Testing and Evaluation of Physical and Chemical Properties of Waste from Desanding

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Abstract

The study concerns evaluating the physical and chemical properties of sand from sand separators of wastewater treatment plants in terms of requirements for construction aggregates. Thus, an analysis of the physical properties of sand was carried out, i.e. its moisture content, bulk density, and grain density, as well as an analysis of the chemical composition of sand. The intention of the research is to find an alternative to the dwindling supply of this type of raw material, which is essential for the construction sector. It is currently estimated that within 20 years there will be a shortage of sand of suitable quality for use in construction. The article presents the results of physicochemical tests and leachability of selected harmful substances (P, F, N-NH_4^+, Cl, SO_4^{2-}) and heavy metals (Ba, Zn, Cu, Pb, Cd, Cr, Co, Fe, Ni) from waste from desanding.

Keywords: *municipal wastewater treatment, waste, sand, desanding, reuse*

1. Introduction

Municipal waste treatment plants are a set of facilities and processes that are used to purify domestic sewage or mixes of domestic sewage with industrial wastewater or stormwaters and meltwaters. The process of treatment of municipal waste is accompanied by the generation of waste. The waste generated during the technological processes may be divided into three types: screenings, content of sand separators and stabilized municipal sewage sludge [1, 2]. Each of the waste types must be managed according to the binding legal regulations. The waste generated in the process of waste treatment is a financial burden for the waste treatment plant. However, after proper treatment, it may constitute a valuable raw material. Sand from desanding is generated in the waste treatment process in two places: as a content of sand separators and as a result of the separation of impurities from cleaning of the sewerage [2, 3].

A common practice in waste treatment plants is handing over low-quality waste to external companies for purification from the excessive organic particles and management. If the waste meets the requirements specified in the order [4, 5] it ends its life cycle in the landfill. From the legal point of view, there is one more possible way – losing the waste status [6, 7]. Such a solution may be interesting, especially in the case of such a valuable waste as sand from desanding. In construction, sand is used as a component of standard concrete, mortar, plaster mortar, etc. The aggregate which is to be used in the construction industry must meet a number of requirements. One of them is an impact on the environment. The environmental aspect related to the use of sand from desanding as a recycling aggregate requires the determination of the leachability of harmful substances and heavy metals [8].

It assumes that the wastes/side products of one process become the raw material of another process. On one hand, such an attitude allows a reduction in the amount of waste. On the other hand, it helps lower significantly the costs of obtaining natural resources [9, 10]. Such a business model may become a solution in the acquisition of construction materials which are produced through power and material-consuming methods. Natural resources used in the construction industry such as sand, water or clay are not renewable. Once they are used, they are not suitable for recycling. At the same time, their availability decreases year by year. It is estimated that within 20 years the resources of sand of appropriate quality which can be used in the construction may be depleted. More and more the construction industry is forced to assume an ecological approach based on sustainable development. One of the directions of green construction is use of the recycled aggregate for the production of concrete. Over time, such a solution may gain its followers, due to its economic and ecological aspects.

Analysing RILEM [11] guidelines, sand from desanding may be classified as a third category of recycled aggregate – RCAC III. These are materials with at least 80% of the natural aggregate and a maximum of 20% of the recycled aggregate [11]. It needs to be underlined that the concrete based on the recycled aggregate handed over for use will be in contact with all the elements of the natural environment, especially with the soil and surface waters.

The purpose of the article is to evaluate the possibilities of using sand generated in the waste treatment plant in the construction industry. The issue dealt with in the article may form an alternative for the depleting sand resources which is an indispensable aggregate in the construction industry.

Tab. 1. Permissible limiting values for the leachability [4, 5] and the highest permissible value for other polluting substances [8]

Tab. 1. Dopuszczalne graniczne wartości wymywania [4, 5] oraz najwyższe dopuszczalne wartości dla pozostałych substancji zanieczyszczających [8]

Properties	Symbol	Criteria for landfills [4, 5], mg/kg			The maximum permissible value [8], mg/l
		inert waste	non-hazardous waste	hazardous waste	
pH	pH	-	min. 6	-	6.0 – 9.0
Chloride	Cl^-	800	15 000	25 000	1000
Sulphate	SO_4^-	1000	20 000	50 000	500
Phosphorus	P	-	-	-	2
Potassium	K	-	-	-	80
Calcium	Ca	-	-	-	-
Sodium	Na	-	-	-	800
Fluoride	F	10	150	500	25
Barium	Ba	20	100	300	2
Zinc	Zn	4	50	200	2
Copper	Cu	2	50	100	0.5
Lead	Pb	0.5	10	50	0.5
Cadmium	Cd	0.04	1	5	-
Chrome	Cr	0.5	10	70	0.1
Cobalt	Co	-	-	-	1
Iron	Fe	-	-	-	10
Nickel	Ni	0.4	10	40	0.5

