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The Study of Bottom Sediment Characteristics as a Material for Beneficial Reuse

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Sediment is the product of erosion processes that has disaggregated soil into its components of sand, silt, clay, and organic matter, and carried that material into a water body whereupon the particles settle out on the bottom. Sediment is found in every body of water, and can be comprised of one or more of the various particle classes (from fine silts and clays to coarse gravel) in an infinite variety of combinations. Siltation of water reservoirs with sediments belongs to the important problems in water management mainly due to the reducing of the basin's accumulation capacity and also because of the utilization of sediment waste extracted from water reservoirs. It was evaluated that the storage capacity of the world's reservoirs is reducing annually by more than 1 % due to siltation. Enormous volumes of sediments have to be dredged worldwide for both maintenance and also environmental reasons.
Beneficial reuse of dredged materials in confined utilization facilities is a new approach that has the potential to productively utilize large quantities of dredged materials. Dredged sediments have a wide range of uses. Considering their properties, it can be thought about their biotic and abiotic utilization.
This paper is focused on the analyzing of chosen physical and chemical bottom sediment characteristics in the reservoirs. It also describes the impact of determined sediment parameters on their properties and reuse in civil engineering.

1. Introduction

Long-term and very serious world problem is solid wastes production. Waste accumulation includes a variety of negative consequences and therefore possible solution is to find new ways of using various types of waste. Profitability and efficient use of raw materials, recycling and the substitution of conventional raw materials with wastes become increasingly important.
Many studies show, that industrial waste can be used as a replacement of raw materials in concrete production. Utilization of glass and steel making slag as a natural aggregate replacement (Junak and Stevulova, 2013) and the coal fly ash as a substitute for cement (Junak and Stevulova, 2011) can be used in an environmentally friendly concrete production. Another research concentrates on the use of the technical hemp hurds slices as a possible input to lighten concrete mixtures (Stevulova et al., 2013).
Problem with the waste utilization often arises in water management through silting of rivers and reservoirs with sediments (Keesstra et al., 2012). The rapid reduction in the storage capacity of reservoirs due to siltation is a major sediment-related problem world-wide. Most sediment in surface waters derives from surface erosion and comprises a mineral component (sand, silt, clay), arising from the erosion of bedrock, and an organic component arising during soil-forming processes. Dredged material has unique chemical and physical characteristics depending on the source of the material, which is linked to past and present land uses in the watershed. Physically, dredged material can vary from fine clays and silts to coarse sand. Chemically, dredged material may contain valuable nutrients. In some cases the material is clean; other times, it can be burdened by any variety of contaminants from pathogens to polychlorinated biphenyls (Šestinová et al., 2012). According to the dredged material properties, there are two general alternatives that may be considered for its placement (Crawford, 2004): disposal and beneficial use applications. The recycling and the use of alternative materials for building and construction purposes may be a useful

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approach for saving natural resources and for promoting alternative solutions to disposal in landfills of by-products or dumping at sea of marine dredged sediments (Zentar et al., 2008). Therefore dredged material is increasingly regarded as a resource rather than as a waste.
Beneficial reuses involve the placement or use of dredged material for some productive purpose. Physical and chemical characteristics of sediments affect the type of beneficial use options available for dredged material. Material that is free of contaminants obviously has a wider range of beneficial use. Biotic utilization of bottom sediments is their direct application for purposes as land reclamation, at existing landfills, raising the elevation of low-lying areas and/or to construct new land areas, enhancement e.g. landscaping, agriculture, forestry, horticulture, etc. however, it depends on the contaminant content in dredged sediments that is main factor in assessment of possibility application on soil. Abiotic utilization includes construction material used in concrete or raw material for cements preparations instead of clayey components, construction of flood control structures such as dams, levees, dykes. Also sediments can be used as a partial replacement of Portland cement in concrete (Mensinger, 2008) and as natural clay replacement in producing of bricks (Mezencevova et al., 2012).
This paper is focused on the studying of physical and chemical properties of sediments dredged from the small agricultural reservoir. It also contains partial results of pilot study focused on the beneficial reuse of these dredged sediments in civil engineering.

2. Material and methods

2.1 Sediment sampling

Evaluated sediments were sampled from the small water reservoir Klusov, situated in the uncontaminated agricultural watershed in Eastern Slovakia, in Bardejov district. This catchment is affected particularly by non-point sources of pollution from agricultural production areas, and no significant point source of pollution is located there.
Reservoir siltation processes during 19 y resulted in the reduction of the reservoir‘s useful capacity about 33 %. Because of the excessive silting of this water reservoir, it was drained completely. The composite reservoir sediment samples were taken from the drained reservoir from two sites: near the dam due to deposition of the finest particles (S6 - fractions below 63 µm) and at the inflow into the reservoir (S9) because of coarser particles sedimentation. The weight of the composite samples represented about 3 kg. In laboratory conditions, the composite samples were air dried at room temperature, any coarse lumps were crushed and samples were homogenized.

