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Recovery of the raw materials as an element of coal waste management and reusing of landfill sites

Introduction

The Przechlebie dumping ground is one of numerous facilities for the disposal of coal waste, although large amounts of solid waste from coal-fired thermal power plants have also been deposited apart from mining waste. In the years 1965–1999, mining waste from several hard coal mines and solid waste from the Rybnik, Zabrze, Miechowice and Szombierki power plants was stored there. These materials constitute mutual interbedding in many parts of the dumping ground. Only the southern part of the facility constitutes a large reservoir of fly ash covered with a layer of gangue with a thickness of 1 to 3 m.

Continuing the idea contained in the earlier study (Róžański 2019; Róžański et al. 2016), the Przechlebie dumping ground is considered an anthropogenic source of raw materials in the article. The purpose of the study (Róžański 2019) was to assess the environmental impact of mining waste deposited on the dumping ground. As part of the assessment, a qualitative evaluation of this waste, as well as leachates deriving it, was carried out. Tests on significant

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physicochemical properties and chemical composition of the waste were conducted as well. In addition, samples of groundwater present in the immediate vicinity of the dumping ground were tested. A minimal impact of mining waste accumulated on the dumping ground on the environment was stated. On the basis of the obtained results, the possibility of its multi-directional use was confirmed, especially after separating coal from it.

The purpose of this paper was to assess the possibility of coal recovery from mining waste. For the deposited mining waste, an analysis of the basic quality parameters of solid fuels was carried out, in particular, including the determination of the calorific value as well as moisture, coal and ash content. Tests related to the separation of coal from waste using a pulse separator were carried out.

Fly ash is widely used in the production of construction materials (Iyer and Scott 2001; Giergiczny 2006; Ramezaniapour 2014; Uliasz-Bocheńczyk et al. 2015; Nordin et al. 2016); therefore, the possibility of utilizing fly ash accumulated on the Przechlebie dumping ground as an additive in the production of concrete, mortars and grouts is also evaluated in the article. The test results of fly ash properties were referred to the requirements of the PN-EN 450-1 standard. Numerous works have shown that the addition of fly ash to the concrete mix has a positive effect on its properties (American Coal Ash Association 2003; Giergiczny 2009; Ramezaniapour 2014). Limiting the amount of cement consumed by replacing it with fly ash provides both ecological and economic benefits. These include: energy saving possibilities, reduction of CO₂ emission, reduction of consumption of natural resources, management of industrial waste, as well as obtaining final materials with modified properties.

Both partially decarburized coal waste and fly ash can be used for reclamation land after re-exploitation or other degraded land. Such an example of ecological management of mining waste as well as waste from power plants is its use in the excavation pits of sand CTL Maczki-Bór (Bieczek 2007). Meanwhile, coal is recovered from the dump of the former Dębieńsko Mine in Czerwionka-Leszczyna, after which the decarburized gangue is rebuilt into a newly formed reclamation facility. In both cases, such activities significantly reduce the risk of fire due to spontaneous ignition, which is a common phenomenon in coal waste dumps.

1. Materials and methods

1.1. Sampling

Seven samples of primary mining waste were collected in the Przechlebie dumping ground area. The samples were taken from existing mining excavations. No material was collected from the top due to the strong degree of weathering, which had a significant effect on its properties. The minimum weight of each sample amounted to 20 kg.

Samples marked as S1, S2 were collected from the bottom of the excavation located in the western part of the dumping ground. Samples S3 and S4 were taken from a smaller excavation located in the central part of the facility. Samples marked as S5, S6 and S7 were collected from a larger excavation located in the central part of the dumping ground. The depth of sampling was from 3 to 9 m in relation to the top of the dumping ground. Figure 1 shows the locations of the sampling points.

The samples were prepared and averaged for the analysis according to the PN-G-04502:1990 Polish standard. Sample S-I was formed by mixing samples S1 and S2; samples S3 and S4 created sample S-II, while sample S-III was obtained from samples: S5, S6 and S7 collected from the largest central excavation.

