Separation of Materials Containing Rare Earth Elements using Screening and Magnetic Separation

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http://doi.org/10.29227/IM-2024-01-113

Submission date: 25-06-2024 | Review date: 08-07-2024

Abstract

This article presents research on selected materials with the aim of determining their rare earth element (REE) content and attempting to intensify it. The test material was coal slurry, which is a waste product from the operation of a preparation plant of a closed coal mine. Research on REE concentration intensification tests was carried out using magnetic separation. Laboratory analyses determining the REE content in the samples obtained, were carried out using the inductively coupled plasma ionisation mass spectrometry (ICP-MS) technique. Carrying out this research by the KOMAG Institute of Mining Technology, is a continuation of work related to making mining waste economically useful and determining a new source of REE recovery. Previous research and development work showed REE content (scandium 40.49 ppm) in the coal slurries studied. The result of the work carried out is the determination of the economic utility of REE recovery from the studied waste.

Keywords: *rare earth elements (REE), magnetic separation, coal tailings, coal slurries*

1 Introduction

Rare earth elements, REEs (rare-earth elements), are a group of elements of strategic importance, globally. Their importance is related to the need for their use in modern and advanced technologies. The European Union, including Poland, counts REEs among its 30 economically critical raw materials. According to forecasts, their demand is expected to double by 2060.[1] These elements are widely distributed in nature, but have low concentrations. Deposits that can be economically exploited are few in number and are mainly located in China resulting in the need to import these elements [1,2]. Therefore, many projects are underway to identify new sources of rare earth elements.

In a previous study, REEs with a varying distribution of REEs were shown to contribute to the REE distribution (coal samples, mineral aggregate, energy waste or metallurgical waste). The REE contribution was also shown to vary between the raw sample and the separated grain class in the range 0.045–0 mm [3–9].

This article contains the results of a completed study, extending previous research to determine the REE content of a material sample in specific grain classes. The research included an attempt to increase the concentration of REE content using magnetic separation, which separates material based on differences in magnetic susceptibility.

1.1. Rare earth elements

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Fig. 1. Mine heap from which the test sample was taken [own source]
Rys. 1. Hałda odpadów górniczych skąd pochodziły badane próbki

Tab. 1. Overview of the mass distribution of the granulometric classification of coal slurry
Tab. 1. Analiza składu ziarnowego mułów węglowych

No.	Number and identification of the sample	Grain class yield [%]
1.	P8 – Coal slurries >2.0 mm	3.6
2.	P7 – Coal slurries 2.0–1.0 mm	2.1
3.	P6 – Coal slurries 1.0–0.5 mm	11.3
4.	P5 – Coal slurries 0.5–0.25 mm	15.3
5.	P4 – Coal slurries 0.25–0.125 mm	20.5
6.	P3 – Coal slurries 0.125–0.063 mm	13.2
7.	P2 – Coal slurries 0.063–0.045 mm	3.6
8.	P1 – Coal slurries <0.045 mm	30.4
9.	Total	100

Tab. 2. Overview of mass distribution of granulometric classification of basalt aggregate
Tab. 2. Analiza składu ziarnowego kruszywa bazaltowego

No.	Number and Identification of the Sample	Grain Class Yield [%]
1.	P16 – Basalt aggregate >2.0 mm	14.0
2.	P15 – Basalt aggregate 2.0–1.0 mm	2.0
3.	P14 – Basalt aggregate 1.0–0.5 mm	5.8
4.	P13 – Basalt aggregate 0.5–0.25 mm	8.8
5.	P12 – Basalt aggregate 0.25–0.125 mm	12.2
6.	P11 – Basalt aggregate 0.125–0.063 mm	21.1
7.	P10 – Basalt aggregate 0.063–0.045 mm	31.0
8.	P9 – Basalt aggregate <0.045 mm	5.1
9.	Total	100.0

