WYTRZYMAŁOŚĆ POWŁOKI BITUMICZNEJ ZABEZPIECZAJĄCEJ PYLENIE SKŁADOWISKA ODPADÓW FLOTACYJNYCH „ŻELAZNY MOST"

EXAMINATION OF THE DURABILITY OF BITUMEN LAYER/COATING THAT PREVENTS DUSTING OF FLOTATION TAILINGS POND "ŻELAZNY MOST"

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Charakterystyczne właściwości fizykochemiczne osadów flotacyjnych deponowanych na składowisku odpadów „Żelazny Most" oraz niekorzystne warunki atmosferyczne przyczyniają się do dokuczliwego zanieczyszczenia środowiska wywiewanymi pyłami, zagrażającymi zdrowiu ludzi. Przedstawiono charakterystykę osadnika i właściwości gromadzonych w nim odpadów oraz problematykę pylenia i zabezpieczenia przed erozją wietrzną osadów drobnoziarnistych. Jako materiał doświadczalny zaprezentowano wyniki badań wytrzymałości mechanicznej warstwy bitumicznej zabezpieczającej przed pyleniem odpadów flotacyjnych na plażach składowiska.

Słowa kluczowe: *ruda miedzi, odpady flotacyjne, składowisko odpadów „Żelazny Most", pylenie*

Physicochemical characteristics of flotation waste, deposited on the "Żelazny Most" tailings pond, as well as adverse weather conditions, result in troubling dust and environmental pollution which affect human health. Characteristics of tailing pond and properties of its waste were presented, as well as the problem of dusting and prevention of fine dust wind erosion. As experimental material, the results of mechanical durability examination of bitumen layer which prevents dusting of flotation waste on pond beach were presented.

Keywords: *copper ore, flotation tailings, flotation tailings pond "Żelazny Most", dusting*

Introduction

Mining exploitation of copper ore is based on extraction of copper ore in mining facilities such as "Lubin", "Polkowice--Sieroszowice" and "Rudna" which belong to one of the largest industrial establishments in Poland – KGHM Polska Miedź S.A., commonly known as KGHM. [1,2]

From their very beginning Polish copper ore mining facilities deposited 100% of their waste in burrows located nearby while flotation wastes were directed to the ore concentrating plants (OCP) [3]. Currently there is only one functional flotation tailings pond – "Żelazny Most".

Once extracted, copper ore is sifted and crushed, i.e. subject to processes which prepare ore for further grinding, classification and flotation, where useful minerals are separated from gangue. Multistep flotation process, as well as consolidation and drying of the concentrate, creates intermediate product with coper content of 25-30%. Material prepared in this way is then transported to smelters and subject to smelt of copper matte. Tailings generated in the flotation process, which consist of 0.2% of copper, are directed to flotation tailings pond "Żelazny Most" [1-4], one of the largest flotation tailings ponds in the world and the largest one in Europe [3-7]. Each year over 29 million tons of waste is deposited on the landfill. Flotation waste in case of "Żelazny Most" landfill negatively influences the environment due to fine dust scattered from flotation sludge [3].

Landfill, in case of mining waste, according to the act [8] is a mine waste disposal facility, which acts as a building object. Settlers due to the dusting are particularly bothersome near housing estates. Dusting also causes degradation of forest habitats and landfill buildings themselves adversely affect the landscape [3,9]. Flotation tailings pond are objects, which due to their sizes and location became a permanent element of the environment, in which they are located and they may pose a threat to it [3,10].

The hazards and nuisances of this kind of pollution are as follows [10-13]:

- accumulation of waste, that may adversely affect soil, ground and underground water environment.
- Pollution of air, soil and plants with dust from the site.
- Possibility of waste pond failure and leakage of semi-fluid mass of wastes.

Purpose and scope of work

The main purpose of this paper is to present the issue of fine dusting from flotation waste deposited in tailings pond "Żelazny Most” and also to investigate the mechanical properties of bitumen layer protecting and reducing dusting of wastes.

