GOSPODARKA SUROWCAMI MINERALNYMI

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Properties of wet fly ash suspensions seasoned in hard coal mine underground

Introduction

The Polish energetics is based on coal which has been one of our biggest natural resources for many years. Silesian mines, the main hard coal manufacturers, are located in the vicinity of energetic factories in a densely urbanized area which lack land for landfilling sites. These reasons influenced both sides to drive for waste storage. At first it seemed that the mass utilization of fly ashes guaranteed their use as a backfill for once applied hydraulic fills. Tests conducted in the sixties and seventies of the previous century always ended in failure (Mazurkiewicz 1990). Backilling materials did not prevent fine grains of fly ashes from percolating from the liquidated headings to the sediment traps. The "Bolesław Śmiały" mine used ashes in the pneumatic backfill receiving dry fly ashes from the "Łaziska" power plant by means of a pipeline (Gałeczka et al. 1985). The method was dropped after a few years due to significant dusting in the bottom of the mine despite intensive spraying at the exit of the pipeline.

The turning point in the use of fine-grained waste in the mining industry was the introduction of suspension technology (Dłużewski et al. 1984; Ropski et al. 1985). Suspensions received due to the process of dynamic mixing of one or more parts by weight of fly ashes and one part of water are characterized by properties enabling their use in underground mines. A liquid suspension can be transported to the underground by means of a pipeline. The suspension transported to its place of destination (rock fall zone in gob area, liquidated headings, small shafts, and others) binds and hardens emitting little amounts of water.

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For 25 years the underground hard coal mining has extended the application of the suspension by the following technologies (Mazurkiewicz et al. 1997; Mazurkiewicz, Piotrowski 2004; Plewa, Mysłek 2001):

- grouting and isolation of roof fall rock zones,
- fire prevention,
- liquidation of headings,
- decreasing rock fall porosity in the longwall systems,
- backfilling in a shortwall mining exploitation system,
- creating artificial roofs during layer exploitation,
- binding highly mineralized waters,
- their use in the process of mine liquidation,
- liquidation of shallow voids in the orogen and Weber voids,
- filling voids behind the cover,
- self-consolidating backfill,
- a means of transport for inert gases, including CO_2, to the mine undergrounds.

Technological needs, economic effects and environmental protection made the hard coal mining industry the biggest receiver of its own and energetic fine grained waste. In the suspension technology the following wastes are used:

- fly ashes from professional power plants (heat and power plants),
- fly ashes with products of dry desulfurization process,
- fly ashes with products of semi-dry desulfurization process,
- mixtures of the above mentioned wastes from the same power plant,
- fly ashes from power plants in the vicinity of a mine,
- fly ashes from fluidized combustion beds,
- fine grained waste from hard coal mines (i.e. post-flotation waste, waste from mine water sediment traps),
- mixtures of energetic and mine wastes,
- mixtures of energetic waste and other fine grained waste with the addition of components improving the binding process (i.e. cement or waste from its production).

In 2007, the research into the numbers and methods of application of the above wastes in the form of aqueous suspension was carried, with the contribution of the author, in the AGH (AGH University of Science and Technology). The survey analysis allowed for the following general conclusions:

- the majority of mines use the suspension technology above all for ventilation,
- mining demand for energetic waste has stabilized, in the years 2002–2006 it amounted to 2.5 mln Mg per year,
- this amount of energetic waste and others, mainly post-flotation (about 0.92 mln Mg per year) waste and water, usually highly mineralized, cause the use of about 5.7 mln Mg suspension, i.e. 4.5 mln m^3 in mining technologies underground,

— the calculations indicate that on average about 85 kg of suspensions including 35 kg of dry energetic waste is used for 1 Mg of coal in mines using waste.

Technical requirements for ashes and their suspensions are regulated by the standard PN-G/11011 “Mining. Materials for consolidating stowing and goaf sealing. Requirements and testing” and WUG (State Mining Authority) regulations governing the use of waste in the underground mine working („Zasady gospodarczego wykorzystania odpadów w podziemnych wyrobiskach górniczych”). The standard requires assessment on the basis of testing samples seasoned up to 28 days. Skeptics on the underground use of waste asked a question concerning the state of waste located underground after years. The results of research presented in the paper try to answer the question.

