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Chemical and geotechnical properties of ash-slag mixture from "Czajka" landfill near Tarnow

Właściwości chemiczne i geotechniczne mieszaniny popiołowo-żużlowej ze składowiska "Czajki" koło Tarnowa

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Abstract

Nine million tonnes a year of ash-slag wastes generated in Poland by power plants is a serious problem. On the other hand, it is a serious resource that may be used in earthworks, particularly in road engineering. Several mechanical and chemical properties of the mixture were estimated. The results are as follows: the properties classify it as useless for earthworks purposes. Norm requirements [PN-S-02205:1998] concerning usage of furnace waste were not fulfilled with reference to linear swelling value. What is more, frost heaving criteria categorised it as questionable soils, which in combination with high values of linear swelling can cause a decline in the stability structure, which was formed from a tested mixture with lack of proper isolation from water. Concerning fulfilling requirements of the norm, shear strength and load capacity, an attempt to reduce swelling should be made, for example through improving graining of ash-slag mixture by adding some sand. However there are no doubts in matters pertaining to macro and trace elements' content in the potential leachate from the structure, which was formed from the tested mixture.

Streszczenie

W pracy podjęto problem oceny przydatności mieszaniny popiołowo-żużlowej do celów budownictwa ziemnego w oparciu o jej właściwości geotechniczne i chemiczne. Analizowana mieszania pochodziła ze składowiska „Czajki" w Bobrownikach Wielkich koło Tarnowa, gdzie zdeponowano uboczne produkty spalania (UPS) z elektrociepłowni Zakładów Azotowych w Tarnowie [www.slagrecycling.com.pl]. W pracy oceniano: skład uziarnienia mieszaniny (metody: sitowa i areometryczna), gęstość właściwą szkieletu, wilgotność optymalną i maksymalną, gęstość objętościowa szkieletu, oznaczenie wytrzymałości na ścinanie, wskaźnik nośności CBR, wymywalności pierwiastków podstawowych (Ca, Na, K, Mg) i śladowych (Cd, Pb, Cr, Zn, Cu), konduktację i pH.

Uzyskane wyniki badań właściwości geotechnicznych mieszaniny popiołowo-żużlowej kwalifikują ją jako nieprzydatną do celów budownictwa ziemnego. Wymagania normy [PN-S-02205:1998] dotyczące stosowania odpadów poenergetycznych nie zostały spełnione pod względem wielkości pęcznienia liniowego. Również kryteria wysadzinowości kwalifikują ją do gruntów wątpliwych, co w połączeniu z wysokimi wartościami pęcznienia liniowego może spowodować pogorszenie stateczności budowli wykonanej z przedmiotowej mieszaniny przy braku właściwej izolacji od wody. Zastrzeżeń nie budzą natomiast zawartości pierwiastków podstawowych i śladowych w ewentualnym odcieku z budowli wykonanej z przedmiotowej mieszaniny.

Dlatego, uwzględniając spełnienie wymagań wyżej wymienionej normy odnośnie zagęszczalności, wytrzymałości na ścinanie i nośności, należy podjąć próbę ograniczenia wielkości pęcznienia np. przez doziarnienie mieszaniny popiołowo-żużlowej dodatkiem piasku. Zagadnienie to jest o tyle istotne, że wykorzystanie uzdatnionej mieszaniny w budownictwie ziemnym wpłynie korzystnie na stan środowiska naturalnego w wyniku jej zagospodarowania i w konsekwencji rekultywacji składowiska.

