Archives of Mining Sciences 47, 1 (2002) 35–49

FRANCISZEK PLEWA*, JERZY SOBOTA**

PHYSICAL AND MECHANICAL PROPERTIES OF DIFFERENTLY COMPOSED MIXTURES USED FOR A STABILISED BACKFILL[1]

FIZYKOMECHANICZNE WŁASNOŚCI WIELOSKŁADNIKOWYCH MIESZANIN PODSADZKI SAMOZESTALAJĄCEJ

Heavy industry in Poland generates about 120 million tonnes of waste per year. Most of this waste is related to hard coal mining and thermal power generation. Utilisation of those wastes within mining technologies remains one of most effective and valuable method of their disposal. Fly ashes and tailings can be applied in many technological processes accompanying coal mining, among others, the back-filling of voids, isolation of caving zones, strengthening of rock mass, etc. To achieve the expected effects the slurries must meet certain conditions. These are described by a number of parameters, which determine their behaviour as fluids while they are being transported and then their solidifying characteristics and their mechanical properties as a solid bodies. The paper presents a range of parameter measurements considered important from the point of view of their application in mining technologies — fluidity, setting time, load capacity, compressibility, and compressive strength of slurries made in different proportions of fly ashes from two power stations, also flotation tailings, and the use of cement as a binder. All proportions of slurry constituents are expressed in terms of mass.

Key words: utilisation of industrial waste, stabilised backfill, laboratory measurements of self-solidifying slurries containing fine-grained waste

Zagospodarowanie odpadów przemysłowych, w szczególności popiołów lotnych powstających w elektrowniach węglowych oraz odpadów górniczych takich jak skały płonne, odpady flotacyjne i wysoko zasolone wody przemysłowe, stanowią istotny problem dla ochrony środowiska na terenach

* POLITECHNIKA ŚLĄSKA, 44-101 GLIWICE, UL. KONARSKIEGO 18
** AKADEMIA ROLNICZA, 50-365 WROCŁAW, PL. GRUNWALDZKI 24

[1] Part of this paper was presented as a poster during an International Conference: *Rheology in the Mineral Industry II*, March 14–19, 1999, Kahuku, Oahu, Hawaii, USA.

przemysłowych Górnego Śląska, którego rozwiązanie wymaga nie tylko uwzględnienia aktualnego stanu nagromadzenia odpadów, ale musi także zapewniać zgodną z regułami ochrony środowiska utylizację tych odpadów również w przyszłości. Brak alternatywnych źródeł energii pozostawia energetykę węglową jedynym znaczącym dostawcą energii cieplnej i elektrycznej w Polsce, przynajmniej na okres nadchodzących dziesięcioleci.

Zredukowanie ilości wprowadzanych do środowiska naturalnego odpadów górniczych i energetycznych, w tym wód zasolonych jest możliwe poprzez ich wykorzystanie do wypełniania pustek powstających w wyniku prowadzenia podziemnej eksploatacji złóż. Zastosowanie mieszanin sporządzonych na bazie odpadów przemysłowych wymaga, aby spełniały one ściśle określone kryteria.

W artykule przedstawiono badania laboratoryjne własności fizykomechanicznych mieszanin drobnofrakcyjnych odpadów przemysłowych pod kątem ich zastosowania w technologii podsadzki samozestalającej oraz ocenę niezbędnego udziału środków wiążących mającego na celu uzyskanie optymalnych z punktu widzenia górniczego parametrów wytrzymałościowych zestalonych mieszanin na bazie odpadów energetycznych i wody zasolonej.