The author carried out tests on samples of hardened suspensions taken in the mine underground which stayed there for a few or several years. The basic difficulty for the research was a complicated way of reaching the sites in the mines which used wastes, taking a sufficient amount of suspension, successful transportation to the surface, and eventually careful shaping the samples for the size required in the tests.

The author possesses a rich archive of test results concerning various ashes and suspensions prepared of them. The results cover the period of 25 years, which allowed for making comparisons on some properties of suspensions tested in the AGH years ago and test results of the adequate suspensions excavated from the mine underground after many years.

In the paper there are presented test results on samples obtained in the years 2004–2007 from the underground of 7 hard coal mines. The samples were marked with the following letters: B, J, K, M, P, S, Z.

The following properties of the hardened fly ash suspensions or fly ash suspensions with the addition of post-flotation waste were marked:

— specific density,
— compression strength,
— collapsing behaviour,
— filtration,
— chemical leaching.

1. Analysis of the sample test results

The comparison of test results on laboratory samples of wastes from the mines and those on hardened suspensions seasoned for many years in the mine underground was carried out in terms of the analyzed properties.

1.1. Specific density

No significant differences were observed. The maximum differences observed concerned mainly fly ash with the addition of post-flotation waste (samples B and J) and did not exceeded 16%, so even seasoning of suspensions in the hard coal mine undergrounds for many years did not practically influence waste density.

1.2. Compression strength

The test results are presented in Table 1. The table contains test results carried out in the years 2005–2007. Additionally, the table presents the compression strength values of the laboratory samples of hardened suspensions tested during the period of their application in the mines which was 3 to 10 years ago. The test results cover various suspension concentrations, that is why such big differences between the maximum and minimum values can be observed. There is a lack of information or the information is incomplete as regards the concentration of suspensions used underground. The results presented in table 1 can lead to the following conclusions:

— the origin and kind of fly ash mainly influence the value of compression strength,

— samples of the same ash, regardless of their preparation and seasoning place, are characterized by a similar value of compression strength,

TABLE 1

Hardened suspension samples compression strength (Rc)

TABELA 1

Wytrzymałość na ściskanie (Rc) próbek stwardniałych zawiesin

Sample symbol	Kind of waste – suspension component	Laboratory tested samples before being located underground	Samples taken in the mine	
		Compression strength after 28 days Rc [MPa]	Compression strength Rc [MPa]	Underground seasoning [years]
M	Fly ash	0.04–0.07	0.10	7
J	Fly ash of dry desulfurization process + post-flotation waste	0.93–2.90	1.10	5
B	Fly ash of dry desulfurization process + post-flotation waste	2.06–4.35	1.95–2.26	3
Z	Fly ash	0.19–0.38	0.13–0.43	5
K	Fly ash with products of dry desulfurization process	0.56–1.12	0.33–0.92	5
S	Fly ash with products of dry desulfurization process	0.56–1.12	0.28–0.53	6
P	Fly ash	0.06–0.12	0.06–0.12	3, 5, 10

— seasoning of samples underground for many years does not guarantee an increase in their Rc strength (which can be observed in case of samples seasoned in the laboratory),
— laboratory research enables the prediction of compression strength in case of hardened fly ash suspensions after a few years of seasoning in a hard coal mine underground.

1.3. Collapsing behaviour

The collapsing behaviour of hardened suspension samples were evaluated through macroscopic observation of samples soaked in water for 24 hours. The results are collated in Table 2, along with the test results of samples prepared and seasoned in the laboratory (28 days and nights) at the same time when they were applied in the mine. The comparison of the test results for seven mines indicates a slightly more collapsing resistance of laboratory samples. The differences, however, are minute, so it can be assumed that in this respect the laboratory research enables the prediction of hardened suspension collapsing resistance.