1.2. Magnetic separation

the magnetic separation process is a popular method used in rare earth processing. It is one of the first operations in the processing line (after crushing and grinding) to separate medium and low magnetic susceptibility minerals. (after crushing and grinding) with the aim of separating minerals with medium and low magnetic susceptibility. The product, with a concentrated content of the useful ingredient, is directed to the subsequent processing operations, mainly chemical. The efficiency of the process is highly dependent on:

(1) the strength of the magnetic field,
(2) the degree of loosening of the material layer fed to the separator,
(3) the magnetic susceptibility of the material,
(4) the size of the grains,
(5) the resistance posed by the grains (gravitational and frictional forces) [17,18].

Due to the varying magnetic susceptibilities of grains under the effect of a magnetic field, the material is divided into: paramagnetics, diamagnetics and ferromagnetics. Paramagnetic grains are attracted in the direction of the magnetic field strength, while diamagnetic grains are repelled. Ferromagnetic grains have a higher degree of magnetisation at lower magnetic field strengths, retaining a certain level of magnetism when isolated from the magnetic field.

This type of devices differs in design and in the medium in which the separation takes place (dry and wet separators), but the principle of operation, based on the magnet, is identical. Among others, magnetic wheels, hanging magnets, magnetic rotary drums or flat magnets are used. The principle of operation of dry magnetic separators is based on the use of a rotating drum with magnets. Feed material is transported via a conveyor belt underneath the drum, allowing magnetically susceptible grains to be separated by the magnetic field. The material with higher susceptibility is lifted through the magnetic drum and then placed in a separate hopper. It is possible to adjust the intensity of the magnetic field and thus change the separation limit due to the magnetic susceptibility of the grains [19].

Rare earth elements, with the exception of lanthanum, scandium, ytterbium, lutetium and yttrium, have magnetic susceptibility. REE minerals such as bastnazite, monazite and xenotime have varying magnetic properties, so it is possible to use magnetic separation to intensify the REE contribution [20].

1.3. Research carried out by itg komag related to REE

Due to the lack of REE deposits in Poland and their geopolitical value, it is necessary to identify alternative sources of REE. Work has been carried out at the KOMAG Institute of Mining Technology to determine REE content in the following groups of materials, mainly waste materials from their disposal sites:

(1) hard coals – analyses of type 31 thermal coal showed cerium content of 27.2 ppm (2019) [3],
(2) mining wastes – analyses of wastes constituting coal slurries showed a scandium content of 33.4 ppm (2020) [5],
(3) power plant energy waste – analyses of fly ash and power plant slags showed a cerium content of 34.0 ppm and yttrium content of 29.6 ppm (2019) [6],

Fig. 2. Magnetic separator – vibrating material feeder [own elaboration]
Rys. 2. Separator magnetyczny – podajnik wibracyjny nadawy

Fig. 3. Magnetic separator – reception of diamagnetic material [own elaboration]
Rys. 3. Separator magnetyczny – odbiór produktu magnetycznego

Tab. 3. Overview of outputs of magnetic separation products.
Tab. 3. Analiza wychodów produktów wzbogacania magnertycznego

Lp.	Number and Identification of the Sample	Grain Class Yield [%]
1.	P17 – paramagnetic product with higher susceptibility, coal slurries	0.46
2.	P18 – paramagnetic product with low susceptibility, coal slurries	1.41
3.	Non-magnetic product, coal slurries	98.1
4.	Summary	100
5.	P19 – paramagnetic product with higher susceptibility, basalt aggregate	7.3
6.	P20 – paramagnetic product with low susceptibility, basalt aggregate	12.9
7.	Magnetically not susceptible product, basalt aggregate	79.8
8.	Summary	100

(4) energy waste from landfills – analyses showed a neodymium content of 47.76 ppm (2020) [9],
(5) metallurgical waste – analyses of waste from sludge tanks showed a neodymium content of 17.3 ppm (2022) [21],
(6) mineral raw materials – testing showed a proportion of 45 ppm lanthanum in basalt (151.4 cerium in the finest grain class), 22.0 ppm scandium in halloysite, and 21.8 ppm scandium in sands [4,8],
(7) electronic waste – studies to determine the contribution of REE and attempts to recover elements from hard drives and wind turbine components (unpublished research).