Słowa kluczowe: utylizacja odpadów przemysłowych, posadzka samozestalająca, badania laboratoryjne mieszanin samozespalających z udziałem odpadów drobnofrakcyjnych

1. Introduction

Polish industry creates about 120 million tonnes of waste per year, of which about 50% is currently being economically utilised. As a by-product of coal production about 88 million tonnes of mining waste and tailings is created. The Polish power industry is based mainly on the combustion of hard coal and lignite, producing 97.5% of the total generated energy. The power industry burns about 41 million of tonnes of hard coal and 65 million of tonnes of lignite and produces over 20 million tonnes of solid waste in the form of fly ashes and slags. Besides solid waste, gaseous combustion products are created, which also have an environmental impact. Since the adoption by Poland of international standards, a programme of flue-gas de-sulphurisation has been started within the coal-burning power-generation industry. Although intended to reduce atmospheric pollution, the by-products of the process are solid wastes, which must be added to the quantities of wastes already mentioned.

2. The ways of utilisating fly ashes

Of the total amount of solid waste from the power industry the major part is fly ash, with a yearly total of over 15 million tonnes, of which nearly 6 million tonnes is utilised by the industry. The main ways in which it is used are as follows:

- building engineering — the production of cement, lightweight and common concretes, as well as breeze-blocks,
- land engineering — the construction of roadways, embankments, land restoration etc.,
- works associated with in underground coal mines.

In Upper Silesia the main way of utilising fly ashes is to use them in coal mines. Fly ashes can be applied in many technological processes accompanying the winning of coal such as:

- fire prophylactics and the isolation of exploated areas to prevent the ingress of air and the subsequent spontaneous combustion of residual coal deposits,
- grouting of caving areas in an attempt to prevent the entry of methane and water,
- isolation of existing areas where fires are present,
- back-filling of voids,
- simplification of mine ventilation systems,
- mechanical strengthening of the rock mass.

Moreover, the application of fly ashes makes it easier for mines to utilise their own mining waste and tailings. It has been estimated that the coal mines contain a total volume of mine voids of about 47 million m^3.

3. Basic parameters of fly ash-water slurries used in the technologies of underground mining

Fly ashes are used in the technologies of underground mining mainly as mixtures with water and other waste like tailings, as slurries and with binders or setting agents —

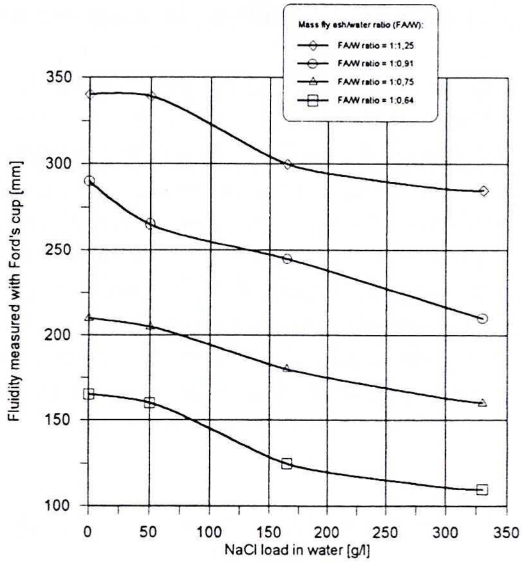

Fig. 1. The relation between fluidity measured with Ford's cup and NaCl content of water for different fly ashes — water ratios FA/W, for slurries made with fly ash from a dry desulphurisation process

Rys. 1. Zależność rozlewności mierzonej przy użyciu kubka Forda od stężenia NaCl w wodzie dla mieszanin o różnej proporcji popiołu do wody sporządzonych z popiołu lotnego po suchym odsiarczaniu spalin mainly cement added in quantities of 2–3% by mass. The ratio of solids to water is very important, and is specific to the intended purpose and the individual situation. For example, in the case of grouting of caving areas the mixture should be smoother with the aim of ensuring good distributory and penetrative properties, and a high fill ratio. From another aspect, the stabilised backfill should be denser to give a quick setting process, with limitation of hydrostatic pressures, etc.

Among the basic parameters of fly ash/water slurries that should be measured are:

1. Fluidity — the diameter of a sample poured onto flat glass surface measured with *Ford's cup* thereby representing the level of its fluidity.