TABLE 2

Collapsing behaviour of suspensions

TABELA 2

Rozmakalność stwardniałych zawiesin

Sample symbol	Kind of waste – suspension component	Place and time of seasoning [years]	Collapsing behaviour (macroscopic evaluation during 24 hour soaking in water) of samples seasoned in:	
			laboratory	mine
B	Fly ash of dry desulfurization process + post-flotation waste	3	No changes	No changes
J	Fly ash of dry desulfurization process + post-flotation waste	5	No changes	No changes
M	Fly ash	7	Collapsed after 1 hr	Collapsed after 0.5 hrs
Z	Fly ash	5	Collapsed after 2 hrs	Collapsed after 0.5hrs
S	Fly ash with products of dry desulfurization process	6	Collapsed after 20 hrs	Collapsed after 16 hrs
K	Fly ash	5	Collapsed after 15 hrs	Collapsed after 10 hrs
P	Fly ash	3	Collapsed after 1hr	Collapsed after 1hr
		5	Collapsed after 3 hrs	Collapsed after 1–2 hrs
		10	Collapsed after 3 hrs	Collapsed after 2 hrs

1.4. Filtration

The test results carried out by means of Kaminsky pipe are juxtaposed in Table 3. The samples prepared in the laboratory are characterized by a slightly lower filtration, which could have resulted from their preparation for the test. The mine samples could have been damaged while being pushed into the pipe which required a large number of sample markings and involved rejecting extreme test results.

TABLE 3

Filtration of hardened suspension samples

TABELA 3

Wodoprzepuszczalność próbek stwardniałych zawiesin

Sample symbol	Filtration [cm/s]	
	Sample collected underground	Equivalent of sample prepared in the AGH years ago
Z	$7.16 \cdot 10^{-4}$ $9.49 \cdot 10^{-5}$ $3.65 \cdot 10^{-4}$	$3.15 \cdot 10^{-5}$ $3.15 \cdot 10^{-5}$ $2.90 \cdot 10^{-5}$
B	$5.00 \cdot 10^{-5}$ $3.90 \cdot 10^{-5}$	$6.90 \cdot 10^{-5}$ $9.20 \cdot 10^{-5}$
S	$5.70 \cdot 10^{-5}$	$2.30 \cdot 10^{-5}$
K	$9.10 \cdot 10^{-6}$ $3.40 \cdot 10^{-4}$ $1.50 \cdot 10^{-5}$	$5.60 \cdot 10^{-6}$ $5.60 \cdot 10^{-6}$ $5.60 \cdot 10^{-6}$
M	$2.15 \cdot 10^{-2}$ $3.20 \cdot 10^{-3}$	$3.07 \cdot 10^{-3}$ $2.70 \cdot 10^{-3}$
P	$2.6 \cdot 10^{-5}$ $8.2 \cdot 10^{-6}$ $5.5 \cdot 10^{-4}$	$3.4 \cdot 10^{-5}$ $5.1 \cdot 10^{-5}$ $2.7 \cdot 10^{-5}$

1.5. Chemical leaching

The test results are presented in Table 4, 5, and 6, along with the results of earlier tests on fly ashes. The comparison of test results for chemical leaching of both mine and laboratory samples indicates differences in the amount of chlorides, sodium, and potassium in a smaller range. Undoubtedly it is connected with the use of highly mineralized waters, so called saline waters, for suspensions. In case of other markings no significant differences were observed.

TABLE 4

Test results for water extract of hardened suspension samples (M-1–3) and fly ash – the sample tested in 1999

TABELA 4

Wyniki analiz wyciągu wodnego z próbek stwardniałych zawiesin (M-1–3) i popiołu lotnego – próbka badana w 1999 roku