Fly ash samples (S8, S9, S10) collected on the dumping ground were taken from three holes (Fig. 1) made with a drilling rig in the southern area of the dumping ground, which

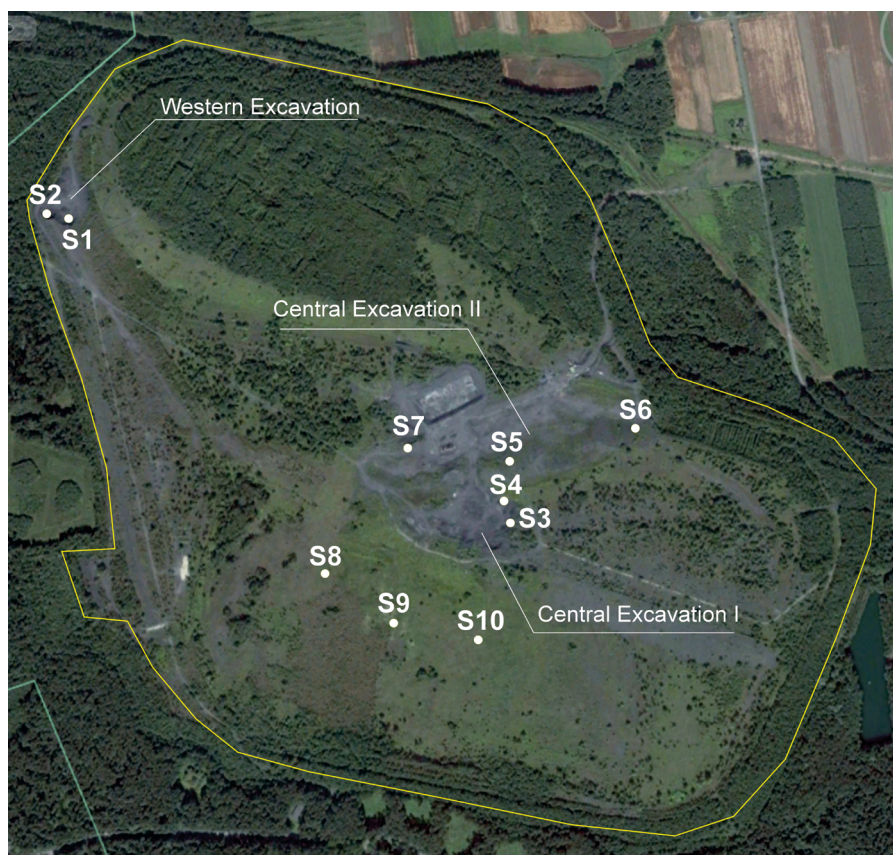


Fig. 1. Location of the sampling points
S1–S7 – samples of coal wastes, S8–S10 – samples of fly ash

Rys. 1. Lokalizacja miejsc poboru próbek
S1–S7 – próbki odpadów górniczych, S8–S10 – próbki popiołów lotnych

constitutes the main reservoir of power plant waste. Drilling was carried out using the rotational method. The depth of the drilled holes was 20 m. The ash samples used for the tests were collected from a depth of 8–10 m. The laboratory sample S-IV of fly ash was prepared according to the PN-G-04502:1990 standard by mixing and averaging three samples: S8, S9 and S10.

For the purposes of tests related to the recovery of coal from mining waste, the raw material was collected from the central excavations with a loader and poured into the infeed hopper of the mining waste enrichment complex (Fig. 2).

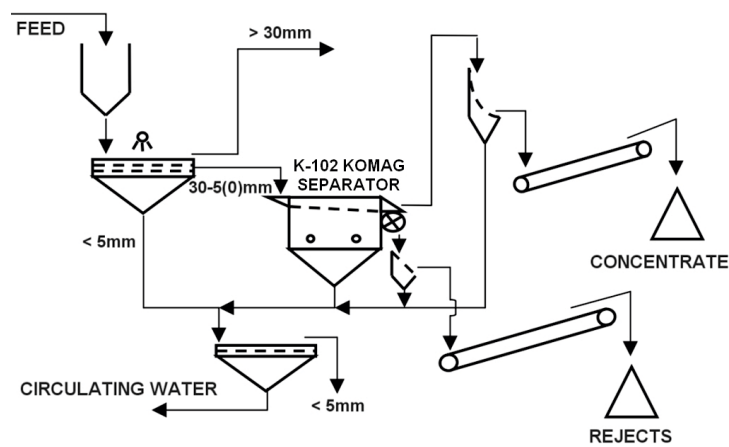


Fig. 2. The mining waste enrichment complex with K-102 Komag pulse separator (Matusiak and Kowol 2016)

Rys. 2. Kompleks wzbogacania odpadów górniczych z separatorem pulsacyjnym K-102 Komag

1.2. Determination of moisture, ash and calorific value content of coal mining waste

The determination of the transient moisture content W_{ex} and hygroscopic moisture content W_h in the analytical samples was carried out according to the PN-80/G-04511 Polish standard. The A^a ash content was determined according to the method described in the PN-ISO 1171:2002 Polish standard, whereas the carbon content C was determined using Tiurin oxidimetric method. The calorific value Q_j was determined in a calorimetric bomb according to the PN-ISO 1928:2002 Polish standard. Due to the lack of initiation of sample ignition, benzoic acid was added as a reaction catalyst.