The scope of work included:

- Characteristics of tailings pond “Żelazny Most”.
- Problematics of fine dusting from mine waste disposal plant “Żelazny Most”.
- Assessment of coat-forming effectiveness and examination of mechanical resistance of the formed stabilizing bitumen layer.

Mine waste disposal plant “Żelazny Most”

The main task of mine waste disposal plant is the disposal of waste from flotation enrichment of copper ores that are generated in enrichment facilities operated by KGHM Polska Miedź S.A. “Żelazny Most” is situated among Dalkow Hills, which are the frontal moraine of Pleistocene glaciations, in the Kalinówka river valley. The landfill is surrounded by a natural barrier (the primary barrier is formed of sands extracted from surrounding fields) [12]. “Żelazny Most” covers the area of 150 ha, and the height of its dams relative to the land is from 36 m on the southern side to 62 m on the eastern site. The amount of water within the pond is approximately 8.4 M m^3 and the maximum water depth is approx. 3.0 m.

Currently “Żelazny Most” is in the expansion stage (south quarter) in order to maintain its further operational status until year 2048. The landfill area will be increased by 609 ha, which will allow the total of 969 M m^3 of waste to be deposited [14,15].

The landfill is expected to be operated until 2075-2080. On the site, some of the waste is used for its further development (about 75%) and the remaining part for disposal. The finest fraction is used to seal the bottom of the pond, while the thickest fraction is utilized for building the object’s embankments [2]. By the end of November 2014 a total of 560 M m^3 of waste was deposited at “Żelazny Most” landfill [16].

Tab. 1. Basic parameters of „Żelazny Most” tailing pond (2014.) [2,12,16]
Tab. 1. Podstawowe parametry obiektu „Żelazny Most” (2014 r.) [2,12,16]

Parameters	Size	
	actual	target
Total surface	16 km^2	22 km^2
Total deposited waste	560 mln m^3	969 mln m^3
Embankments lenght	14.3 km	-
Maximum height of dam (variable)	36 - 62 m	up to 100 m
Basin surface (variable)	7.5-8 km^2	-
Area of beaches (variable)	794 ha	-

Wastes from three active mines (Rudna, Lubin and Polkowice), belonging to KGHM, are deposited by the method of silting the beaches of the landfill in an uncompacted form, the density of which is 1.15 g/cm^3 [15,17]. The settling pond was divided into four parts, in which 26 technological sections for waste storage were separated. The length of each section vary from 500 to 800 m [2,12]. The concentrating plant in Lubin sends its settlements to the eastern and southern dams, the facilities in Polkowice to the western dam or deep into the repository. Rudna concentrating plant sends its settlements to the northern and eastern dam [2]. Waste storage takes place through a system of gravity and pressure pipelines brought to the dam crown. The silting lasts up to three weeks and the subsequent sludge after the drainage occurs after about six weeks. The supernant water is pumped by the siphons in overflow towers, and then by pipeline system located in the bottom of the pond, it flows to the pumping station from where it is directed to the concentrating plant for re-use in the flotation process [15,18]. The excess of supernant water is periodically discharged to the Odra River [18].

In the South Quarter constructed on the flotation pond the waste will be deposited in a thickened form, the density of the coarse fraction will be approx. 1.7 g/cm^3 and the fine grain fraction will be approx. 1.6 g/cm^3.

Characteristics of flotation waste

Flotation waste is a finely divided fraction of waste rock, in which there are small amounts of useful minerals. The granulometric test of flotation sludge samples, depending on the mine, show the following shares: 59, 42 and 16% of the sand fraction, 29,56 and 79% of the dust fraction and 12, 2 and 5% of the clay fraction respectively for the mines in Lubin, Rudna and Polkowice-Sieroszowice [19]. The graining of waste from the western and central part of flotation pond is on average 25--65%. Wastes from the eastern side are characterized by greater grain size – on average 0.106 – 0.150 mm, and the share of silty fraction ranges from 5 to 25%.