Indicator or type of pollution	Unit	Sample M-1	Sample M-2	Sample M-3	Fly ash
pH	–	7.2	7.5	7.5	7.6
Chlorides	mg Cl/dm^3	1 280	1 710	920	51
Sulfates	mg SO_4/dm^3	320	245	202	182
Sodium	mg Na/dm^3	43.6	68.2	43.1	12.5
Potassium	mg K/dm^3	10.4	12.6	18.5	6.7
Zinc	mg Zn/dm^3	0.020	0.020	0.025	0.025
Cadmium	mg Cd/dm^3	0.0001	0.0001	0.0001	0.0001
Nickel	mg Ni/dm^3	0.005	0.005	0.005	0.005
Lead	mg Pb/dm^3	0.0014	0.0018	0.0010	0.0012
Copper	mg Cu/dm^3	0.0004	0.0004	0.0004	0.0004
Chromium	mg Cr/dm^3	0.020	0.022	0.002	0.024
Cyanides	mg CN/dm^3	0	0	0	0
ChZT	mg O_2/dm^3	75.4	68.8	70.4	58.0

TABLE 5

Test results for water extract of hardened suspension samples (Z-1–3 – tested in the year 2001) and fly ash as well as the mixture of fly ash and post-flotation waste samples – tested in the same year

TABELA 5

Wyniki analiz wyciągu wodnego z próbek stwardniałych zawiesin (Z-1–3 – z 2001 roku) oraz z tego samego roku próbek popiołu lotnego i mieszaniny popiołu lotnego z odpadem poflotacyjnym

Indicator or type of pollution	Unit	Z-1	Z-2	Z-3	Fly ash	Mixture
pH	–	6.8	7.0	7.3	7.4	7.1
Chlorides	mg Cl/dm^3	1 450	1 508	508	46,2	1 110
Sulfates	mg SO_4/dm^3	208.5	221.2	105.2	148.4	231.5
Sodium	mg Na/dm^3	301.8	283.7	510.1	6.83	1 114.2
Potassium	mg K/dm^3	18.7	21.9	23.5	14.7	33.2
Zinc	mg Zn/dm^3	0.005	0.005	0.005	0.005	0.005
Cadmium	mg Cd/dm^3	0.006	0.001	0.007	0.0006	0.002
Nickel	mg Ni/dm^3	0.012	0.0044	0.010	0.0008	0.018
Lead	mg Pb/dm^3	0.007	0.009	0.007	0.007	0.007
Copper	mg Cu/dm^3	0.001	0.0003	0.002	0.0008	0.002
Chromium	mg Cr/dm^3	0.028	0.018	0.022	0.037	0.015
Cyanides	mgCN/dm^3	0	0	0	0	0
ChZT	Mg O_2/dm^3	71.9	45.2	53.1	55.8	36.8

TABLE 6

Test results for water extract of hardened suspension samples (J-1, J-2) and the mixture of fly ash with products of dry desulfurization process and post-flotation waste sample – (sample from the year 2001)

TABELA 6

Wyniki analiz wyciągu wodnego z próbek stwardniałych zawiesin (J-1, J-2) oraz z próbki mieszaniny popiołu lotnego z produktami odsiarczania spalin i odpadu poflotacyjnego (próbka z 2001 roku)

Indicator or type of pollution	Unit	Sample J-1	Sample J-2	Mixture of fly ash with post-flotation waste
pH	–	9.5	9.7	11.6
Chlorides	mg Cl/dm^3	1820	1945	441.7
Sulfates	mg SO_4/dm^3	1120	1010	1036
Sodium	mg Na/dm^3	420	305	10.16
Potassium	mg K/dm^3	64	52	4.68
Zinc	mg Zn/dm^3	0.02	0.02	0.027
Cadmium	mg Cd/dm^3	< 0.005	< 0.005	0.00014
Nickel	mg Ni/dm^3	0.006	0.006	0.0062
Lead	mg Pb/dm^3	0.001	0.002	0.00107
Copper	mg Cu/dm^3	0.0003	0.0003	0.0003
Chromium	mg Cr/dm^3	0.15	0.10	0.02
Cyanides	mg CN/dm^3	0	0	0
ChZT	mg O_2/dm^3	61	72	55.2

Conclusions

The detailed conclusions from the research are presented above. They can lead to the following generalization:

The laboratory research and conclusions can be analyzed considering two aspects. Firstly, as the test results of material samples used for technological goals; secondly as the comparison of properties in case of samples prepared and seasoned in the laboratory and those of samples seasoned in an underground hard coal mine for many years.