1.3. Tests on the possibilities of coal recovery

Coal contained in mining waste accumulated on numerous dumping grounds is the cause of endogenous fires. Numerous fire prevention methods have been developed (Sułkowski et al. 2008; Łączny et al. 2012). However, the most effective method in this area is to strip the dumping ground and use the material collected on it. Since the coal content in the material limits the scope of direct use of coal waste, the separation of coal from waste is proposed in the work, not only reducing the fire hazard, but also providing economic benefits from the sale of coal and increasing the use of decarbonized mining waste, whether on site in order to reconstruct the dumping ground or outside its area.

Similarly to the enrichment of bituminous coal in processing plants, the recovery of coal from coal mining waste is mainly based on gravity methods, i.e. enrichment in heavy liquids, in cyclones with heavy liquid or in jigs (Blaschke 2009). The initial attempts to separate coal from the mining waste collected on the Przezchlebie dumping ground with the use of heavy liquids failed to produce satisfactory results due to the significant pollution of the mining waste by fly ash, which significantly influence the parameters of the heavy liquid. Therefore, tests on the possibility of coal grains recovery were carried out in a pulsating water medium in a typical gravitational mineral enrichment process consisting in delamination according to the density of ingredients. The principle of operation of such a device is described in the works (Drzymała 2007; Matusiak et al. 2012).

In the tests, the K-102 KOMAG-type pulse separator was used in the 30–5 mm grain class. The feed directed for enrichment was an intersieving product from a double-deck classifying screen with sieve openings equal to: 30 mm (upper deck) and 5 mm (lower deck). Loading of the pulse separator with the material during the tests was at the level of approx. 80 Mg/h (Matusiak and Kowol 2016; Róžański et al. 2016).

As a result of enrichment, three products were obtained: concentrate, waste and by-product of the separation, i.e. fall of fine grains through the sieving deck, which was not analyzed in the present tests. The diagram of the entire enrichment complex is shown in Figure 2.

After their purging (removal of grains <0.5 mm), the collected samples were subjected to laboratory analyses in terms of density composition and determination of ash content and calorific value in the obtained fractions.

1.4. Tests of fly ash for their utilization

Sample S-IV prepared from fly ash that was deposited in the southern part of the dumping ground was subjected to tests for the possibility of using them in the production of concrete, mortars and grouts. The tests were carried out at the Institute of Ceramics and Building Materials in Krakow according to PN-EN 450-1, PN-EN 196 standards. The following properties were determined:

- ◆ chemical composition,
- ◆ total moisture content,
- ◆ loss on ignition,
- ◆ fineness,
- ◆ content of free lime,
- ◆ content of reactive lime (calculations),
- ◆ Cl⁻ content,
- ◆ indicator of pozzolanic activity after 28 and 90 days,
- ◆ radioactivity rate.

Additionally, phase composition studies were performed using X-ray diffraction (XRD).

2. Results and discussion

2.1. The contents of moisture and ash as well as calorific value in mining waste

The tests on energy parameters of mining waste samples showed the following values: carbon content $C = 10.08\text{--}12.91\%$ (Róžański 2019), ash content $A^a = 70.7\text{--}79.05\%$, calorific value $Q_j = 6987\text{--}8695$ kJ/kg, the transient moisture content $W_{ex} = 2.1\text{--}3.8\%$ and hygroscopic moisture content $W_h = 1.67\text{--}3.08\%$. The test results for individual samples and average values are presented in Table 1. The extent of ash and carbonaceous substance content, confirmed with the calorific value significant for waste, indicates the validity of tests on the possibility of recovering coal from the analyzed material. Based on the experience of business entities dealing in the processing of mining waste, it appears that there are economically justified methods for recovering coal from waste collected on dumping grounds. Depending on current coal prices, they allow a profitability of the process to be obtained with an 8% coal content or even 6% with the use of some gravitational methods.