1. INTRODUCTION

In Poland, the main use for furnace waste is in earthworks, in particular road engineering [Gruchot 2010; Gruchot & Zawisza 2007; Zydron et al. 2007]. Research conducted indicates its usability in hydrotechnical engineering also, for example, to seal coarse-grained materials like colliery shales [Zawisza 2007] or as a sealing in municipal landfills [Zabielska-Adamska 2006]. Such a range of usage of this waste does not solve the problem of its utilisation. In the year 2010, nearly 9 million tonnes of ash-slag mixture from wet treatment of furnace waste and nearly 4 million tonnes of fly ash were produced in Poland. In Malopolska province, there were almost 174,000 tonnes of ash-slag mixture and nearly 230,000 tonnes of fly ash. The total amount of furnace waste that was accumulated on landfills at the national level, at the end of the year 2010, was 253.7 million tonnes. It is estimated that in the year 2010, 14% of ash-slag mixture and 89% of fly ash were exploited [GUS 2011]. When using furnace waste in earthworks, there is a risk of endangering neighbouring ecosystems by the emission of substances that are in ash-slag mixture and fly-ash. These substances are, among others, heavy and alkaline metals. In addition, this waste can be the cause of salinity and alkalising of the water and soil, as well as of secondary air pollution. The direct influence on the chemical composition of furnace waste has a type of burnt coal, co-burnt additions, for example biomass, burning technology used and technical parameters of appliances that are used in energy production process. Chemical composition also depends on the mode of transport and storage [Rosik-Dulewska & Karwaczynska 2008].

2. PURPOSE AND SCOPE OF TESTS

The purpose of the tests was to determine ash-slag mixture usability for earthworks based on its geotechnical properties and leaching macro elements (Ca, Na, K, Mg) and trace elements (Cd, Pb, Cr, Zn, Cu). The determination of the amount of leaching elements was used to evaluate the impact on the ecosystem around the earth structure. The tested mixture came from "Czajka" landfill in Bobrowniki Wielkie near Tarnow, where by-products of burning from the heat and power plant of a chemical company in Tarnow were deposited [www.slagrecycling.com.pl].

Basic physical characteristics and compaction parameters were determined using standard methods. Graining was determined using combined method – sieve (for d ≥ 0.063 mm) and aerometric (for d < 0.063 mm) – whereas specific density of solid particles was determined using volumetric flask method with distilled water. Optimum moisture content and maximum dry density of solid particles were determined in Proctor apparatus in the cylinder that has the capacity of 2.2 dm^3, at the compaction energy of 0.59 $J \cdot cm^{-3}$. Shear strength tests were carried out in the standard direct shear box apparatus in 12 × 12 × 7.7 cm boxes with transitional frames that created a shearing zone that was 1.0 cm high. Samples were formed at an optimal moisture content and at the compaction index IS = 1.00. Bearing ratio was determined directly after compaction and after 4 days of soaking in water [PN-S-02205:1998] on samples that were penetrated with a plunger of 20 cm^2 area, at a velocity of 1.25 mm per minute. Value of CBR ratio was calculated at the depth penetration of 2.5 and 5.0 mm and the higher one was accepted as a reliable one. During soaking, samples' height increase, caused by saturation, was registered and then linear swelling was calculated.

Tests for leaching of soluble substances from ash-slag mixture were carried out using water extract method [Rozporządzenie 1999]. In this method, 100 g sample of the mixture was dried at 105°C temperature and then sieved through net sieve no. 10. After that, the taken sample was poured in the flask with 1 dm^3 of distilled water and shaken on the laboratory shaker for 4 hours. Next it was left for 12 hours and shaken again for 2 hours. After 6 hours, the mixture was filtered through a medium filter to get a water extract, for which pH, specific electrolytic conductance and some macro and trace elements content were determined using atomic absorption spectroscopy method FAAS in Unicam Solaar M6 spectrometer.

3. TESTS RESULTS AND THEIR ANALYSIS. PHYSICAL AND MECHANICAL CHARACTERISTICS

According to the geotechnical nomenclature [PN-EN ISO 14688-2:2006], ash-slag mixture was classified as well-graded sandy silt (saSi). In graining, silt fraction dominated in the amount of 45%, there was 38% of sand fraction and less than 3% of clay fraction (fig. 1). Gravel fraction content did not exceed 15%.

Specific density was on average 2.31 $g \cdot cm^{-3}$. Maximum dry density of solid particles was 1.24 $g \cdot cm^{-3}$ with optimal moisture content about 31%. Passive capillary was above 0.6 m and sand equivalent over 9%. Tests for shear strength of ash-slag mixture showed high values. At the compaction index IS = 1.00, the angle of internal friction was on average 33° and cohesion about 35 kPa (Table 3). Ash-slag mixture also had high values of bearing ratio. For samples loaded with the force of 22 N directly after compaction, bearing ratio was on average about 23% and after 4 days of soaking and increase in moisture content of about 10%, bearing ratio decreased to about 12%. Values of linear swelling for samples at the load of 22 N did not exceed 1%, whereas for samples without loading they were over four times higher and they amounted to 4.6%.