Tab 2. Flotation waste grade size from each OCP [1]
Tab 2. Skład frakcyjny odpadów flotacyjnych z poszczególnych ZWR-ów [1]

Size grade [mm]	Procentage of size grade [% mas.] Concentrating plant		
	„Lubin”	„Polkowice”	„Rudna”
>0.2	3.4	-	5.4
0.2 – 0.1	23.1	-	31.1
0.1 – 0.075	23.1	1.87	8.7
0.075 – 0.045	11.7	8.29	7.2
<0.045	38.7	89.84	47.6

Wind erosion of flotation sediments and the environmental problem

Due to the high permeability of sediments deposited in the landfill the wastes are overdried, of which conductive factor is uplift of “Żelazny Most” mine waste disposal facility and also wind exposure. This causes dusting of fine-grained sediments from the surface of the beaches outside the landfill, sometimes at considerable distances. The increase of dusting within the impact zone of the “Żelazny Most” becomes particularly noticeable at wind speeds over 4 m/s. Such conditions occur at 12 UTC in the spring months of March, April and in autumn – September, October, November [20]. The observed “dust storms” from above the pond can reach a height of several hundred meters above the landfill level and range up to 8 km during strong winds (10 – 15 m/s). Atmosphere dusting near human settlements is particularly troublesome during the periods of drought [21,22]. Emissions of dust from the landfill beaches affect the surrounding vegetation. Heavy metals contained in the dust accumulate in plants and soil at the foreground of the landfill [21,22]. The tests have revealed that the surrounding soil contains an increased amount of copper and lead. They have also shown the correlation between the copper and lead content in the soil, and the distance of the place of sampling from the banks of the flotation pond. In the surface layer of the soil, the content of these elements decreases with increasing distance from the "Żelazny Most" flotation pond [20]. A statistically significant reduction of copper and arsenic levels in the surface layer of soils around the landfill has been also indicated [23]. The permanent influence of post-flotation settling dust also causes the progressive degradation of forest habitats [9].

The erosion of flotation waste on dam superstructures may cause temporary increase in dust concentration in the air and its fallout at the landfill foreground, which impair the quality of the atmosphere and aerosanitary conditions in the surrounding rural settlements. Pollutant sediments containing up to 0.2% Cu, 0.03% Pb and up to 100 ppm As which after drying on pond beaches in the outer part of the repository become susceptible to dusting, are dangerous for the quality of air and soils [23]. The problem of dusting of Żelazny Most" mainly includes the following towns: Rudna, Grodowiec, Krzydłowice, Komorniki, Kaźmierzów, Tarnówek and other settlements located further [23].

Tab. 3. Chemical composition of flotation waste from each OCP [11]
Tab. 3. Skład chemiczny odpadów flotacyjnych z poszczególnych ZWR-ów [11]

Component	Unit	Concentrating plant		
		Rudna	Polkowice	Lubin
Cu	% mas.	0.23	0.23	0.16
Pb	% mas.	0.046	0.03	0.06
Zn	% mas.	0.010	0.010	0.010
Fe	% mas.	0.37	0.44	0.58
S_{total}	% mas.	1.01	0.78	0.32
$S_{sulfate}$	% mas.	0.90	1.58	0.12
C_{total}	% mas.	3.17	9.66	3.74
$C_{organic}$	% mas.	0.72	0.7	0.68
SiO_2	% mas.	61.6	18.03	59.18
CaO	% mas.	9.8	26.08	8.82
MgO	% mas.	4.3	6.75	3.73
Al_2O_3	% mas.	3.6	4.65	5.14
Mn	% mas.	0.12	0.189	0.111
Ti	% mas.	0.092	0.60	0.1
Na	% mas.	0.34	0.41	0.418
K	% mas.	1.25	1.27	1.326
Cl	% mas.	0.46	-	0.56
As	g/Mg	22	20	35
Ag	g/Mg	7	5	13
Co	g/Mg	8	6	43
Ni	g/Mg	6.8	5.5	11.6
V	g/Mg	34	89	64.8
Mo	g/Mg	8	14	18
Cd	g/Mg	-	-	0.2
Au	g/Mg	0.003	0.004	0.002