Table 1. Energetic features of mine waste from the Przezchlebie dump

Tabela 1. Energetyczne własności odpadów górnictwa ze zwałowiska Przezchlebie

Parameter	Unit	Sample I	Sample II	Sample III	Average
A ^a	%	77.49	79.05	70.70	75.75
W _{ex}	%	2.1	2.6	3.8	2.8
W _h	%	1.67	2.08	3.08	2.28
Q _j	MJ/kg	6.99	7.75	8.69	7.81
Benzoic acid content	%	13.8	14.3	11.7	13.3

2.2. Coal recovery in the pulse separator

The feed in a larger amount intended for enrichment was characterized by a high ash content of 77.91% and a low calorific value of 4.44 MJ/kg. Two products were obtained as a result of waste enrichment in the pulse separator: concentrate and waste. The test results presented in Figure 3 showed that the predominant presence in the feed included the fraction with density $>1.8 \text{ g/cm}^3$ equal to 90.53%. The yield of the concentrate obtained due to the enrichment of coal mining waste amounted to 7.66%. The average ash content in the said product amounted to 19.96%, while the calorific value was equal to 26.16 MJ/kg.

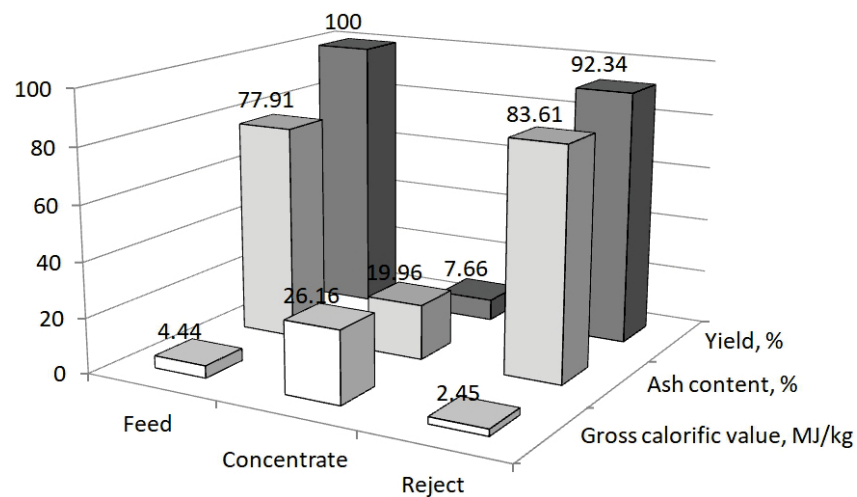


Fig. 3. The parameters of feed and the products of washing – industrial tests (Różański et al. 2016)

Rys. 3. Parametry nadawy i produktów wzbogacania – testy przemysłowe

The waste from the enrichment process with the yield equal to 92.34% was characterized by a trace content of coal grains ($<1.5 \text{ g/cm}^3$) – 0.15%, high ash content – 83.61%, and very low calorific value – 2.45 MJ/kg. After the separation of coal, the waste resulting from the enrichment process may have a wider application due to only a negligible amount of coal remaining.

During further tests carried out on the separator, additional laboratory analyses of four concentrate product samples were carried out, which showed highly favorable quality parameters of this product, i.e. low ash content of 11.45% on average as well as a relatively high calorific value equal to 26.5 MJ/kg on average. The results of the determinations are presented in the operating condition in Table 2.

Table 2. Parameters of the concentrate from the pulse separator (Róžański et al. 2016)

Tabela 2. Parametry koncentratu z separatora pulsacyjnego

No. sample	Total moisture W_t [%]	Ash content A^a [%]	Gross calorific value Q_c [MJ/kg]
1	8.1	12.0	26.14
2	7.8	11.3	26.79
3	8.3	11.7	26.65
4	9.2	10.8	26.46
Average	8.35	11.45	26.51

2.3. Assessment of the possibilities of using power plant waste

Analyzing the phase composition of fly ash based on the obtained diffractogram (Fig. 4), it was found that the main crystalline phases of ash are: quartz, mullite, hematite, calcite and