4. LEACHING OF SOLUBLE SUBSTANCES

From the ecological point of view, the most important characteristic of waste for quality and environment safety is leaching of chemical substances, which can cause pollution of ground or surface waters in a large area. Metals that are part of fly-ash composition are in many forms and phases that differ in mobility, bioavailability and toxicity. All these characteristics determine a specific behaviour in environmental conditions and influence on organisms, including humans' health [Swietlik & Trojanowska 2009]. Reemission of metals from industrial ashes to the environment can occur in two ways, i.e. directly through ashes' influence on the environment in the place of their production and deposition or secondarily, through their usage or chemical processing. Metal's ability to migrate from ash to water and soil in the environmental conditions is defined as mobility, and quantity evaluation indicates the degree of mobility of the given metal [Kalembkiewicz & Soco 2009]. When evaluating the nuisance of furnace waste, tests on leachates from a given landfill are carried out in the aspect of potential pollution's leaching [Gilewska & Spychalski 2005; Kapuscinski & Strzalkowska 2005; Rosik-Dulewska & Karwaczynska 2008; Zawisza 2001]. Based on

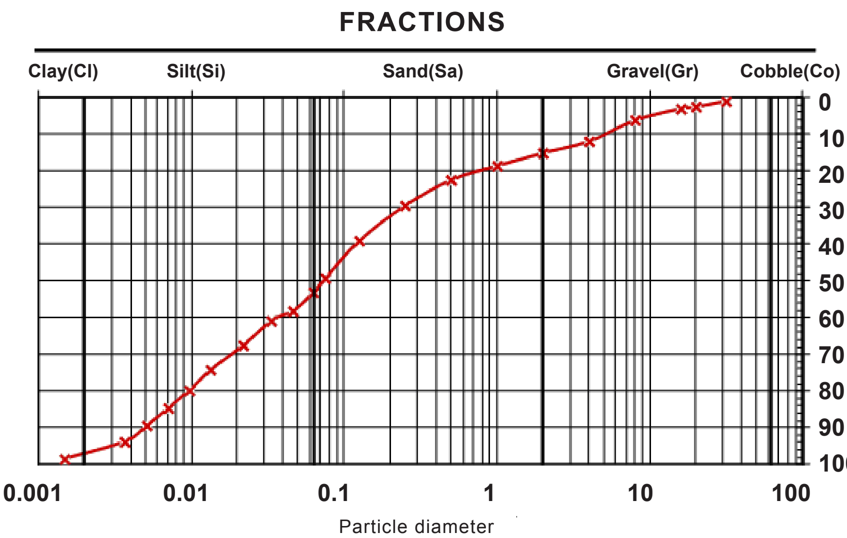

Figure 1 Grading curve of ash-slag mixture

Table 1. Geotechnical properties of ash-slug mixture

No.	Parameter		Value
1	Fraction content [%]: – gravel Gr: 63 ÷ 2 mm – sand Sa: 2 ÷ 0.063 mm – silt Si: 0.063 ÷ 0.002 mm – clay Cl: < 0.002 mm		 14.9 38.1 44.5 2.5
2	Name acc. to [PN-EN ISO 14688-2:2006]		saSi sandy silt
3	Content of particles [%]: – ≤ 0.075 mm – ≤ 0.02 mm		 50.8 31.0
4	Uniformity coefficient, C_U [-]		28.1
5	Coefficient of curvature, C_C [-]		0.5
6	Specific gravity ρ_s [$g \cdot cm^{-3}$]		2.37
7	Optimal moisture content w_{opt} [%]		31.4
8	Maximum dry density ρ_{ds} [$g \cdot cm^{-3}$]		1.24
9	Passive capillary h_{cp}[m]		0.64
10	Sand equivalent SE [-]		9.4
11	Angle of internal friction, ϕ [°] at compaction index I_S = 1.0		31.2–35.0
12	Cohesion, c [kPa] at compaction index I_S = 1.0		35.3–35.4
13	Bearing ratio CBR, $w_{noś}$ [%] after time of soaking [days]	0	22.5–24.0
		4	11.5–12.0
14	Linear swelling after 4 days of soaking, p [%] at the load of 22 N		0.81–0.92
15	Linear swelling after 4 days of soaking, p [%] without load		4.47–4.70