2.2 Sediment characterization

For sediment general characterization, granularity as a basic physical parameter in studied samples was defined. Particle size of coarse-grained sediment sample (S9) was determined by passing the dry composite sediment sample through a standard series of sieves with mesh sizes from 4 mm to 0.125 mm. Undersize particles were analyzed by laser diffractometry using a Mastersizer 2000 (Malvern Instruments, UK) with a Hydro 2000S wet dispersion unit, capable of analyzing particles between 0.02 and 2,000 μm. Also using this equipment, particle size distribution of fine-grained sediment sample (S6) was analyzed. The refractive index used for the sediment samples was set to the value 1.503 (clay minerals). Sediments were suspended in water with a refractive index of 1.330. The samples were run at 2800 rpm on the sample stirrer and cell pump respectively. Agglomerates were broken up by the action of the ultrasonic, turned on for 5 min after sample addition.
The chemical composition of collected sediments (oxide analysis) was determined by x-ray fluorescence (XRF) method using SPECTRO iQ II (Ametek, Germany).
Crystalline minerals present in the sediments were identified by x-ray diffraction (XRD) analysis with diffractometer Bruker D2 Phaser (Bruker AXS, GmbH, Germany) in Bragg-Brentano geometry (configuration Theta-2Theta), using the 1.54060 Å CuKα radiation, Ni Kβ filters and scintillation detector at a voltage of 30 kV and10 mA current. Scan conditions were: recording times about 2 h, a step size of 0.04° (2Θ) and step time of 3 s. The XRD patterns were processed using the software Diffrac. EVA v. 2.1. The ICDD PDF database (ICDD PDF – 2 Release 2009) was utilized for the phase identification.

2.3 Sediment reuse in civil engineering

Given the composition of the sediment and its continuous availability, it is likely that this material may be suitable as a component in civil engineering (Mensinger, 2008).
In this study, sediments dredged near the inflow to the reservoir (S9 coarse-grained) were used as a partial substitute of natural aggregate (fraction 0-4 mm) and fine-grained sediments collected by the dam (S6) were used as a partial cement replacement in concrete production.

Table 1: Composition of 1 m^3 of concrete, type C 25/30

Concrete composition C 25/30	[kg]
CEM I 42.5 N	350
Fine aggregate 0/4	1,123
Coarse aggregate 4/8	717
Water-cement ratio	0.5

Table 2: Composition of concrete mixtures with replacement of cement and natural aggregate by sediments

Concrete	Mixture composition [%]		Aggregate fraction 0/4 [%]		Aggregate fraction 4/8 [%]		Water
composite	CEM I	Sed. S6	Natural agg.	Sed. S9	Natural agg.	Sed. S9	[%]
N0	100	-	100	-	100	-	100
N1	60	40	100	-	100	-	100
N2	100	-	80	20	100	-	100
N3	60	40	80	20	100	-	100

Portland cement (CEM I 42.5 N) and two different fractions of natural aggregate (0-4 mm and 4-8 mm) from company VSH, a.s. (Turna nad Bodvou, Slovakia) were used as another raw materials for preparing the concrete mixtures. Natural aggregate was evaluated according to the Slovakian standard STN EN 12 620 (2008).
Concrete for strength class C 25/30 (Table 1) was prepared according to STN EN 206-1 (2002). The composition of 1 m^3 of concrete is presented in Table 1. In order not to influence behavior of used sediment waste in fresh and hardened concrete, no plastification admixture was added.
To study the sediment utilization in concrete production four concrete mixtures were prepared (Table 2). Control concrete mixture (N0) was prepared by mixing cement (CEM I 42.5 N), natural aggregate (0-4 mm and 4-8 mm) and water at solid/liquid ratio of 0.5. Sediment/cement mixture (N1) with a weight ratio of 40 % fine-grained reservoir sediment (S6) as a replacement of Portland cement to 60 % Portland cement was prepared. For research of partial natural aggregate replacement by coarse-grained sediments (S9) in concrete (20 wt.% of 0-4 mm sediment fraction), another mixture (N2) was proposed according to Junak and Stevulova (2013). The last mixture (N3) consists of variation of sediment/cement and sediment/aggregate replacement in concrete.
The compressive strengths and tensile strengths were measured at the concrete mixture prisms (40mm x 40mm x 160mm) after 2 and 7 days of hardening evaluated according to the STN EN 206. Compressive and tensile strength testing machine for all studying composites was ELE 2000 (ELE INTERNATIONAL LIMITED, GB).