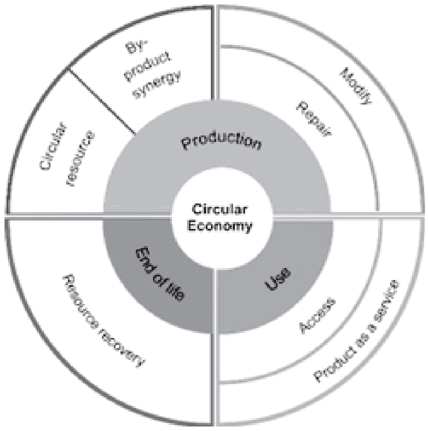

Fig.1. Circular economy business models based on a circular model [2, 9, 10]

Rys. 1. Model kołowy GOZ [2, 9, 10]

2. Materials and Methodology

2.1. Materials

The analysed material was a waste of code 19 08 02 [12]. This is the content of the sand separator. The waste is produced in the process of the mechanical treatment of waste as a result of sedimentation of the mineral suspension. Analysed sands (S) came from three municipal waste treatment plants:

- Municipal sewage treatment plant 1, which has a maximum daily capacity of 124 000 m³/d.
- Municipal sewage treatment plant 2 is a plant with a maximum daily capacity of 84 000 m³/d.
- Municipal sewage treatment plant 3 with a maximum daily capacity of 29 575 m³/d.

Analysed sands (19 08 02) were not classified as dangerous waste. Sand_1 (S_1) was relatively homogenous with minor contaminations, i.e. small stones, fragments of glass and fragments of plastics. Dark yellow colour, neutral scent.

Sand_2 (S_2) is characterized by a dark yellow colour and neutral scent. The sand was relatively homogenous. It was contaminated with mineral and organic fractions: small pebbles, seeds, stems, fruit stones, glass and pieces of plastic.

Sand_3 (S_3) had a black colour and unpleasant smell – faecal. Moreover, during storage, it underwent rotting.

2.2. Methods

As a first testing step, the water content in the taken samples was determined according to the standard PN-EN 15934 [13]. Bulk density was also tested according to the standard PN-EN 1097-3 [14]. In order to obtain testing material of appropriate graining, the sand was dried out at the temperature of 105°C, cooled and screened through the sieves. Material prepared in such a way underwent the selected physical and chemical analyses. The loss on ignition of dry mass was determined in accordance with standard PN-EN 15935 [15]. Tested samples were also tested for the total content of organic carbon (TOC) - PN-Z-15011-3 [16] and ammonium nitrogen [17].

The aqueous extracts were prepared according to the standard PN-EN 12457-2 [18].

From the sampled waste an aqueous extract was prepared with a liquid-solid ratio of L/S = 10 l/kg. Elution liquid was distilled water of pH 6.9 and conductivity of 61.18 µS/cm. Then, the prepared sample was shaken in a laboratory shaker for 24 hours and afterwards filtrated. Analysis of the aqueous extracts from the tested sands covered several determinations. The pH of the solutions was determined with the use of Elmetron CPC-501 device in accordance with the standard PN-Z-15011-3[16]. The content of chlorides was determined with Mohr method with the use of silver nitrate (V) as a titration reagent and potassium chromate (VI) as an indicator (PN-ISO 9297) [19]. The determination of the sulphates (VI) (SO_4^{2-}) was performed with a gravimetric method with barium chloride according to the standard PN-ISO 9280 [20]. Determination of the content of sodium, calcium, potassium, lithium and barium in aqueous extracts from sands was performed through flame emission spectroscopy following stan-