Dusting prevention

To limit dust emissions from OCP "Żelazny Most" the following methods were used [15,25]:

- Water sprinkling (the so called water curtain).
- Stabilization with chemical agents.
- Biological reclamation of the dam slopes.

The spraying was aimed to increase the humidity of the sediments on the beach which prevented the sludge from drying and blowing dust through the wind [25,26]. The very first attempts to use chemical preparations to stabilize the beaches of the OCP "Żelazny Most" were made in 1988-1989. The purpose of these chemical agents was to create a protective coating on the surface of the settling tank, that prevented dusting [24, 26]. Due to the low efficiency of polymer preparations, which were then available on the market, it was decided that during both laboratory and field tests a few cheaper preparations will be used, such as: asphalt-latex emulsion, a mixture of water glass solution and calcium chloride, aqueous solution of polyethylene and propylene poliglycols, resin formaldehyde – urea and asphalt emulsion used in road construction (beta emulsion) [24,26].

The limitation of the use of tested preparations was the toxicity of some of them and the possibility of gradual environment degradation (sulphite lye, Anti-freeze liquid). Domestic preparations used to stabilize the ash from the power plants could not be used to stabilize flotation sediments due to the lack of binding properties which are characteristic to ashes.

Since 1989, the beaches and escarpments have been stabilized with aqueous asphalt-cationic emulsion of average decay time, originally produced for road construction [24, 25]. Helicopters equipped with typical agricultural sprinklers and farm tractors were used to spray the emulsified asphalt solution. This shortened the time of spraying in a significant way and influenced both quality and durability of the applied protective coating on the beaches of the flotation pond. Thanks to this action the number of dust emission days was reduced by 50-60% per annum. In 1995, the formula of a new type of emulsified asphalt, called "Beta 21B" was introduced. This emulsion is characterized by high stability and durability as well as an adaptation to the chemical and physical properties of flotation waste. Both hydrochloric acid and petroleum based plasticizers were removed from its composition [24, 26]. Aeolian processes also occur on the slope surface (scarps). Biological shield of the slopes prevents water erosion and deflation on the slopes of "Żelazny Most" dams. Therefore, to alleviate this problem, the slopes are systematically covered with soil and worn with grass [24, 28].

Mechanical tests of bitumen coating from the „Żelazny Most" tailing pond

The fragments of the bitumen coating layer obtained from the beach surface, two weeks after its application on the surface of the flotation sludge at "Żelazny Most" tailing pond, were subjected to mechanical properties tests performed in the Laboratory of Advanced Polymer Materials and Recyclinf of the Wrocław University of Science and Technology with the use of the LLOYD LR10K and CEAST DARESTER test equipment.

Tenacity analysis

While preparing the samples from solidified bituminous mass it was observed that the material is highly brittle and non--uniformly-sized (uneven thickness of layer). A part of samples designed for testing was damaged at the stage of preparation – during the cutting of shapes of samples or placing them in the measuring jaws of apparatus.

Static tenacity analysis is a basic method of examining mechanical properties of brittle materials. Tenacity analysis consists in deforming a sample of bitumen layer under the influence of an external force, working at the axis of the sample (relationship between sample length increase and tensile force).

For analysis oar-shaped samples were prepared (fot. 1) according to ISO 527-3 and ASTM D 882 with the use of punching press. Having placed a sample in jaws, stress for maximum breaking extension was experimentally identified. The measurements were conducted at ambient temperature 22^{o}C ±2. Specialist software conducted automatic control of measuring processes, recordings and data processing.