In the present study, analyses were carried out with the application of magnetic separation, where again the REE content of the mining muds and natural aggregate was determined. The study was extended, compared to the previous stages of research, to determine the REE content of individual grain classes (classes differing in grain size).

2. Materials and methods

Material was extracted from the post-mining waste dumps of the DZW (Lower Silesian Coal Basin). The material deposited at the landfill is characterised by a diversified structure due to the method of its disposal and atmospheric influence. The material was collected from three selected locations of the landfill, representing different density structures (Figure 1).

Another test material is natural aggregate, i.e. basalt aggregate. This aggregate comes from the mine, which exploits a basalt deposit located in south-western Poland. This mine produces basalt aggregate in a range of grain sizes. The mine's deposit is excavated using drilling and blasting operations. The plant's technology includes multi-stage grading and crushing. The material used in the research is one of the mine's commercial products and is a 2–0 mm basalt aggregate.

In order to determine the content of rare earth elements in the extracted material, the following laboratory and research methods were used:
(1) granulometric classification and grinding,
(2) magnetic separation,
(3) analysis of REE content by ICP-MS for the obtained products of granulometric classification and magnetic separation.

2.1. Granulometric classification

Based on the results obtained in previous stages [7,9], the REE content was shown to vary according to grain size (grain class). The sieve analysis performed, yielded the following eight grain classes:
(1) >2.0mm.
(2) 2.0–1.0mm.
(3) 1.0–0.5mm.
(4) 0.5–0.25mm.
(5) 0.25–0.125mm.

Tab. 4. Overview of results of REE content in coal slurries, for individual grain classes

Tab. 4. Analiza zawartości REE w klasach ziarnowych, w odpadach węglowych

No.	**Number and identification of the sample**	**Rare earth content [ppm].**					
1.	P1 Grain class >2 mm	**Sc**	**Y**	**La**	**Ce**	Pr	Lu
2.		2.35	2.36	2.08	1.86	1.93	2.11
4.		Nd	Sm	Eu	Gd	Tb	**ΣREE**
5.		1.93	1.92	2.44	2.18	1.85	**34.44**
6.		Dy	Ho	Er	Tm	Yb	
7.		2.64	1.86	2.54	1.86	2.53	
8.	P2 Grain class 2–1 mm	Sc	Y	La	Ce	Pr	Lu
9.		2.69	2.72	2.4	2.15	2.22	2.43
10.		Nd	Sm	Eu	Gd	Tb	**ΣREE**
11.		2.22	2.21	2.81	2.52	2.14	**39.67**
12.		Dy	Ho	Er	Tm	Yb	
13.		3.04	2.15	2.92	2.14	2.91	
14.	P3 Grain class 1–0.5 mm	Sc	Y	La	Ce	Pr	Lu
15.		2.11	2.14	1.89	1.69	1.75	1.91
16.		Nd	Sm	Eu	Gd	Tb	**ΣREE**
17.		1.75	1.74	2.21	1.98	1.68	**31.2**
18.		Dy	Ho	Er	Tm	Yb	
19.		2.39	1.69	2.3	1.68	2.29	
20.	P4 Grain class 0.5–0.25 mm	Sc	Y	La	Ce	Pr	Lu
21.		2.68	2.72	2.39	2.14	2.21	2.42
22.		Nd	Sm	Eu	Gd	Tb	**ΣREE**
23.		2.21	2.2	2.8	2.51	2.13	**39.66**
24.		Dy	Ho	Er	Tm	Yb	
25.		3.03	2.28	2.91	2.13	2.9	
26.	P5 Grain class 0.25–0.125 mm	Sc	Y	La	Ce	Pr	Lu
27.		2.84	2.87	2.53	2.26	2.34	2.47
28.		Nd	Sm	Eu	Gd	Tb	**ΣREE**
29.		2.34	2.33	2.96	2.65	2.25	**41.69**
30.		Dy	Ho	Er	Tm	Yb	
31.		3.2	2.26	3.08	2.25	3.06	
32.	P6 Grain class 0.125–0.063 mm	Sc	Y	La	Ce	Pr	Lu
33.		2.44	2.47	2.17	1.94	2.01	2.11
34.		Nd	Sm	Eu	Gd	Tb	**ΣREE**
35.		2.01	2	2.55	2.28	1.93	**35.83**
36.		Dy	Ho	Er	Tm	Yb	
37.		2.75	1.94	2.65	1.94	2.64	
38.	P7 Grain class 0.063–0.045 mm	Sc	Y	La	Ce	Pr	Lu
39.		3.1	3.19	2.6	3	2.2	2.31
40.		Nd	Sm	Eu	Gd	Tb	**ΣREE**
41.		2.53	2.22	2.72	2.54	2.05	**41.27**
42.		Dy	Ho	Er	Tm	Yb	
43.		3.0	2.06	2.86	2.04	2.85	
44.	P8 Grain class <0.045 mm	Sc	Y	La	Ce	Pr	Lu
45.		3.47	4.12	3.04	4.29	2.39	2.38
46.		Nd	Sm	Eu	Gd	Tb	**ΣREE**
47.		3.19	2.45	2.88	2.81	2.13	**46.61**
48.		Dy	Ho	Er	Tm	Yb	
49.		3.12	2.16	3.05	2.11	3.02	