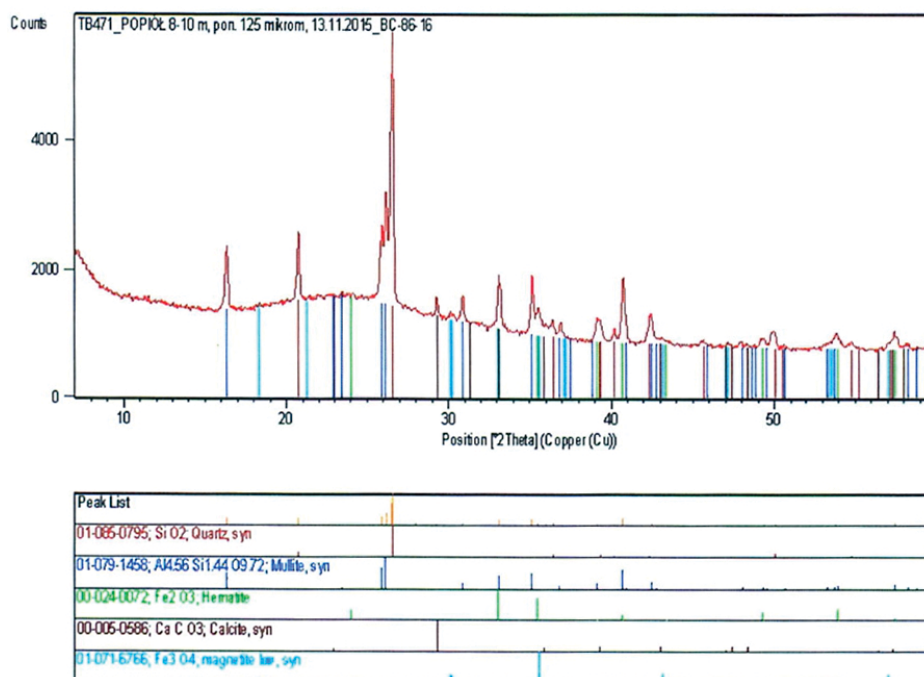


Fig. 4. Diffractogram of fly ash sample S-IV.

The main crystalline phases of ash are quartz, mullite, hematite, calcite and magnetite

Rys. 4. Dyfraktogram próbki popiołu S-IV.

Głównymi fazami krystalicznymi popiołu są kwarc, mulit, hematyt, kalcyt i magnetyt

magnetite. The test results of the chemical composition of ash from the Przechlebie dumping ground are presented in Table 3. These results do not differ from the composition of fly ash generated from the combustion of bituminous coal in other countries. The work (Roy et al. 1981) provides the test results on the composition of fly ash carried out in the 1970s, i.e. the period from which the waste partially deposited on the Przechlebie dumping ground originates. It can be stated that according to the still frequently encountered Polish classification of fly ash (according to the outdated BN-79/6722-09 standard), as regards ash from the Przechlebie dumping ground, the following conditions (in % by weight) are met: $\text{SiO}_2 > 40$; $\text{Al}_2\text{O}_3 < 30$; $\text{CaO} < 10$ and $\text{SO}_3 < 4$. Therefore, they should be classified as silica fly ash “K” formed as a result of bituminous coal combustion. Another classification found in the literature (i.a. Thomas 2007; Obla 2008) is the classification according to the American ASTM C 618 standard, which distinguishes two classes due to the type of coal from which fly ash originates. As the analyzed ash meets the following requirements (in % by weight): $\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3 > 70$; $\text{SO}_3 \leq 5$; loss on ignition ≤ 6 , according to the aforementioned standard, it can be qualified in class F including fly ash generated as a result of bituminous coal combustion. These are mainly silica ashes which have pozzolanic properties, and so they bind after adding water in the presence of calcium hydroxide (Vassilev and Vassileva 2007; Wons 2010).

Fly ash has been a valuable mineral additive in the production of cement, multi-component binders and concrete for many years. Multiple factors determine the properties of fly

Table 3. Chemical composition of fly ash from the Przechlebie dumping ground (sample S-IV) and other sources

Tabela 3. Skład chemiczny popiołu lotnego ze zwałowiska Przechlebie (próbka S-IV) oraz z innych źródeł

Component	Content in fly ash [% wgt]	
	from Przechlebie dump	from power plants in other countries acc. Roy et al. 1981
SiO_2	51.25	2.19–68.1
Al_2O_3	26.06	3.39–39.4
Fe_2O_3	7.52	3.6–29.2
K_2O	3.28	0.2–8.1
CaO	2.65	0.2–31.0
MgO	2.13	0.4–12.8
TiO_2	1.13	0.5–2.55
Na_2O	0.63	0.2–8.0
P_2O_5	0.48	0.08–6.0
SO_3	0.26	0.1–7.28
Loss on ignition	4.45	no data