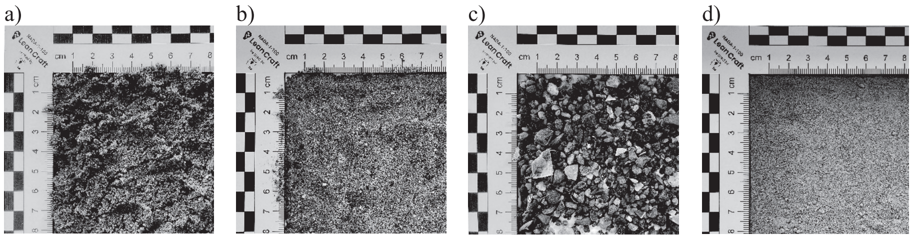

Fig. 1. Tested sand from desanding (S_1) a) raw fraction, b) fraction below 2 mm, c) fraction above 2 mm, d) analytical fraction

Rys. 1. Badany piasek z piaskownika (S_1) a) frakcja surowa, b) frakcja poniżej 2 mm, c) frakcja powyżej 2 mm, d) frakcja analityczna

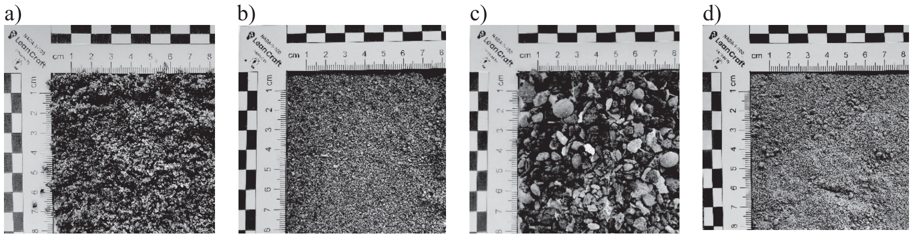

Fig. 2. Tested sand from desanding (S_2) a) raw fraction, b) fraction below 2 mm, c) fraction above 2 mm, d) analytical fraction

Rys. 2. Badany piasek z piaskownika (S_2) a) frakcja surowa, b) frakcja poniżej 2 mm, c) frakcja powyżej 2 mm, d) frakcja analityczna

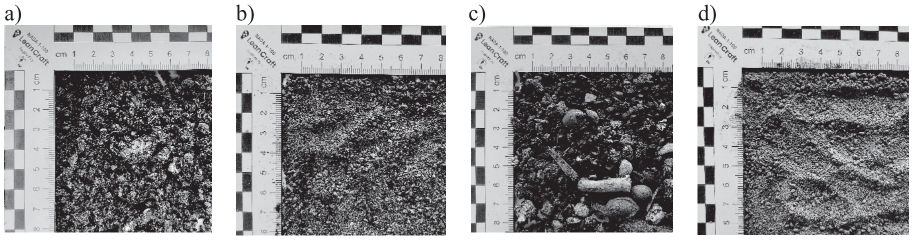

Fig. 3. Tested sand from desanding (S_3) a) raw fraction, b) fraction below 2 mm, c) fraction above 2 mm, d) analytical fraction

Rys. 3. Badany piasek z piaskownika (S_3) a) frakcja surowa, b) frakcja poniżej 2 mm, c) frakcja powyżej 2 mm, d) frakcja analityczna

Tab. 2. Basic physicochemical properties of tested sands from desanding

Tab. 2. Podstawowe właściwości fizykochemiczne badanych piasków z piaskowników

Properties	Symbol	Unit	S_1	S_2	S_3
Moisture total	M_T	%	15.93	13.50	30.32
Dry matter	DM	%	84.07	86.50	69.68
Moisture analytical	M_a	%	0.44	0.74	0.84
Bulk density	ρ_n	kg/dm^3	1.38	1.33	0.85
Degradable organic substances	DOS	%	1.21	3.79	8.21
Total organic carbon	TOC	%	0.57	1.78	3.86
Ammonium nitrogen	$N-NH_4^+$	mg/kg	23.47	loq**	182.20

*blq –values below the limit of quantification, **loq - the limit of quantification

dard PN-ISO 9964-3 [21]. Phosphorus was determined with the spectrophotometric method with ammonium molybdate and tin(II) chloride as reductors (PN-EN ISO 6878:2006) [22]. Photometric determination of fluorides was performed with the use of 1,8-Dihydroxy-2-(4-sulfophenylazo)naphthalene-3,6- disulfonic acid (SPADNS) [23]. For the evaluation of the content of heavy metals in aqueous extracts atomic absorption spectrometer AVANTA PM from GBC company was used which allows the determination of the elements with flame atomic absorption spectroscopy.