3. Results and discussion

Particle size distribution (PSD) of dredged sediments divided into individual size groups of mineral particles according to (USDA, 1987) is summarized in Table 3. There were determined the following fractions: clay (<0.002 mm), silt (0.05–0.002 mm), sand (2.0–0.05 mm), and gravel (>2.0 mm). Table 3 shows variability in clay, silt, sand and gravel composition within the samples of dredged material collected from two confined disposal sites. Fine-grained sediment S6, used as a partial substitute of cement in concrete, contains more than 99 % of particles smaller than 50 μm and more than 92 % are particles under 30 μm. On the other hand, coarse-grained sediment, used as a replacement of 0/4 fine aggregate fraction in concrete, has about 50 % sand and gravel particles. PSD of fine-grained sediment is shown in Figure 1.

Table 3: Particle size composition of dredged sediments

Sediment sample	Particle size distribution [%]			
	clay	silt	sand	gravel
S6 fine-grained	1.07	98.16	0.77	-
S9 coarse-grained	0.04	49.60	41.37	8.05

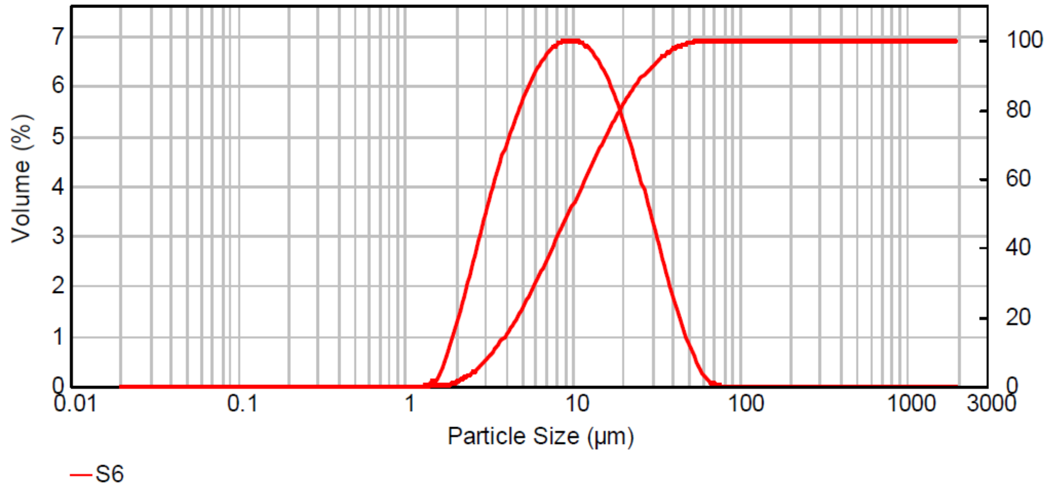

Figure 1: Particle size distribution profile of fine-grained sediment sample

Chemical composition data of the dredged sediments expressed as percentage of major oxides is shown in Table 4. Toxic compounds were not recorded in investigated sediments. The data of sediment sample S6 indicate that the main components in this dredged material were SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO and K_2O. These components are important in Portland cement manufacture. Molar ratio of SiO_2/Al_2O_3 for sample S6 is 3.8. The SiO_2 content in sediment is associated with quartz particles, as well as Si and Al oxides are associated with muscovite structure, that were identified by XRD analysis as major phase minerals in analyzed samples (Figure 2).
According to the study of physical and chemical properties of sediments, they were used as a component in civil engineering. Fine-grained sediment S6 was used as a partial replacement of cement in concrete with a weight ratio of 40 % sediment to 60 % of Portland cement. Coarse-grained sediments S9 were used as a partial substitute of 0/4 natural fine aggregate in concrete in weight ratio 20 % of sediment to 80 % of natural aggregate. The compressive and tensile strengths of concrete composites after 2 and 7 days of hardening are presented in Table 5.

