note: FA – fly ash

Three prisms (40 mm × 40 mm × 160 mm) from each set were prepared for mechanical strength and water absorption capacity tests per studied age.

The compressive strengths of hardened mixtures were determined after 28 and 90 days of curing in accordance with standard STN EN 12390-3 [23]. The mechanical tests were carried out with an ELE ADR 2000 (ELE International Ltd, Leighton Buzzard, Bedfordshire, UK) testing machine after 28 and 90 days of curing in water.

The total absorption water capacity, as an important indicator of concrete durability, was another tested parameter in hardened specimens. It was determined according to STN 73 1316 [24]. The test consisted of two major steps: drying the specimens and their saturating. Specimens were dried in ventilated oven at a temperature of 105±5°C until the difference in mass was less than 0.1% (m_d).

Then specimens were immersed in water for 24 hours to obtain saturated mass (m_s). The water absorption by immersion (N) was expressed as the water uptake relative to the dry mass using this formula:

$$N = \frac{m_s - m_d}{m_d} * 100\ (\%) \qquad (1)$$

3. Results and discussion

The compressive strength of the prepared sediment-based composites as a filler and control mixture after 28 and 90 days of curing are shown in table 2. All data are presented as the mean ± standard deviation of the six determinations made on a double set of three prisms.

Table 2. Composition of mixtures.

Composite	Compressive strengths (MPa)	
	28 d	90 d
SM0-control	38.3	47.2
SRM1	20.3	20.7
SRM2	4.6	6.1
SRM3	22.7	22.0
SRM4	8.4	10.3
SRM5	6.3	9.6
SRM6	8.2	10.9

The average compressive strength of composites prepared with milled sediment as a 40% partial cement replacement was at about 20 MPa after 28 and 90 days of hardening. However, a higher percentage of cement replacement by sediment resulted in a decrease of compressive strengths compared to a control mixture by half.

Mechanical activation of the sediment by its milling together with fly ash (with the purpose of adding CaO into the mixture) increases the compressive strength of prepared composites after 28 days of hardening by more than 10%, with the strength values achieved at 23 MPa. The addition of fly ash did not affect the development of compressive strength after 90 days of curing. The composite' compressive strength was at the same level with the addition of ash (SRM3) and without its addition (SRM1) after 90 days of hardening. The expected increase in compressive strength due to the addition of fly ash to the mixture has not been demonstrated [25]. It can be due to the low contents of SiO_2 and Al_2O_3 in fly ash that are essential for the formation of C-S-H / C-A-H gels important for strength development.

The last group of composites was prepared with mechano-chemical activated sediments by milling with the presence of NaOH activator in solid form and in the form of 5M solution. These composites achieved the lowest compressive strengths of all studied mixtures (see table 2). Higher initial compressive strengths achieved blends with addition of fly ash (SRM4 and SRM6). It has also been observed that the composites prepared with NaOH in the form of solution achieved higher strengths compared to the granulated NaOH application in the milling process. The results have shown that the method of the activator application (granulated NaOH vs NaOH solution) may influence the development of compressive strengths. However, significantly lower compression strengths of SRM2 and SRM4-SRM6 composites compared to others indicate that the conversion degree to the C-S-H gels in the composite system is too low due to the high concentration of hydroxyl ions in the system (pH of fresh blended mixtures were 13.8). This causes the shift of equilibrium towards the left side in the hydration process of C_3S and C_2S [26-27].

In composites, the total absorption water capacity was also studied (figure 1). Results have shown that the addition of fly ash to the mixture increases the total absorption water capacity of the hardened composites. Examples are SRM1 and SRM3, where addition of ash into the mixture has increased the absorption capacity of the hardened sample by more than 20%.

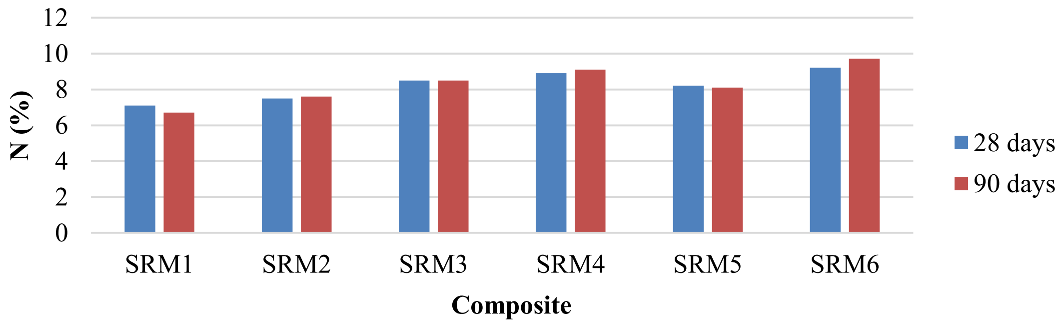

Figure 1. The total absorption water capacity of composites after 28 and 90 days of curing.

The absorptivity results of the prepared sediment-based composites with addition of fly ash and NaOH as an activator also showed that even the presence of NaOH in the mixture and also the form of NaOH application influences the resulting total absorption water capacity. Pouring the mixture with 5M NaOH slightly increased the absorptivity of the hardened composites compared to the mixtures prepared with the granulated NaOH added into the grinding process.