2. Load capacity — the ability of a sample to bear an external load measured by a modified *Vicat's apparatus* equipped with a pivot with a surface of 1 cm^2. Setting-time measured with the Vicat's apparatus.

3. Uni-directional compressive strength.

4. Compactness degradation in water — measured as the decrease in compressive strength of a sample after 48 hour immersing in water.

5. Compressibility.

The relation between fluidity and solid contents — water-content of initial mixtures (saline water) are listed in Fig. 1.

4. Applications of fly ashes and tailings in stabilised backfill slurries

In aim to determine the practical possibilities of the application of fly ashes and mine tailings in underground mine technologies a research work has been carried out, the results of which have determined the composition of mixtures which ensure a maximum utilisation of waste. As components for the preparation of mixtures, tailings from the "Jankowice" mine, fly ash from the dry de-sulphurisation plant of the "Rybnik" power station, and Portland cement type 350 were used. The proportion of cement used was calculated in terms of its mass as compared with a mixture of fly ash with tailings. The results of laboratory measurements of binding time, load capacity, compressive strength, and compactness degradation in water of seasoned samples are listed in Figs. 2–5. The results confirm that these kinds of waste might be suitable for coal mining with back-filling.

5. Results of laboratory tests of physical-mechanical properties of stabilised backfill

5.1. Composition of mixtures of stabilised backfill

The compositions of backfill mixtures, based on percentages by mass of constituents, are described in Table 1 and in Fig. 6. As components of backfill mixtures, fly ashes

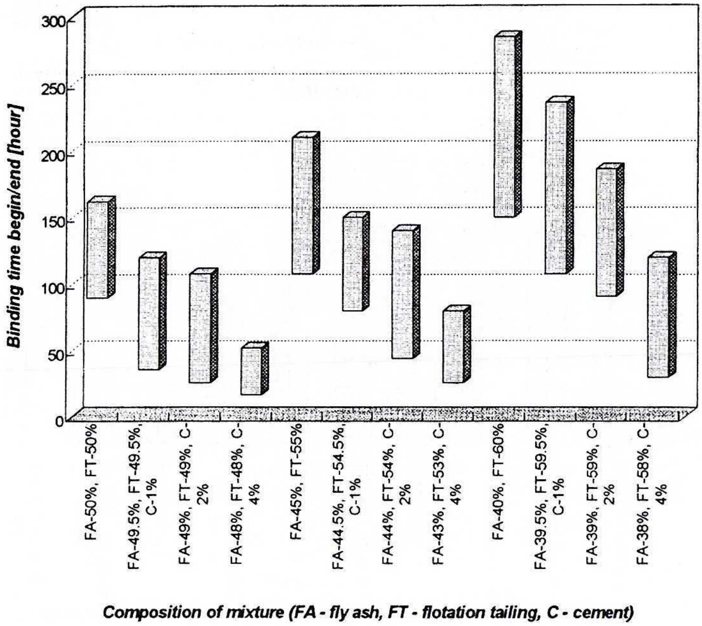

Fig. 2. Setting characteristics of slurries made with flash, flotation tailing and cement

Rys. 2. Przebieg wiązania mieszanin sporządzonych z popiołu lotnego, odpadów flotacji i cementu