tests concerning occurrence of toxic elements in fly ash, it can be stated that most of these elements concentrate in stable structures of aluminosilicate phases, which do not, or only to a small extent, leach in water. Therefore, their content in eluate is usually on the detection border and only in a few cases exceeds allowable limits for drinking and surface waters. Low solubility of heavy metals is usually caused by strong alkaline reaction of water extract from ashes (pH = 9.0–12.0) [Kapuscinski & Strzalkowska 2005]. It is confirmed with reference to tested furnace waste for which eluate reaction was 9.7 (Table 2). Tested water extract was also characterised by low concentration of analysed elements, particularly noticeable in case of Cd, Pb, Cu, Zn contents, whose concentrations were a few times lower in ash tests (both static and dynamic) as presented by Rosik-Dulewska and Karwaczynska [2008] as well as by Wozniak and Zygadlo [2002].

Obtained test results were also analysed in the aspect of ash-slag mixture's potential influence on the surrounding earth structure ecosystem. Considering lack of guidelines, evaluation was carried out with regard to surface and ground water pollution, assuming that water percolating through mixture layers can get to these waters [Rozporządzenie 2011, Rozporządzenie 2008]. In the evaluation, the following documents were used: Regulation of Minister of Economy and Labour on procedures of allowing waste for given type of landfill [Rozporządzenie…2005] and Regulation of Minister of Environment on conditions that have to be fulfilled when introducing sewage to water and soil, as well as on substances which are particularly harmful to water environment [Rozporządzenie…2006]. In the tested eluate, determined contents of heavy metals (Table 2) are much lower than allowable limits for surface and ground waters [Rozporządzenie…2011, Rozporządzenie…2008] and do not have an influence on potential pollution of these waters. Contents of mentioned elements were also within the values of geochemical background for surface water that is presented by Kabata-Pendias and Pendias [1999] and are from a dozen to a few dozen times lower than allowable concentrations that are set for sewage quality [Rozporządzenie…2006] as well as for leachates to form landfills [Rozporządzenie…2005].

Determined values of conductance and magnesium concentration allow us to classify tested sample for the I class of surface and ground water purity. Calcium contents in the tested eluate fulfil given criteria for surface water quality; however, in the top determined range they exceed allowable value for the I class of groundwater. Regulations concerning surface water quality do not set the limit values for sodium and potassium, allowable

Table 2. Results of tests on leaching of soluble substances from ash-slag mixture

No.	Determined index	Unit	Content in eluate
1	pH	–	9.7
2	Conductance	$\mu S \cdot cm^{-1}$	460
Macro and trace elements content			
3	Cd	$\mu g \cdot dm^{-3}$	< 0.4
4	Pb		<0.1
5	Zn		4.9–5.2
6	Cu		2.7–3.8
7	Cr		0.6–2.8
8	Na	$mg \cdot dm^{-3}$	5.5–11.5
9	K		13.8–15.4
10	Ca		32.2–67.6
11	Mg		0.3–18.3

concentrations of these elements are presented in groundwater quality evaluation. In the case of evaluated eluate, sodium content fulfils the I class criteria, whereas potassium occurs in concentrations that are characteristic of the IV class of quality of groundwater. The second indicator of the tested mixture which exceeds allowable limits given in all mentioned regulations is a pH reaction. It should however be remembered that water extracts from furnace waste tend to have a strong alkalinity [Wozniak, Zygadło 2002, Rosik-Dulewska, Karwaczynska 2008]. Tests that were carried out in the longer period of time indicate that high value of pH occurs only at the beginning of storage of ash-water emulate. On landfills there are binding processes that change the character of water extracts that are carried out into the environment. pH reaction is lowering and after binding processes are over, it is close to neutral [Adamczyk, Skrzypczak 2004, Wozniak, Klisik 2007]. Similar relations can also occur in reference to the tested mixture.