ash, the most important of which include (Giergiczny 2007): type of coal burnt, type of coal combustion installation (boiler type) and technological conditions of combustion, method of fuel preparation, method of ash capture, discharge and storage, and gas desulphurization technology. The assessment of the properties of fly ash from the Przechlebie dumping ground was carried out in terms of the possibilities of using it in the production of concrete, mortars and grouts. For this purpose, the obtained test results were compared with the requirements regarding chemical and physical properties as well quality control procedures for silica fly ash provided in the PN-EN 450-1 Polish standard (Table 4). From a practical point of view, the most important properties of fly ash as an additive to concrete are the loss of ignition content and fineness. With reference to the fly ash tested, the loss on ignition was 4.45%. It is a value that corresponds to other fly ash from bituminous coal obtained in Polish power plants. In recent years, the reported losses on ignition in fly ash have decreased and usually fluctuate within the limits of 1–5% (Giergiczny 2009). The value obtained for the tested ashes allows them to be qualified in category A (loss on ignition $\leq 5\%$). A parameter that slightly deviates from the requirements of the standard is fineness, determined by the remaining grains on a sieve with a mesh diameter of 45 μm . For the tested waste, it was stated that the value exceeded the maximum value of 40% for category N by 2%. Silica fly

Table 4. Properties of fly ash from the Przechlebie dumping ground (sample S-IV)

Tabela 4. Właściwości popiołów lotnych ze zwałowiska Przechlebie (próbka S-IV)

Properties	Determination method	Results	Requirements acc. PN-EN 450-1	Accordance with requirements
Total moisture	weight method	19.25%	–	–
Loss on ignition	PN-EN 196-2	4.45%	< 5% for category A	yes
Flammable parts	DTA/TG	2.70%	< 5% for category A	yes
Fineness	PN-EN 451-2	42.0%	< 40% for category N	no
Free CaO	PN-EN 451-1	0.08%	< 2.5%	yes
Reactive CaO	PN-EN 196-2	1.5%	< 10%	yes
SO ₃	PN-EN 196-2	0.26%	< 3%	yes
Cl ⁻	PN-EN 196-2	0.01%	< 0.1%	yes
Indicators of pozzolanic activity: ♦ after 28 days ♦ after 90 days	PN-EN 196-1	81.5% 88.5%	> 75% > 85%	yes yes
Indicators of radioactivity: ♦ f ₁ ♦ f ₂	Instruction ITB 234/2003	1.04 Bq/kg 98.8 Bq/kg	Requirements for buildings with people and animals 1.2 Bq/kg 240 Bq/kg	yes yes

ash consists predominantly of spherical particles with a diameter of 3–40 μm . Frequently, the unburnt coal residue in the form of irregularly shaped crumbs is contained in a fraction thicker than 45 μm . An overly large proportion of these grains, and therefore fly ash, increases their water demand, which negatively affects the properties of the concrete produced (Giergiczny 2007, 2009). Therefore, grinding or mixing with fly ash of a lower fineness should be considered. The differentiation of grain composition and the variable specific surface are of little importance if the ashes are ground together with clinker and gypsum to obtain cement (Giergiczny 2007). The use of silica fly ash as an additive in cements intended for the production of concrete and mortars can improve their properties (i.e. consistency and workability), reduce the heat of hydration reaction as well as increase tightness and resistance to chemical aggression while extending the bonding and hardening process (Giergiczny 2006, 2007; Ramezaniapour 2014).

Other properties of ashes derived from the dumping ground, i.e. the content of flammable parts, free and reactive lime, SO_3 and Cl^- content also meet the requirements of the PN-EN 450-1 Polish standard. The results of the tests on the properties of the fly ash sample collected from the Przechlebie dumping ground together with the values of K_{28} and K_{90} activity indicators, as well as indicators including the content of natural radioactive isotopes, are presented in Table 4. The concentrations of basic natural radionuclides in the sample tested amounted to: $^{40}\text{K} = 802.3 \text{ Bq/kg}$, $^{226}\text{Ra} = 98.8 \text{ Bq/kg}$ and $^{228}\text{Th} = 89.4 \text{ Bq/kg}$. Radioactivity indicators f_1 and f_2 determined on their basis meet the requirements for materials used in buildings intended for human and animal stay.

Conclusions

The tests carried out using the pulse separator proved that coal concentrate with the calorific value of 26.5 MJ/kg and with an average ash content of approx. 11.45% and yield above 7% can be recovered from mining waste. Not only will the separation of coal from mining waste accumulated on the dumping ground favorably increase the scope of their use, but it will also help reduce the fire hazard resulting from the presence of a carbonaceous substance in waste, which is currently close to 12%.