Characteristic values determined in tenacity analysis have only limited application for tested samples because of lack of reference to other materials covering the surface of a sludge, nevertheless they allow on estimated defining of samples flexibility.

The above chart shows that the examined bituminous mass samples created form asphalt emulsion at the moment of breaking obtained unit elongation between 3-4% - in the case of four out of six samples - and about 2,5% for two others.

In terms of mar resistance, the material is very weak. This is confirmed by observation of layers behavior on the sludge surface during strong wind blasts. With no doubts material aging plays an important role here. The material is exposed to variable atmospheric conditions and cracks created by them contribute to tearing fragments of the layer at wind blasts causing surface damage and lifting its pieces to the air or on a surface of reservoir.

Fot. 1. Prepared for testing bitumens mass samples from Żelazny Most (on the surface glued monolayer of flotation sludge is visible)
Fot. 1. Przygotowane próbki testowe z masy bitumicznej pobranej z OUOW Żelazny Most. (widoczna na powierzchni przyklejona monowarstwa osadu flotacyjnego)]

Fot. 2. An example of bituminous mass sample after tenacity examination
Fot. 2. Przykładowa próbka z masy bitumicznej po badaniu na rozciąganie

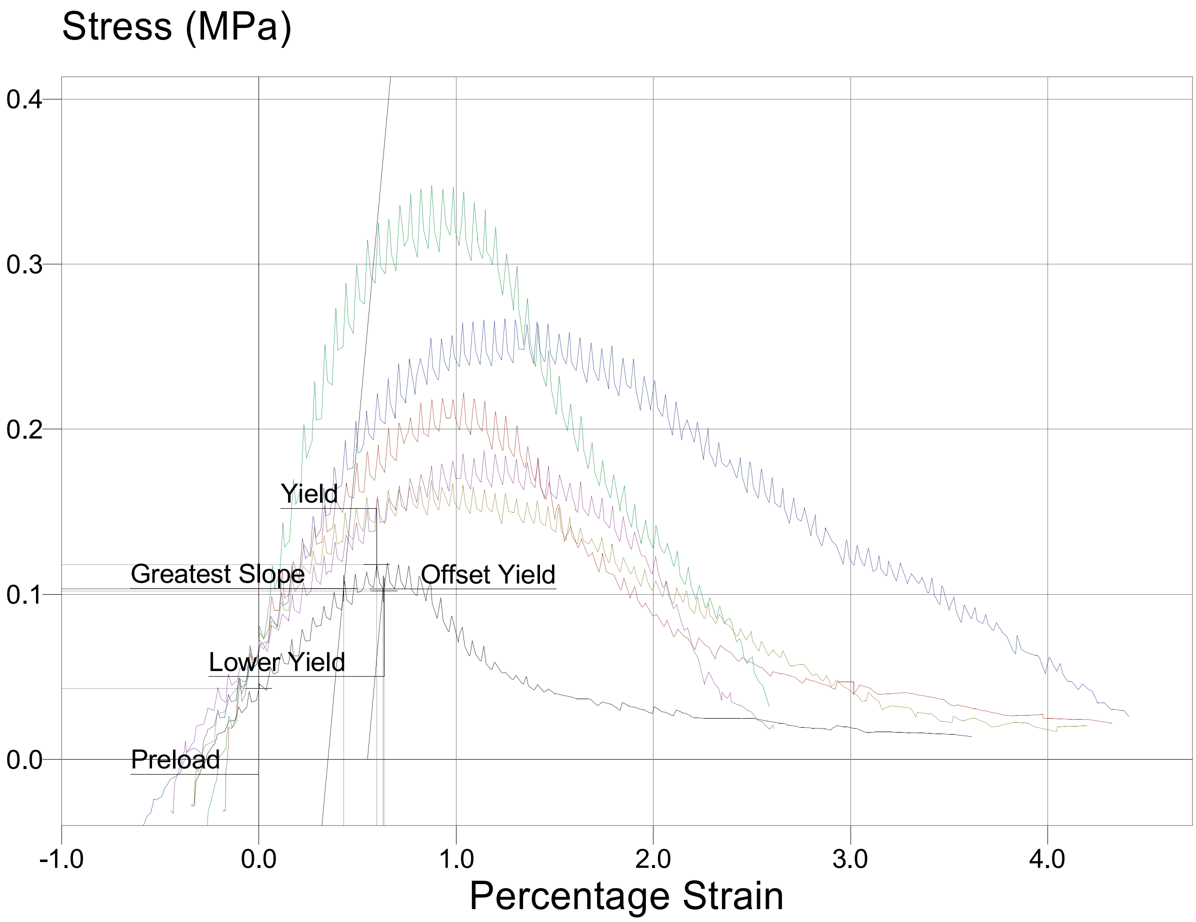

Fig. 1. Extention chart (relationship between elongation and stress (load)) – statistics
Rys. 1. Wykres rozciągania (zależność wydłużenia od naprężenia (obciążenia))– statystyka

Tab. 4. Results of samples tenacity analysis
Tab. 4. Wyniki badań na rozciąganie próbek

Tenacity	Variance	Elongation	Variance	Longitudinal deformability module	Variance
[MPa]	[%]	[%]	[%]	[MPa]	[%]
0.22	±33.5	3.5	±26.7	171	±32.5

Resilience analysis - drop hammer method

Resilience describes material impact resistance and is a measure of material brittleness. For analysis, a CEAST DARTERSER drop hammer was used.

Characteristic of measuring device:

- measurement of impact resistance with a method of drop weight with a registration of sample destruction in time,
- operating range:
  - destruction energy: up to 50 J,
  - impact speed: up to 4.43 m/s,
  - height of free fall: 1000 mm,