In the first case we can assess the tested properties on the basis of standard PN/G-11011 "Mining. Materials for consolidating stowing and goaf sealing. Requirements and testing" and conclude that the requirements are met. Qualified representatives of the mines involved also confirm the efficiency of fly ash suspensions.

The second, more significant, case indicates a big coincidence of the test results for samples prepared and seasoned in the laboratory with those taken underground. It allows to express an opinion that ***earlier laboratory research enables the prediction of some properties in case of hardened fly ash suspensions exploited in various mining technologies.***

REFERENCES

Dłużewski E. i in., 1984 – Przemysłowe zastosowanie popiołów w postaci wodnej ich zawiesiny – emulgatu w KWK „Generał Zawadzki". Wiadomości Górnicze nr 5–6.

Gałeczka S i in., 1985 – System ścianowy z podsadzką pneumatyczną pyłem lotnym. Wiadomości Górnicze nr 8.

Mazurkiewicz M., 1990 – Technologiczne i środowiskowe aspekty stosowania stałych odpadów przemysłowych do wypełniania pustek w kopalniach podziemnych. Zeszyty Naukowe AGH, Górnictwo z. 152, Kraków.

Mazurkiewicz M., Piotrowski Z., Tajduś A., 1997 – Lokowanie odpadów w kopalniach podziemnych. Kraków, Biblioteka Szkoły Eksploatacji Podziemnej.

Mazurkiewicz M., Piotrowski Z., 2004 – Problemy likwidacji kopalń podziemnych. Kraków, AGH Uczelniane Wydawnictwa Naukowo-Dydaktyczne.

Plewa F., Mysłek Z., 2001 – Zagospodarowanie odpadów przemysłowych w podziemnych technologiach górniczych. Gliwice, Wydawnictwo Politechniki Śląskiej.

Ropski S., Mazurkiewicz M., Piotrowski Z., 1985 – O możliwościach stosowania zawiesiny popiołów lotnych w wodzie w kopalniach podziemnych. Przegląd Górniczy nr 1.

WŁAŚCIWOŚCI ZAWIESIN POPIOŁOWO-WODNYCH SEZONOWANYCH W PODZIEMIACH KOPALŃ WĘGLA KAMIENNEGO

Słowa kluczowe

Odpady drobnofrakcyjne, technologie górnicze, zawiesiny popiołowo-wodne, górnictwo podziemne

Streszczenie

Górnictwo węgla kamiennego w Polsce jest jednym z głównych odbiorców popiołów lotnych z energetyki. Są one, w postaci wodnej zawiesiny, wykorzystywane w różnych technologiach górniczych. Odbywa się to zgodnie z wymaganiami środowiskowymi i technicznymi określonymi w odpowiednich przepisach i normie PN-G-11011. Norma ta stawia wymagania materiałom po 28 dobach sezonowania sporządzonych z nich próbek. Brak jest opracowań, które oceniają własności próbek po dłuższym okresie sezonowania, a szczególnie w warunkach naturalnych. Autor uzyskał z 7 kopalń próbki. Wydobyto je z podziemi kopalń po kilku latach od ich użycia. Odpowiednio przygotowane poddano badaniom w laboratorium. Wyniki tych badań przedstawiono w artykule.

PROPERTIES OF WET FLY ASH SUSPENSIONS SEASONED IN HARD COAL MINE UNDERGROUND

Key words

Fine grained waste, mining technology, fly ash-water suspensions, underground mining

Abstract

Hard coal mining industry in Poland is one of the biggest recipients of fly ashes produced by the power industry. They are used in the form of aqueous suspensions in various mining technologies on the basis of environmental and technical requirements defined in adequate regulations and standard PN/G-11011. The standard sets requirements for material samples after 28 days of seasoning. There is a lack of studies which evaluate properties of samples seasoned for a longer period of time, especially in natural conditions. The author received samples from 7 mines. The samples were excavated after a few years of staying underground. They were tested in the laboratory after adequate preparation. The test results are presented in the paper.