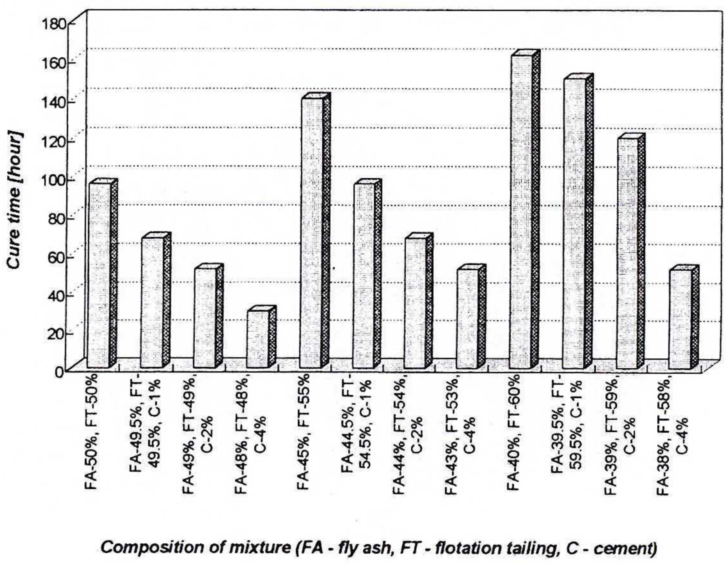

Fig. 3. Curing time necessary to achieve a load capacity of 5 kG/cm^2 for slurries made with fly ash, flotation tailings, and cement

Rys. 3. Czas uzyskiwania nośności 5 kG/cm^2 dla mieszanin sporządzonych z popiołu lotnego, odpadów flotacji i cementu

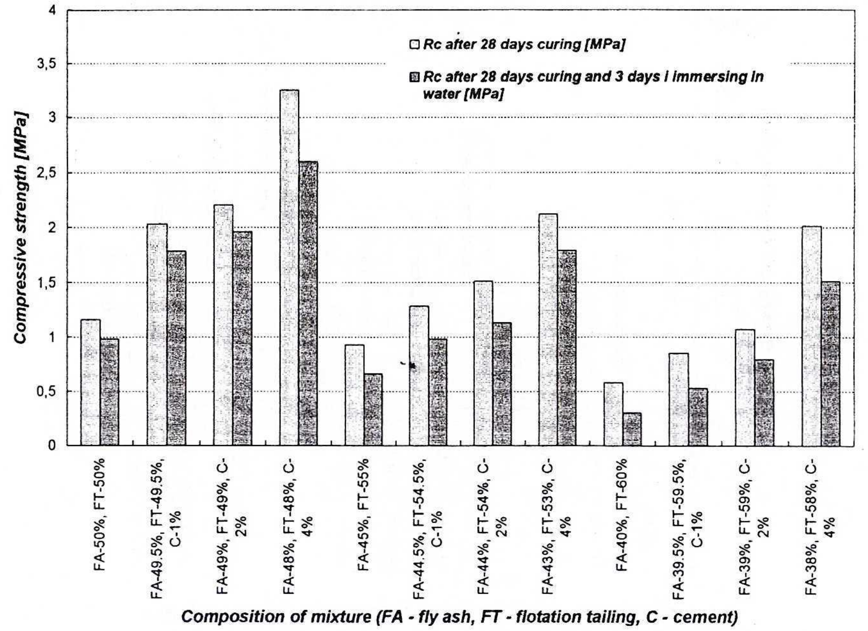

Fig. 4. Compactness degradation of slurries made with fly as, flotation tailing, and cement

Rys. 4. Rozmakalność mieszanin sporządzonych z popiołu lotnego, odpadów flotacji i cementu