- standardized analysis methods: ISO 179, ISO 6603-1/2, ISO 7765-1/2, ASTM D 1709, ASTM D 3763, DIN 53443-1/2.

A method of dynamic resilience analysis with a drop hammer consists in dropping a laden weigh (with a sensor) in a direction of a sample from a height proper to a breakdown. The device allows to obtain the maximum impact speed of 4.43 m/s with the maximum mass of 1 kg. The installed sensors measure a force in the hammer face, displacement of hammer face, speed before hitting the sample and after its disintegration.

A range of results is presented in a table below.

Tab. 5. Results of bituminous layer samples resilience
Tab. 5. Wyniki udarności próbek powłoki bitumicznej

Force at the moment of breakdown	Resilience
[N]	[kJ/m^2]
2-6	0.2 – 0.4

The material of bituminous layer shows low resilience, characteristic of brittle materials. The samples have a low resilience to mechanical impact, 2-6 N.

Summary

The samples of solidified asphalt emulsion collected from the surface of Żelazny Most reservoir were subject to strength testing. Based on the applied research methods it was stated that the material samples have low mechanical tensile strength and high brittleness.

The results allow to confirm low persistence and mecha-

Fot. 3. Bituminous mass samples before resilience analysis
Fot. 3. Próbki testowe z masy bitumicznej przed badaniem udarności

Fot. 4. Bitumen mass layer samples after resilience analysis with method of drop hammer (uneven breakthrough)
Fot. 4. Próbki powłoki masy bitumicznej po badaniu udarności metodą młota spadowego (nierównomierne przebicie)

nical disintegration of bitumen layer due to its low strength. In practice, it is connected with a necessity of successive repeating of stabilization processes of flotation sludges surfaces in a part of reservoir beaches. It increases the cost of these processes, particularly in seasons conductive to dusting. Optimally selected emulsion properties should ensure stabilization abilities of a layer adjusted to silting frequency. Covering the surfaces of beaches with emulsion with available equipment should be conducted in a way which excludes a necessity of covering the "old" layer or partly damaged layer created by wind blasts and wind speed exceeding 4 m/s.

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