(6) 0.125–0.063mm.
(7) 0.063–0.045mm.
(8) <0.045mm.

The analyses were carried out using a laboratory wet vibrating classifier, in order to correctly separate the fine grains.

The very last material preparation process was to dry the samples in a laboratory dryer to get rid of moisture.

The products were assigned the following designation:

P1. coal slurries in the class >2.0 mm.
P2. coal slurries in the class <2.0–1.0 mm.
P3. coal slurries in the class <1.0–0.5 mm.
P4. coal slurries in the class <0.5–0.25 mm.
P5. coal slurries in the class <0.25–0.125 mm.
P6. coal slurries in class 0.125–0.063 mm.
P7. coal slurries in the class <0.063–0.045 mm.
P8. coal slurries in the class <0.045 mm.
P9. basalt aggregate in class >2.0 mm.
P10. basalt aggregate in class 2.0–1.0 mm.
P11. basalt aggregate in class 1.0–0.5 mm.
P12. basalt aggregate in class 0.5–0.25 mm.
P13. basalt aggregate in class 0.25–0.125 mm.
P14. basalt aggregate in class 0.125–0.063 mm.
P15. basalt aggregate in class 0.063–0.045 mm.
P16. basalt aggregate in class <0.045 mm.

The mass distribution (Tables 1 and 2) of the classification products obtained varied. The finest grains (<0.045mm) presented the highest yield among the analysed grain classes of coal slurry, and in the case of basalt aggregate, the grain 0.063–0.045mm had the highest proportion.

Prior to magnetic separation, the grain class >2mm was crushed in a laboratory grinder, due to the characteristics of the instrument and the testing process.

2. Magnetic separation

Based on information from the literature (magnetic dependencies of individual elements) [20], a magnetic separation test was carried out using a magnetic separator (Fig.2, 3).

Magnetic separation was carried out with the device set at 25V. The selected voltage value determines the magnetic field strength of the device. The value of 25V was chosen based on previous experience.