3. Results and Discussion

Table 2 presents the results which picture the basic physico-chemical properties of tested sands from desanding. Tested sands differed in the degree of leachability and dehydration. Sample S_3 contained approximately 30% of water, whereas samples S_1 and S_2 contained half of this water. According to the report RILEM [11] minimum density of recycled aggregate RCAC III in a dry state equals 2.400 kg/dm³. Tested waste sands had lower density which may limit their reuse in the construction industry. However, the content of organic carbon (TOC) for samples S_1 and S_2 did not exceed 2% of the sand mass. Sample S_3 contained approximately 4% of organic carbon. Total organic carbon in tested samples did not exceed the permissible values for waste other than hazardous and neutral deposited in landfills (TOC≤5%) and for hazardous waste (TOC≤6%) [4, 5].

Fig. 4 presents a simple grain size distribution chart of tested sands. After drying, the sands were mechanically sieved into two fractions: above 2 mm and below 2 mm. An important parameter of aggregates used for the production of concrete is the so-called sand point. This is a percentage of fraction 0,063–2 mm in the total amount of the aggregate. The sand point for standard sand used in the construction industry reaches 100%. Tested samples had the sand point of about 95.2%, 90.4% and 57.3%.

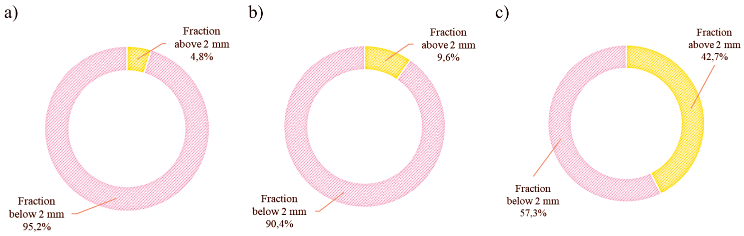

Fig. 4. Simple grain size distribution scheme of tested sand a) S_1, b) S_2, c) S_3

Rys. 4. Uproszczony skład granulometryczny badanych piasków, a) S_1, b) S_2, c) S_3

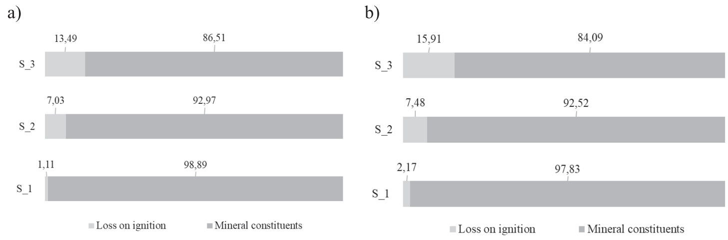

Fig. 5. Loss on ignition (LOI), a) temp. 440°C, b) temp. 600°C

Rys. 5. Loss on ignition (LOI), a) temp. 440°C, b) temp. 600°C

Tab. 3. Results of leachability of contaminants from tested sands expressed in mg/kg and mg/l (except for pH)

Tab. 3. Wyniki badań wymywalności zanieczyszczeń z badanych piasków wyrażone w mg/kg oraz mg/l (z wyjątkiem pH)

Properties	Symbol	S_1		S_2		S_3	
		mg/kg	mg/l	mg/kg	mg/l	mg/kg	mg/l
pH	pH	7.0		7.3		6.6	
Chloride	Cl-	69.12	6.91	691.20	69.12	115.20	11.52
Sulphate	SO4-	1508.47	150.85	442.94	44.29	809.09	80.91
Phosphorus	P	1.31	0.13	blq*	blq*	13.07	1.31
Potassium	K	23.90	2.39	24.20	2.42	147.80	14.78
Calcium	Ca	223.60	22.36	174.90	17.49	198.80	19.88
Sodium	Na	20.80	2.08	24.90	2.49	39.40	3.94
Fluoride	F	7.56	0.76	4.00	0.40	12.41	1.24
Barium	Ba	0.60	0.06	blq*	blq*	45.60	4.56
Ammonium nitrogen	N - NH_4^+	23.47	2.35	loq**	loq**	182.20	18.22
Zinc	Zn	1.00	0.10	1.10	0.11	3.50	0.35
Copper	Cu	0.60	0.06	0.80	0.08	blq*	blq*
Lead	Pb	0.05	0.005	0.50	0.05	0.20	0.02
Cadmium	Cd	0.10	0.01	0.20	0.02	blq*	blq*
Chrome	Cr	0.30	0.03	0.20	0.02	0.40	0.04
Cobalt	Co	0.20	0.02	0.40	0.04	blq*	blq*
Iron	Fe	blq*	blq*	blq*	blq*	1.30	0.13
Nickel	Ni	blq*	blq*	blq*	blq*	blq*	blq*