5. EVALUATION OF MIXTURE USABILITY FOR EARTHWORKS

Polish norm [PN-S-02205:1998] classifies ash-slag mixtures as materials suitable for earthworks, but with some conditions. They are allowed to be used in the bottom layers of embankments below frost penetration zone if they are in dry places or are isolated from water. These mixtures can also be used for top layers of embankments within frost penetration zone if they are improved with hydraulic binding agents (cement, lime, silment).

Sand–gravel fraction content in the tested mixture was about 53%, and grains below 0.075 mm were about 51%, which fulfilled appropriate requirements concerning fraction content. Bearing ratio after 4 days of soaking was insignificantly higher and angle of internal friction was 1.5 times higher than the required values. Also, values of maximum dry density of solid particles (0.3 g•cm^{-3} higher than the required value) and passive capillary (nearly 1.4 m lower than required value) fulfilled the requirements of the appropriate norm. Therefore, it can be stated that the tested ash-slag mixture fulfils most of norm requirements (Table 3). However, because of high values of swelling of samples without load which exceeded allowable values by two times, the mixture cannot be used for earthworks purposes.

As regards frost heaving, the tested ash-slag mixture was classified as frost-susceptible soil (Table 4). According to the presented criteria, only values of passive capillary allowed for classifying it as non-frost-susceptible soil.

Analysis of macro and trace elements as well as conductance indicates that leachate that occurs as a result of percolating or filtration through the tested mixture should not influence the surrounding ecosystem in a negative way. Doubts in this matter are raised only by increased value of pH reaction, which exceeds allowable, by norms, values to a small extent (0.5–1.2 unit) and by potassium leaching in relation to potential ground water pollution (the IV purity class).

6. CONCLUSIONS

Obtained test results of ash-slag mixture's geotechnical properties classify it as useless for earthworks purposes. Norm requirements [PN-S-02205:1998] concerning usage of furnace waste were not fulfilled with reference to linear swelling value. What is more, frost heaving criteria categorised it as questionable soils, which in combination with high values of linear swelling can cause a decline in the stability structure, which was formed from the tested mixture with lack

Table 3. Ash-slag mixture parameters in comparison to norm requirements

No.	Parameter	Symbol	Unit	Value: Determined	Value: Required by PN-S-02205
1	Content of: – Sand-gravel fraction – Grains below 0.075 mm	—	%	 53 50.8	 ≥ 35 ≤ 75
2	Maximum dry density	ρ_{ds}	g•cm^3	1.24	≥ 1.0
3	Bearing ratio after 4 days of soaking	BR	%	11.8	≥ 10
4	Linear swelling: – without load – with load of 20 N		%	 0.9 4.6	 lack of value 2.0
5	Angle of internal friction	ϕ	°	33.1	≥ 20
6	Passive capillary	h_{cp}	M	0.64	≤ 2.0

Table 4. Ash-slag mixture parameters in comparison with soils' classification criteria concerning frost heaving

Parameter	Requirements for soils [PN-S-02205:1998]: Non-frost-susceptible	Questionable	Frost-susceptible	Determined value	Category
Content of particles [%]: **– ≤ 0.075 mm** **– ≤ 0.02 mm**	 < 15 < 3	 15–30 3–10	 > 30 > 10	 50.8 31.0	**frost-susceptible**
Passive capillary h_{cp}[m]	< 1.0 m	≥ 1.0 m	> 1.0 m	0.64	**non-frost-susceptible**
Sand equivalent SE [-]	> 35	25–35	< 25	9.4	**frost-susceptible**

of proper isolation from water, whereas there are no doubts in the matter of macro and trace elements content in the potential leachate from the structure, which was formed from the tested mixture.

Therefore, concerning fulfilling requirements of the mentioned norm about compaction, shear strength and load capacity, an attempt to reduce swelling should be made, for example through improving graining of ash-slag mixture by adding some sand. This issue is important because usage of mentioned mixture in earthworks will positively influence natural environment as a result of its putting to use and, as a consequence, landfill reclamation.

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