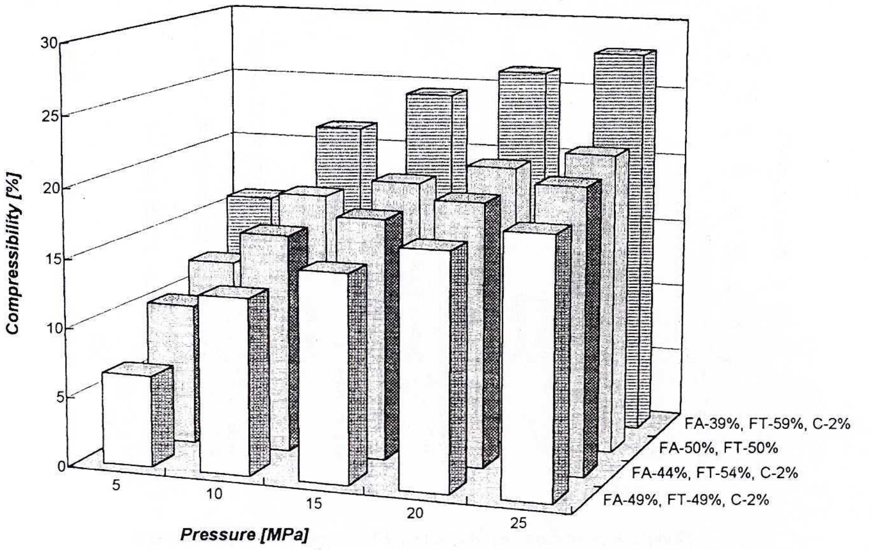

Fig. 5. Compressibility of cured backfill slurries made from fly ash (FA), flotation tailings (FT), and cement (C)

Rys. 5. Ściśliwość zestalonych mieszanin podsadzkowych sporządzonych z popiołu lotnego (FA), odpadów flotacji (FT) i cementu (C)

TABLE 1

Composition of stabilised backfill mixtures with the use of fly ashes from "Jaworzno" and "Rybnik" power stations measured fluidity 25 [cm]

TABLICA 1

Składy mieszanin podsadzki zestalanej sporządzonej z udziałem popiołów lotnych z elektrowni „Jaworzno" i „Rybnik" przy rozlewności równej 25 cm

No.	Number of mixture	Source of fly ash	Percentage of solids by mass [%]		Mass percentage [%] of water related to NaCl content [g/cm^3]		
			Cement	Fly ash	330 g/dm^3	165 g/dm^3	0 g/dm^3
1	1	Jaworzno	0	100	19.5	21.0	21.7
2	2	Jaworzno	5	95	20.9	22.0	22.9
3	3	Jaworzno	10	90	21.0	22.3	23.6
4	4	Jaworzno	15	85	22.0	22.9	24.4
5	5	Jaworzno	20	80	22.8	23.7	24.5
6	6	Rybnik	0	100	26.3	25.9	29.0
7	7	Rybnik	5	95	26.1	25.4	29.4
8	8	Rybnik	10	90	25.4	24.9	29.1
9	9	Rybnik	15	85	25.6	25.6	28.9
10	10	Rybnik	20	80	25.2	26.8	28.4

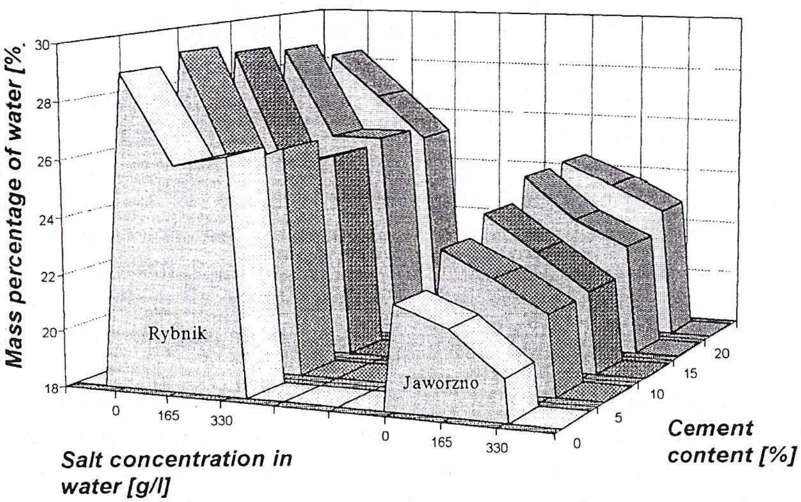

Fig. 6. Water-content by mass of mixtures with a fluidity-radius of 25 cm, in relation to salt concentration, addition of binder, and source of fly ash

Rys. 6. Koncentracja masowa mieszanin zachowujących rozlewność równą 25 cm w zależności od stężenia soli, udziału środka wiążącego i rodzaju popiołu lotnego from the "Jaworzno" and "Rybnik" power stations, Portland cement type 350, brines of strengths 165 and 330 g/dm^3, and fresh water were used. Percentages of water in fly ash/water slurries based on fly ash from the "Rybnik" power station are 2.4–7.3% greater then those made from "Jaworzno" power station ash.