According to the Polish classification taking the chemical composition into account, power plant waste located on the Przechlebie dumping ground is silica fly ash “K”, which belongs to class F according to the American standard. It was found that this ash has a beneficial composition as well as chemical and physical properties from the point of view of their possible use in the production of cement, concrete, mortars and grouts. They meet all the requirements of the PN-EN 450-1 standard except for the requirement concerning fineness. This parameter currently makes fly ash a non-class material. However, this property can be improved by grinding or mixing with fly ash with a lower fineness.

A more accurate determination of the usefulness of the tested fly ash in the production of construction materials will require additional strength tests on concrete samples prepared

with their addition. In addition to the production of construction materials, a wider use of fly ash is possible, e.g. as a filling material in mining, for soil stabilization in road construction, and even for the alkalization of acidic soils in agriculture. However, the assessment of such use of fly ash from the analyzed dumping ground will require additional tests on physical and chemical properties as well as ecological or hydro-geological analyses in relation to a specific area where the waste is planned to be utilized. This will be the subject of further research in the future.

Based on the test results presented in the work, a scenario of managing the Przechlebie dumping ground and the resources collected thereon, shown in Figure 5, was developed. The same or similar management scenario can be applied to other dumping grounds located in coal basins around the world.

Summing up the results presented in the articles, it can be concluded that treating the coal waste dumping ground as an anthropogenic deposit and recovery of raw materials in the form of coal, aggregate and fly ash as additives in the production of construction materials will provide numerous benefits (Fig. 5). These mainly include: obtaining energy raw material, obtaining materials for construction purposes, eliminating the fire hazard,

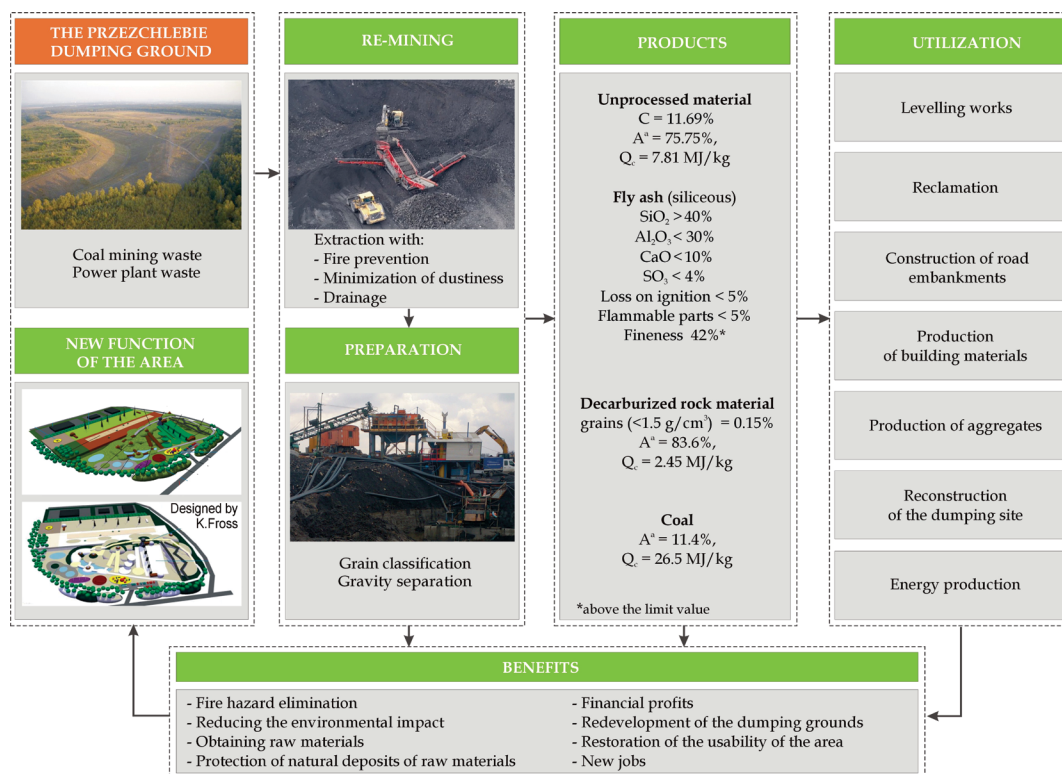


Fig. 5. Scheme illustrating proposed scenario to manage the Przechlebie dumping ground

Rys. 5. Schemat ilustrujący proponowany scenariusz zagospodarowania zwałowiska Przechlebie

reducing uncontrolled leaching of contaminations into the environment, the possibility of safe land development. In order to limit the temporary increase of environmental impact (increase of fire hazard, air pollution, reactivation of contamination leaching processes) accompanying the re-mining process, developing a safe mining technology taking the individual features of the dumping ground and local conditions into account is necessary.