4. Conclusions

Presented results of testing the strength parameters of composites based on partial cement replacement by activated reservoir sediments have shown the possibility of sediment reuse in building materials. The use of higher masses of cement substitutes by fine-grained sediment (40%) from water reservoirs is furthermore environmentally and economically advantageous. The use of fly ash and sediment together as a partial cement substitution is advantageous in the case of requirement to reuse large volumes of sediment and fly ash at the same time. Addition of NaOH as an activator of sediment into composites in the concentration of 5M acts negatively to the compressive strength development and thus sodium hydroxide isn't effective pozzolanic activator for sediments.

Sediment-based composites as binder in concrete achieve the absorptivity values above 7. Addition of fly ash and sodium hydroxide increase the absorptivity. Also the form of NaOH application influences the resulting total absorption water capacity. Pouring the mixture with 5M NaOH has increased the absorptivity of the hardened composites compared to the mixtures prepared with the granulated NaOH added into the grinding process.

Acknowledgments

This research has been supported by the Slovak Grant Agency for Science (Grant No. 1/0563/15).

References

[1] Wohl E 2011 A World of Rivers: Environmental Change on Ten of the World's Greatest Rivers (Chicago, IL, USA: University of Chicago Press)
[2] Junakova N and Balintova M 2012 *Chem. Eng. Trans.* **26** 591-596
[3] Junakova N and Balintova M 2011 Model for predicting the nutrient content in reservoir bottom sediments *11th International Multidisciplinary Scientific Geoconference and EXPO - Modern Management of Mine Producing, Geology and Environmental Protection, SGEM 2011* 3 475-482
[4] Slezingr M 2016 Lowering the water level at the dam reservoir Brno *Public Recreation and Landscape Protection - With Nature Hand in Hand, Conference Proceedings* (Brno: Mendel university in Brno) pp 102-104
[5] Sedimentation Committee 2009 Sedimentation and Sustainable Use of Reservoirs and River Systems: http://www.icold-cigb.org/userfiles/files/CIRCULAR/CL1793Annex.pdf (online)
[6] Deibel I, Lampe C, Ulbricht J P, Cnudde T and van Dessel G. 2007 Beneficial Use *Sustainable Management of Sediment Resources: Sediment and Dredged Material Treatment* eds P Bortone, L Palumbo (Amsterdam, The Netherlands: Elsevier) pp 119–132

[7] Junakova N and Balintova M 2014 *Chem Eng Trans.* **39** 637-642
[8] Langland M and Cronin T 2003 A Summary Report of Sediment Processes in Chesapeake Bay and Watershed Available at: http://pa.water.usgs.gov/reports/wrir03-4123.pdf (accessed on 15 March 2017)
[9] PIANC-World Association for Waterborne Transport Infrastructure 2009 Dredged material as a resource. Options and constraints (Brussels, Belgium: PIANC)
[10] Hamer K, Hadeler A, Muschalla T, Schroter J and Timmer G 2003 *J Soils Sediments* **4** 284-291
[11] Hung M F, Hwang C L 2007 *Waste Manag. Res.* **25** 449–456
[12] Chen H J, Yang M D, Tang C W, Wang S Y 2012 *Constr Build Mater* **28** 387-394
[13] Samara M, Lafhaj Z and Chapiseau Ch 2009 *J Hazard Mater* **163** 701-710
[14] Romero M, Andrés A, Alonso R, Viguri J and Rincón J M 2009 Valorisation of contaminated marine sediments to produce ceramic construction materials. *Spanish National Conference on Advances in Materials Recycling and Eco – Energy* pp 45-48
[15] Torres P, Manjate R S, Fernandes H R, Olhero S M, Ferreira J M F 2009 *Ind Ceram* **1** 5-12
[16] Harborrock. Company summary. Available at: http://www.harborrock.com/HarborRockSummary.pdf (accessed on 15 March 2017).
[17] Mensinger M C 2008 Cement-Lock® Technology for Decontaminating Dredged Estuarine Sediments *Topical Report on Beneficial Use of Ecomelt from Passaic River Sediment at Montclair State University* (Essex County, NJ, USA: Montclair State University)
[18] Junakova N and Junak J and Balintova M 2015 *Clean Technol. Environ Policy* **17** 1161-1169
[19] Junakova N and Junak J 2017 Sustainable use of reservoir sediment through partial application in building material *Sustainability* **9** 1-13
[20] Granizo M L, Blanc-Varela M T, Puertas F and Palomo A 1997 Alkaline activation of metakaolin: Influence of synthesis parameters *Proceedings of the 10th International Congress on the Chemistry of Cement* (Gothemburg, Göteborg, Sweden)
[21] Palomo A, Grutzeck M W, Blanco M T 1999 *Cem. Concr. Res*. **29** 1323–1329
[22] STN EN 206 2017 Concrete. *Specification, Performance, Production and Conformity* (Slovakia, Bratislava: Slovak Office of Standards, Metrology and Testing)
[23] STN EN 12390-3 2010 Testing hardened concrete. Part 3: *Compressive strength of test specimens* (Slovakia, Bratislava: Slovak Office of Standards, Metrology and Testing)
[24] STN 73 1316 1989 *Determination of moisture content, absorptivity and capillarity of concrete* (Slovakia, Bratislava: Slovak Office of Standards, Metrology and Testing)
[25] Beeghly J and Schrock M 2009 *International Journal of Soil, Sediment and Water* **3** 1-21
[26] Abdullah A, Taufiq-Yap Y H, Jaafar M S, Alhozaimy A, Al-Negheimish A and Noorzaei J 2012 *Sci. Res. Essays* **7** 719–729
[27] Martinez-Ramirez S and Palomo A 2001 *Cem. Conc. Res.* **31** 1581-1585