The separation process consisted of placing 90g (for each material) of raw material in a feeder, which was then transported by conveyor belt. The central separator structure contains a rotary magnet, which causes the separation of grains based on magnetic susceptibility. Three products were thus obtained – with higher, lower and material showing no magnetic susceptibility. The products showing magnetic susceptibility, lifted by the rotary magnet from the conveyor belt, were picked up by suitable slides, while the rest of the material

Tab. 5. Overview of results of REE content in basalt, for individual grain classes

Tab. 5. Analiza zawartości REE w klasach ziarnowych, w bazalcie

No.	Number and identification of the sample	Rare Earth Content [ppm].					
1.	P9 Basalt aggregate >2.0 mm	**Sc**	**Y**	**La**	**Ce**	Pr	Lu
2.		5.83	9.26	30.64	58.3	6.22	0.14
4.		Nd	Sm	Eu	Gd	Tb	**ΣREE**
5.		22.75	4.33	1.47	5.38	0.6	**151.23**
6.		Dy	Ho	Er	Tm	Yb	
7.		3.08	0.54	1.41	0.18	1.1	
8.	P10 Basalt aggregate 2.0–1.0 mm	Sc	Y	La	Ce	Pr	Lu
9.		7.67	10.84	38.08	69.02	7.14	0.17
10.		Nd	Sm	Eu	Gd	Tb	**ΣREE**
11.		26.13	4.99	1.68	6.23	0.69	**179.78**
12.		Dy	Ho	Er	Tm	Yb	
13.		3.5	0.61	1.58	0.21	1.24	
14.	P11 Grain class 1–0.5 mm	Sc	Y	La	Ce	Pr	Lu
15.		8.35	12.47	44.18	81.8	8.92	0.2
16.		Nd	Sm	Eu	Gd	Tb	**ΣREE**
17.		33.2	6.53	2.23	7.84	0.87	**215.25**
18.		Dy	Ho	Er	Tm	Yb	
19.		4.33	0.76	1.91	0.24	1.42	
20.	P12 Basalt aggregate 0.5–0.25 mm	Sc	Y	La	Ce	Pr	Lu
21.		6.08	10.65	41.3	80.82	8.38	0.16
22.		Nd	Sm	Eu	Gd	Tb	**ΣREE**
23.		30.94	5.95	2.03	7.11	0.75	**201.68**
24.		Dy	Ho	Er	Tm	Yb	
25.		3.77	0.66	1.62	0.22	1.24	
26.	P13 Basalt aggregate 0.25–0.125 mm	Sc	Y	La	Ce	Pr	Lu
27.		15.52	18.22	52.37	96.52	10.48	0.26
28.		Nd	Sm	Eu	Gd	Tb	**ΣREE**
29.		38.86	7.66	2.64	9.33	1.06	**264.16**
30.		Dy	Ho	Er	Tm	Yb	
31.		5.46	0.96	2.51	0.32	1.99	
32.	P14 Basalt aggregate 0.125–0.063 mm	Sc	Y	La	Ce	Pr	Lu
33.		17.03	16.42	42.89	80.12	8.67	0.25
34.		Nd	Sm	Eu	Gd	Tb	**ΣREE**
35.		32.46	6.54	2.24	7.97	0.92	**225.14**
36.		Dy	Ho	Er	Tm	Yb	
37.		4.68	0.82	2.12	0.28	1.73	
38.	P15 Basalt aggregate 0.063–0.045 mm	Sc	Y	La	Ce	Pr	Lu
39.		25.2	21.86	52.13	99.32	10.74	0.29
40.		Nd	Sm	Eu	Gd	Tb	**ΣREE**
41.		40.41	8.2	2.78	10.06	1.15	**284.14**
42.		Dy	Ho	Er	Tm	Yb	
43.		5.79	1.04	2.67	0.35	2.15	
44.	P16 Basalt aggregate <0.045 mm	Sc	Y	La	Ce	Pr	Lu
45.		21.85	31.37	82.89	165.06	17.53	0.42
46.		Nd	Sm	Eu	Gd	Tb	**ΣREE**
47.		61.93	12.02	4.08	14.55	1.62	**430.08**
48.		Dy	Ho	Er	Tm	Yb	
49.		8.12	1.45	3.73	0.5	2.96	

