Alternative reuse of bottom sediments in construction materials: overview

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Abstract. In this paper, the paths of management of the dredged bottom sediments are discussed. Focus is made on the possibility of a recycling method, which consists of the reuse of sediments as a raw material in constructions. The results of selected studies concentrated on the sustainable sediment reuse as a raw material to manufacture lightweight aggregates, bricks and concrete are summarized.

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 paths of management of various types of waste [1-3].

In the center of the sustainable economic approach is the improvement of environmental effectiveness and the effectiveness of the use of materials, which is of specific importance to waste management [4]. Profitability and efficient use of raw materials, recycling and the substitution of conventional raw materials with wastes [e.g. 5-8] become increasingly important. A useful approach for saving natural resources and for promoting alternative solutions to disposal in landfills of by-products or dumping at sea of wastes may be a replacement of raw materials in concrete production by selected wastes [9].

Problem with the solid waste accumulation arises in household, municipal and industrial sphere but also in water management through silting of rivers and reservoirs with sediments [10]. In the world, there are many water structures such as dams and reservoirs that are silted with sediments [11-16]. Reservoirs’ silation causes except for the environmental problems [17, 18] also the problems to water management organizations with disposal of the dredged sediments and their use after dredging [19, 20]. Managers try to find environmentally friendly solutions for these materials. Considering the physical and chemical characteristics of the sediments and their perpetual formation, their use in the construction industry is common practice in the world.

In this paper, the results of selected studies focused on the reuse of sediments in construction materials are summarized.

2. Sustainable reuse of sediment in civil engineering

Several studies have pointed out the possibility of applying dredged sediments as the main or minor material in civil engineering.
2.1 Sediment as raw material to manufacture lightweight aggregate

The sediments can be used as a raw material to manufacture lightweight aggregates (LWA), because the sediments contain high portion of clay particles, which are basic raw material in their production. Several studies [e.g. 21-24] have focused on the reuse of contaminated sediments, whether from harbours or reservoirs, in the production of LWA, as an alternative to landfilling. The results showed that LWA based on the fine sediments meet the requirements of low bulk density for LWA and is also suitable for structural concrete. It is even possible to consider full replacement of raw materials with sediments [22, 23]. The results of selected studies focused on possibilities of sediments’ utilization as raw material in the production of lightweight aggregates are summarized in table 1 [25, 26].

Table 1. Sediment as raw material to manufacture lightweight aggregate.

| Sediment                      | Sediment proportion in mixture (%) | Other components (%) | Treatment                  | Properties                          |
|-------------------------------|-----------------------------------|----------------------|----------------------------|-------------------------------------|
| Harbour sediments:            |                                   |                      |                            |                                     |
| Bremen, Germany [21]          | 60                                | Al(OH)$_3$, red sludge, bleaching earth, recycled glass/alternatively a by-product of the wool top production | 1150°C, 17 min. | - bulk density: 440 - 710 kg/m$^3$ |
| Harbour sediments:            |                                   |                      |                            |                                     |
| Taichung, Taiwan [23]         | 100                               | -                    | 1050–1150 °C, 18 min.      | - bulk density: 490-1260 kg/m$^3$   |
| Reservoir sediments:          |                                   |                      |                            |                                     |
| Shihmen, Taiwan [24]          | 50, 70, 90                        | municipal solid waste incinerator fly ash | 1070, 1100, 1120, 1150 °C 20 min. | - water sorption capacity (24h): 2-20% |
| Reservoir sediments:          |                                   |                      |                            |                                     |
| Shihmen, Taiwan [22]          | 100                               | -                    | 1175–1200 °C, 30 min.      | - bulk density: 622 - 859 kg/m$^3$  |
|                               |                                   |                      |                            | - water sorption capacity (24h): 10.4-12.3% |

2.2 Sediment as raw material to manufacture bricks

Due to the high proportion of clay particles, sediments can also be used as a clay substitute for brick production [27] and ceramics [28]. They can be used in the production of bricks as a substitute for quartz sand. Samara et al. [29] used treated sediments as a 15% substitute for quartz sand in bricks. In the experiments, about 15,000 perforated sediment-based bricks were made and the results showed that these produced bricks meet the requirements for clay bricks as well as the relevant environmental requirements. Although the above-mentioned studies and other ones [e.g. 29-31] have shown that the application of sediments in brick production is feasible there are some economic, technical and social limitations. Based on surveys [32], consumers are distrustful of the use of sediments in the production.
of bricks (lower brick quality, use of contaminated sediments, etc.). Table 2 presents the results of selected studies focused on the reuse of sediments as a raw material in the production of bricks.