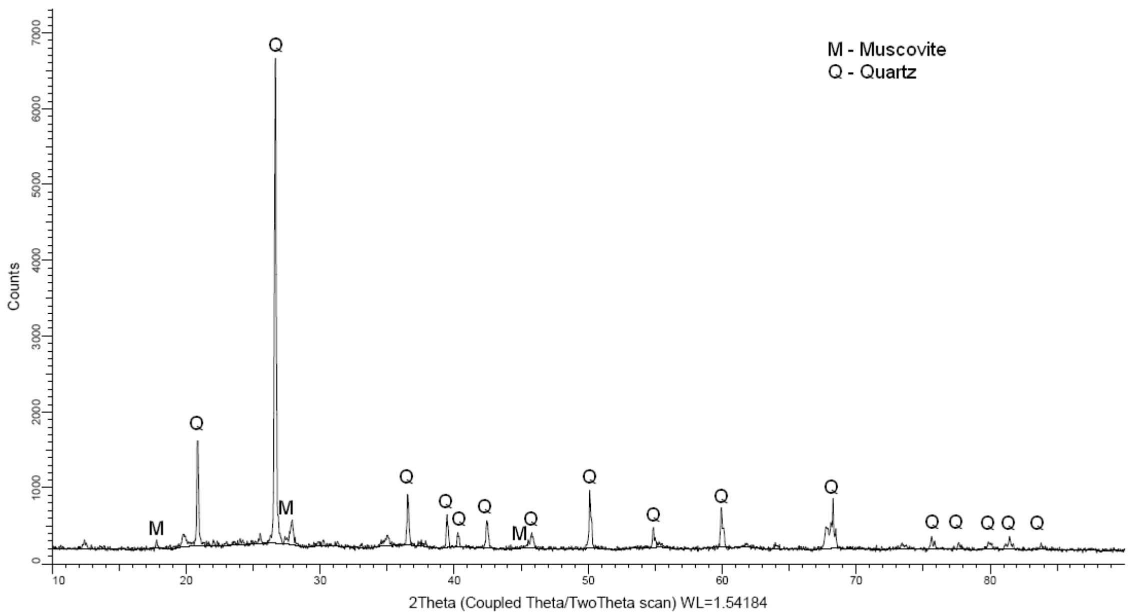

Figure 2: XRD spectrum of sediment sample

Table 4: Chemical composition of sediments

Chemical composition [wt.%]	fine-grained S6	coarse-grained S9
SiO_2	68.56	49.66
Al_2O_3	18.01	5.39
Fe_2O_3	5.15	1.51
CaO	1.10	0.57
MgO	2.40	1.06
K_2O	2.95	0.68
TiO_2	1.12	0.20
MnO	0.09	0.03
P_2O_5	0.30	0.13
SO_3	0.11	0.05
Cl	0.03	0.01
Loss on ignition	7.2	6.4

Table 5: The compressive and tensile strengths of composites after 2 and 7 d of hardening

Concrete composite	Strengths [MPa]			
	2 d		7 d	
	Compressive	Tensile	Compressive	Tensile
N0	6.80	1.03	24.89	3.14
N1	4.88	0.84	15.70	2.53
N2	7.43	0.95	24.93	3.24
N3	3.92	0.71	13.34	2.32

The results (Table 5) showed that N2 composite made with 20 % of 0/4 aggregate replacement by coarse-grained sediment S9 reached the highest value of the compressive strength (7.43 MPa) after 2 d of hardening in comparison with other 2 mixtures. This compressive strength was even in excess of 9 % versus the strength of control concrete mixture (6.8 MPa). The compressive strength of concrete composite N1 prepared with 40 % cement replacement by fine-grained sediment after 2 d of hardening were 4.88 MPa what presents 72 % of N0 control concrete mixture compressive strength. Mixture N3 prepared with variation of sediment/cement (40:60 %) and sediment/aggregate (20:80 %) replacement in concrete showed the lowest compressive strength (3.92 MPa). A progress of the tensile strength after 2 days of hardening was similar to the compressive strength. The highest value of tensile strength had N2 mixture (0.95 MPa). The measured tensile strength was 92 % of the control concrete composite (1.03 MPa). Compressive and tensile strengths of concrete mixtures increased with hardening duration.
After 7 d of hardening, the highest value of the compressive and tensile strength again reached mixture N2 (24.93 MPa; 3.24 MPa), which was identical or exceeded to that measured in control concrete mixture (24.89 MPa; 3.14 MPa). The lowest compressive (13.34 MPa) and tensile (2.32 MPa) strength after 7 d of hardening was measured in N3 mixture.

4. Conclusions

Over the last few years, the protection of the environment and sustainable development has become increasingly important in all sectors of activity. Due to increasing environmental regulations, there is a focus on using suitable recycled materials for beneficial purposes.
This paper summarizes the physical and chemical properties of sediments dredged from the small water reservoir and the possibilities of their reuse in concrete production. Based on this study, it appears appropriate to their use as a partial substitute for the natural aggregate in the concrete production. The research results show, that concrete mixtures prepared in weight ratio 20 % of coarse-grained sediments as a partial substitute of 0/4 natural aggregate fraction in concrete to 80 % of natural aggregate reached even exceeded the compressive and tensile strength after 2 and 7 d of hardening to those measured in control concrete mixture. For evaluation of the dredged sediments reuse as a partial substitute of natural aggregate or partial cement replacement in concrete production it is necessary to realize measurements of the compressive and tensile strengths from the longer time period. Simultaneously, it should also study

other properties of concrete (e.g. resistance of concrete to aggressive environment), which requires its intended application according to the proposed class of concrete.

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