*blq –values below the limit of quantification, **loq - the limit of quantification

Fig. 5 presents the results of the content of organic substances (LOI). The content of organic particles was determined through the ignition method at the temperatures of 440°C and 600°C. The temperature of 440°C was selected based on the scientific literature [24]. Tested sands varied in the content of organic particles. In the case of samples S_1 and S_2, it was noted that the loss on ignition (LOI in 600°C) met the criteria for depositing in the landfills other than hazardous and neutral (LOI≤8%) [4, 5]. However, the sample S_3 does not meet the requirement that allows for depositing in landfills of hazardous waste (LOI≤10%) [4, 5].

Table 3 presents the scope of leachability of selected contaminants from the tested sands, which may pose a potential nuisance to the environment. The obtained results of leachability of hazardous substances and heavy metals from the tested sands were compared to the highest permissible values for the contaminants specified in the order [8] and permissible limiting values of contaminants that allow for depositing of waste in the landfills specified in order [5, 6]. The leachability of chlorides does not exceed the permissible levels stipulated in the discussed legal regulations. The leachability level for sulphates in tested samples did not exceed the acceptable levels for depositing in landfills of waste other than hazardous or neutral.

An exception is sample S_1 for which the sulphates level exceeds the permissible values for neutral landfills. In the case of sample S_3 the highest leachability was achieved for barium and ammonium nitrogen. Their levels exceeded the permissible values.

Furthermore, in aqueous extracts obtained from the tested sands the content of the heavy metals was determined, i.e.: zinc, lead, copper, cadmium, chrome, cobalt, iron, manganese and nickel. The obtained concentrations of heavy metals in aqueous extracts were compared with the permissible values for wastes destined for landfills other than hazardous and neutral and for hazardous wastes. It needs to be underlined that the content of heavy metals leachable from the tested sands did not exceed the permissible values for the discussed cases.

Analysing the obtained results and based on the performed determinations we may state that sands S_1 and S_2 meet the binding requirements and their reuse can be considered. However, the results for sand S_3 show that out of all the tested substances barium and ammonium nitrogen exceed the limits specified in legal regulations.

4. Conclusions

Growing demand for sand for construction may in the near future lead to an ecological catastrophe. Wasteful exploitation of such precious resources as sand causes large damage to the natural environment.

Evaluating tested sands S_1 and S_2 in light of environmental impact, we may state that the obtained levels of leachability of hazardous substances and heavy metals do not pose any potential damage to the natural environment. There are objections concerning the use of sand S_3 whose results do not meet the two parameters specified in the binding legal regulations.

In the context of the reuse in construction, the tested sands should undergo a careful washout which would decrease the amount of contaminants and result in a significant improvement in the quality of this aggregate. This simple procedure would increase the possibility of using the tested sand in the construction industry to a wider extent.

The presented results are preliminary tests. In further tests, the sand will undergo the toxicity tests and microbiological evaluation, including the determination of the indicator bacteria and selected pathogens.

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Badanie i ocena właściwości fizykochemicznych zawartości piaskowników

W artykule dokonano oceny właściwości fizykochemicznych piasku z piaskowników oczyszczalni ścieków pod kątem wymagań stawianych kruszywom budowlanym. W związku z tym przeprowadzono analizę właściwości fizycznych piasku: wilgotność, gęstość nasypową, a także analizę składu chemicznego piasku i poziom wymywalności substancji szkodliwych oraz metali ciężkich. Celem badań było znalezienie alternatywy dla malejącej zasobów tego cennego surowca, niezbędnego dla sektora budowlanego. Obecnie szacuje się, że w ciągu 20 lat zabraknie piasku odpowiedniej jakości do wykorzystania w budownictwie. W artykule przedstawiono wyniki badań fizykochemicznych oraz wymywalności wybranych substancji szkodliwych (P, F, N-NH_4^+, Cl, SO_4^{2-}) i metali ciężkich (Ba, Zn, Cu, Pb, Cd, Cr, Co, Fe, Ni) z zawartości piaskownika.

Słowa kluczowe: *oczyszczalnie ścieków komunalnych, odpady, piasek, piaskownik, ponowne wykorzystanie*