Tab. 6. Overview of total rare earth element contents of dry magnetic separation products

Tab. 6. Analiza zawartości REE w produktach wzbogacania magnetycznego

No.	Sample Identification	Raw material	Paramagnetic product with higher susceptibility		Paramagnetic product with lower susceptibility	
		Rare earth content [ppm].	Sample number	Rare earth content [ppm].	Sample Number	Rare Earth Content [ppm].
1.	Coal slurries	263.8	P17	**40.45**	P18	**36.29**
2.	Basalt aggregate	190.0	P19	**26.35**	P20	**212.87**

was removed from the machine using a brush. The resulting product yields are presented in Table 3. The yield of the non--magnetic product was calculated as the difference of 100% and the sum of the yields of the weaker and stronger magnetic products.

The products obtained, were sent to the Laboratory of Materials Engineering and Environment, ITG KOMAG, for determination of rare earth elements. These tests were performed using the ICP-MS method.

3. Materials and methods

Table 4 presents the detailed results of rare earth element content for each analysed grain size class of the coal slurries.

Table 5 presents the detailed results of rare earth element content for each analysed grain size class of the basalt.

Table 6 presents the summarised results of rare earth element content for each analysed magnetic separation product.

4. Discussion

The research found that 16 rare earth elements were included in the samples, with varying proportions of individual elements. To summarise the study of REE content in the individual grain classes of coal slurry, the summed contents of these elements are shown in Figure 4. and are as follows:

P1. (>2 mm)–34.44 ppm.
P2. (2–1 mm)–39.67 ppm.
P3. (1–0.5 mm)–31.2 ppm.
P4. (0.5–0.25 mm)–39.66 ppm.
P5. (0.25–0.125 mm)–41.69 ppm.
P6. (0.125–0.063 mm)–35.83 ppm.
P7. (0.063–0.045 mm)–41.27 ppm.
P8. (<0.045 mm)–46.61 ppm.

Separation of the coal slurries material into grain classes in the magnetic separator did not result in an increase in rare earth element concentrations. The 8 grain classes obtained

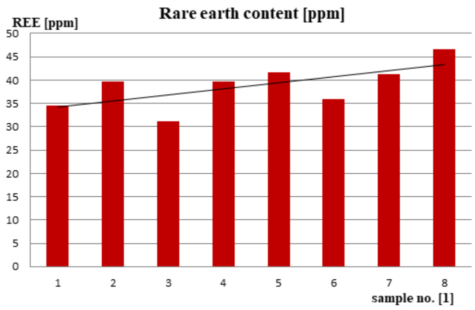

Fig. 4. Graph of REE content in coal slurries
Rys. 4. Zawartość REE w odpadach węglowych

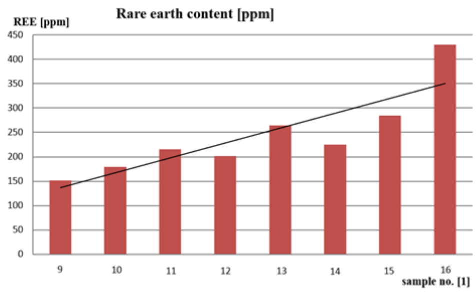

Fig. 5. Graph of REE content in basalt aggregate
Rys. 5. Analiza zawartości REE w próbkach bazaltu

have similar REE contents (average of 40.6 ppm). The highest REE content is represented by the finest grain classes, 0.063–0mm, and the 0.250–0.125mm grain class (above 41 ppm). The contribution of individual elements in the samples, which range from about 1.5 to just over 4 ppm, is negligible.