Considering the number of coal waste dumping grounds in Poland and in the world, it can be stated that they may constitute an important source of secondary raw materials, the recovery of which will bring a number of environmental and economic benefits.

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**RECOVERY OF THE RAW MATERIALS AS AN ELEMENT OF COAL
WASTE MANAGEMENT AND REUSING OF LANDFILL SITES**

Key words

fly ash, anthropogenic deposit, recovery of raw materials,
fire hazard, coal waste dumping ground

Abstract

There are a huge number of objects constituting a storage place of coal mining waste in the coal basins in Poland and around the world. The article is a continuation of the study on the possibilities of using raw materials deposited on the coal mining waste dumping grounds on the example of the Przezchlebie dumping ground. The possibility of coal recovery from mining waste located on the dumping ground was analyzed. Tests on the quality parameters of waste were carried out, i.e. moisture and ash content, as well as the calorific value of raw waste. The relatively high calorific value and low ash content in the waste served as the basis for further tests related to the separation of coal. Tests on the mining waste enrichment using the complex based on the K-102 Komag pulse separator were carried out. As a result of coal separation, 7.66% of concentrate was obtained (in relation to feed) with the calorific value of 26.16 MJ/kg and ash content of 19.96%. Apart from mining waste, power plant waste (fly ash) can also be found on the dumping ground. They were subjected to tests for the possibility of using them in the production of construction materials, especially concrete and cement. Fly ash from the Przezchlebie dumping ground was classified as silica ash and it was found that it meets the requirements of Polish standard, except for the fineness of 42%. The separation of coal will eliminate the fire hazard on the dumping ground. A possible scenario of managing waste material on a dumping ground, which can be implemented in similar facilities, has been presented.

**ODZYSK SUROWCÓW JAKO ELEMENT ZAGOSPODAROWANIA ODPADÓW POWĘGLOWYCH
I PONOWNEGO WYKORZYSTANIA TERENÓW ICH SKŁADOWANIA**

Słowa kluczowe

popioły lotne, zagrożenie pożarowe, zwałowisko odpadów powęglowych,
złóże antropogeniczne, odzysk surowców

Streszczenie

Artykuł stanowi kontynuację badań nad możliwościami wykorzystania surowców zgromadzonych na zwałowiskach odpadów powęglowych na przykładzie zwałowiska Przezchlebie. W artykule poddano analizie możliwość odzysku węgla z odpadów wydobywczych ulokowanych na zwałowisku. Wykonano badania parametrów jakościowych odpadów tj. zawartość wilgoci i popiołu, wartość opałowa surowych odpadów. Stosunkowo wysoka wartość opałowa i niska zawartość popiołu w odpadach były podstawą do dalszych badań związanych z separacją węgla. Przeprowadzono testy wzb-

gacania odpadów powęglowych z wykorzystaniem kompleksu opartego na separatorze pulsacyjnym K-102 Komag. W wyniku separacji węgla uzyskano 7,66% koncentratu (w odniesieniu do nadawy) o wartości opałowej 26,16 MJ/kg i zawartości popiołu 19,96%. Oprócz odpadów wydobywczych na zwałowisku zalegają również odpady energetyczne (popioły lotne). Poddano je badaniom pod kątem możliwości wykorzystania ich w produkcji materiałów budowlanych, zwłaszcza betonu i cementu. Popiół lotny ze zwałowiska w Przechlebiu zakwalifikowano jako krzemionkowy i stwierdzono, że poza miakkością wynoszącą 42%, spełnia on wymagania normy PN-EN 450-1. Separacja węgla wyeliminuje zagrożenie pożarowe na zwałowisku. Reeksploatacja z równoległą odbudową obiektu ukierunkowaną na docelowe zagospodarowanie terenu zwałowiska korzystnie wpłynie na środowisko, przy jednoczesnych korzyściach ekonomicznych wynikających z wykorzystania surowców znajdujących się w odpadach. Przedstawiono możliwy scenariusz zagospodarowania materiału odpadowego na zwałowisku, który może zostać zaimplementowany na innych tego typu obiektach.