### Table 2. Sediment as raw material to manufacture bricks.

| Sediment          | Sediment proportion in mixture (%) | Other components (%) | Treatment       | Properties                      |
|-------------------|-----------------------------------|----------------------|-----------------|---------------------------------|
| River sediments:  | 100                               | -                    | 1000 °C         | - porosity: 15,4%               |
| Dampremy-         |                                   |                      |                 | - water sorption capacity       |
| Charleroi, Belgium|                                   |                      |                 | (24h): 7,5%                    |
| [29]              |                                   |                      |                 | - compressive strength: 36 MPa  |
| River sediments:  | 5, 10                             | plastic red clay,    | 950, 1000,      | - water sorption capacity       |
| Ria de Aveiro,    |                                   | a low plasticity     | 1050, 1100 °C   | (24h): 3,5-15,5%               |
| Portugal [30]     |                                   | yellow clay          |                 | - compressive strength: 7,5-35  |
| Harbour sediments:| 100                               | -                    | 900 – 1200 °C   | - porosity: 12-38%              |
| Santander, Spain  |                                   |                      |                 | - bulk density: 1600-2450 kg/m³ |
| [28]              |                                   |                      |                 | - water sorption capacity       |
| Harbour sediments:| 100                               | -                    | 900-1000 °C     | (24h): 4-22%                    |
| Savannah, USA [27]|                                   |                      |                 | - compressive strength: 34 MPa  |
| River sediments:  | 80, 85, 90, 95, 100               | rice husks           | 700 °C          | - compressive strength: 8,3-11,7|
| Lumsai, Bangkok   |                                   |                      |                 | MPa                             |
| [31]              |                                   |                      |                 | - bulk density: 1130-1570 kg/m³ |
|                   |                                   |                      |                 | - water sorption capacity       |
|                   |                                   |                      |                 | (24h): 17,8-29%                 |
|                   |                                   |                      |                 | - compressive strength: 1,9-9 MPa|

2.3 Sediment as a binder in concrete

The unconventional and innovative idea in recent years is the use of dredged sediments as a partial Portland cement substitute in concrete production [16, 33, 34]. In 2008, the technology to produce cement from dredged material was developed by Gas Technology Institute and Unitel Technologies, USA [33]. Since then, the studies in the field of sediments reuse as a substitute of cement in concrete have subsided until 2015 (table 3).

Kazi Aoual-Benslafa et al. [34] studied several cement substitutes (5, 10, 15 and 20% by mass of cement) with sediments dredged from the port of Oran (Algeria). They found that the 5% cement replacement with dredged sediment is the most appropriate, due to the mechanical properties and durability of the composites.

Junakova et al. [25, 26] assessed the possibilities of abiotic reuse of sediments extracted from water reservoirs in Slovakia (Kľušov and Ružín) as a 40% substitute for binder in the concrete production. Composites were prepared with fine-grained sediments without any admixtures and treatment. The
Sediments were also treated by milling and grinding with the addition of biomass fly ash with the aim of CaO adding in the mixture. The authors investigated the long-term mechanical properties of sediment-based composites as binder. The results showed that the higher (40%) cement replacement with uncontaminated fine-grained reservoir sediments can be considered in the future, especially from the environmental, water management and economic point of view. Treatment of the sediment with short-term grinding with fly ash has not been effective in the long-term strengths’ development, but may be optimal in the case of requiring the use of emerging large volumes of sediment and fly ash simultaneously.

Table 3. Sediment as a binder in concrete.

| Sediment                     | Sediment proportion in mixture (%) | Other components (%) | Treatment     | Properties                  |
|------------------------------|-----------------------------------|----------------------|---------------|-----------------------------|
| River sediments: Passaic, New Jersey, USA [33] | 40                                | admixtures and mineral modifiers | melting       | - compressive strength: 52 MPa |
|                              |                                    |                      |               | - flexural strength: 6.3 MPa|
| Harbour sediments: Oran, Algeria [34] | 5, 10, 15, 20                    |                      | dewatering    | - compressive strength: 28-37 MPa|
| Reservoir sediments: Ružin and Kľušov, Slovakia [25, 26] | 40                                | biomass fly ash      | milling       | - compressive strength: 19-23 MPa |
|                              |                                    |                      |               | - flexural strength: 4.3-5.3 MPa|

3. Conclusions
Reservoir bottom sediments represent a significant environmental, socio-economic and geomorphological resource that is one of the key components of aquatic ecosystems. However, an excessive supply of sediments into the aquatic environment leads to environmental and water management problems. An essential part of maintaining the reservoirs’ functionality is sediment extraction, however, there is a problem with their utilization. Depending on properties of extracted materials, they can be used for various abiotic purposes.

With the emphasis on sustainable sediment management, paper presents the results of selected studies focused on the reuse of sediments as a raw material to manufacture lightweight aggregates, bricks and concrete. The results of studies reveal that the application of sediments in construction materials are feasible, however there are some economic, technical and social limitations. This type of incorporation of followed waste - sediment - in the concrete production will allow to reduce the consumption of non-renewable raw material and to extend the extraction duration of quarries.

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