The total REE contents of the individual grain classes of basalt aggregate are as follows:

P9. (>2 mm)–151.23 ppm.
P10. (2–1 mm)–179.78 ppm.
P11. (1–0.5 mm)–215.25 ppm.
P12. (0.5–0.25 mm)–201.68 ppm.
P13. (0.25–0.125 mm)–264.16 ppm.
P14. (0.125–0.063 mm)–225.14ppm.
P15. (0.063–0.045 mm)–284.14 ppm.
P16. (<0.045 mm) – 430.08 ppm.

Based on the REE content of the different grain classes of basalt aggregate, the graph shown in Figure 5 was made.

The separation of the basalt aggregate into grain classes resulted in an increase in the concentration of rare earth elements in the finest grain classes. An increasing content of rare earth elements in the finest classes was observed. This observation is confirmed by the alignment of the trend line, which clearly increases towards the finest grain classes. The highest total rare earth element content was recorded for grain classes <0.045 mm and was 430.08 ppm. The lowest REE content was recorded for the grain class with the largest grain size and was 151.23 ppm.

Based on the summary of results in Table 6, it can be concluded that the dry magnetic separation had no effect for the coal slurries sample. The results obtained for the REE content are lower than for the raw material. Separation of the basalt aggregate resulted in a higher REE concentration in the less susceptible material to 212.87 ppm compared to the raw material content of 190.0 ppm. The more susceptible product showed a decrease in REE content to 26.35 ppm.

5. Conclusion

In the research carried out in this phase, the work programme consisted of determining new sources of rare earth elements in Poland, using coal slurries and basalt aggregate. The materials were selected and prepared for testing, which was then carried out by determining the proportion of REEs, using the ICP-MS technique.

The tests carried out showed the presence of rare earth elements in the samples analysed. Separation of the raw material into grain classes showed a disproportion of the sought after elements in the different grain classes. The REE content of the finest classes increased relative to the raw sample.

The lack of increase or low increase in rare earth elements in the susceptible products of the magnetic separation process may indicate that the intensity of the applied magnetic field in the equipment used is too low.

At present, the results obtained for the REE content of the samples analysed, do not represent the designated concentration of approximately 1000 ppm [22], which allows an economically viable separation.

The results obtained allow us to conclude that further research is required, by analysing the effect of increasing magnetic field on material separation with the intention of obtaining a product with a higher concentration of rare earth elements. In the further work of ITG KOMAG, related to the search for alternative sources of REE, further research is required using a magnetic separator with a higher field strength. It is also necessary to continue the search for a new group of materials that will contain a higher proportion of REE.

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Rozdział surowców zawierających pierwiatki ziem rzadkich w procesach przesiewania i separacji magnetycznej

W artykule przedstawiono badania wybranych materiałów mające na celu określenie zawartości pierwiastków ziem rzadkich (REE) oraz próbę ich wzbogacania. Materiałem badawczym była zawiesina węglowa, która jest produktem odpadowym z eksploatacji zakładu przeróbczego zamkniętej kopalni węgla kamiennego. Badania nad testami wzbogacania REE przeprowadzono z wykorzystaniem separacji magnetycznej. Analizy laboratoryjne określające zawartość REE w pobranych próbkach przeprowadzono z wykorzystaniem techniki spektrometrii mas z jonizacją plazmą wzbudzoną indukcyjnie (ICP-MS). Przeprowadzenie tych badań przez Instytut Techniki Górniczej KOMAG jest kontynuacją prac związanych z ekonomiczną przydatnością odpadów górniczych oraz określeniem nowego źródła odzysku REE. Poprzednie prace badawczo-rozwojowe wykazały zawartość REE (skand 40,49 ppm) w badanych zawiesinach węglowych. Wynikiem przeprowadzonych prac jest określenie ekonomicznej użyteczności odzysku REE z badanych odpadów.

Słowa kluczowe: *pierwiastki ziem rzadkich (REE), separacja magnetyczna, odpady węglowe, zawiesiny węglowe*