Salinity of water decreases the amount of water that can be admixed within the stabilised backfill. In case of mixtures based on fly ash from "Jaworzno" power station, the highest percentage of water attained was with mixtures that contained fresh water (from 21.7 to 24.5%) and the lowest with mixtures containing brine with a salt concentration of 330 g/dm^3 (from 19.5 to 22.8%). Increasing the salt concentration from 0 to 330 g/dm^3 resulted in a decreasing of the water content by 2% on average.

Among mixtures based on fly ash from "Rybnik" power station the greatest water percentages were observed in mixtures with fresh water (from 28.4 to 29.0%). As the salt content of the water increased from zero to 165 g/dm^3 the water content decreased by 3% in average. Further increases of salt concentration from 165 up to 330 g/dm^3 resulted in a small or no change in the mass percentage of water. An exception was the sample containing 20% of Portland cement, where the mass percentage of water continued to decrease with increasing salt concentrations, as was the case with mixtures based on fly ash from "Jaworzno" power station.

5.2. Measurements of setting times of stabilised backfill mixtures

The measurements of setting times for mixtures based on fly ashes from "Rybnik" and "Jaworzno" power stations are shown in Table 2 and Fig. 7.

The setting process took between 6 and 104 hours in the case of mixtures based on "Jaworzno" power station fly ash and between 6 and 63 hours in the case of "Rybnik" power station fly ash. Generally, the setting process was slower in case of mixtures based on "Jaworzno" power station fly ash. Increasing the salt concentration from 0 to 165 g/dm^3 resulted in delay of the final setting time in the case of mixtures containing fly ash from "Jaworzno" power station from 0.5 hour using 20% of cement to 9 hours for a mixture without the addition of cement. For mixtures containing fly ashes from "Rybnik" power station the final setting time occurred sooner and amounted from 0.5 hour for a mixture without cement addition to 8.5 hours for a mixture with a 5% cement addition.

The times of starting and completion of setting were similar for mixtures containing fresh water and saline water at a concentration of salt 165 g/dm^3. The setting process observed for these samples lasted from between 10.5 and 29 hours in the case of fly ash from "Jaworzno" power station and between 6 and 24 hours in the case of fly ash from "Rybnik" power station. A significantly negative influence of salt concentrations on the prolongation of binding time was observed with salt concentrations of 330 g/dm^3. For slurries based on "Rybnik" power station fly ash, the setting process took between 6 and 104 hours, in the case of fly ash from "Jaworzno" power station between 21 and 63 hours.

TABLE 2

Binding time of stabilised backfill mixtures based on fly ashes from "Rybnik" and "Jaworzno" power stations in relation to concentration of salt in water

TABLICA 2

Czas wiązania mieszanin podsadzki zestalanej sporządzonej z udziałem popiołów lotnych z elektrowni „Rybnik" i „Jaworzno" w zależności od stężenia soli w wodzie

Number of mixture	Source of fly ash	Setting process of mixture with brine concentration 330 g/dm^3		Setting process of mixture with brine concentration 165 g/dm^3		Setting process of mixture with fresh water	
		Begin	End	Begin	End	Begin	End
1	Jaworzno	6	76	16.5	28.5	10.5	19.5
2	Jaworzno	22	96	21	27	15	20.5
3	Jaworzno	21	104	23.5	28.5	18.5	25.5
4	Jaworzno	72	82	24	29	24.5	27
5	Jaworzno	56	72	22.5	26.5	24.5	26
6	Rybnik	21	45	14.5	18	14.5	18.5
7	Rybnik	37	63	12	15.5	20	24
8	Rybnik	35	55	8.5	11	13	17.5
9	Rybnik	31	40	7	8.5	12	17
10	Rybnik	28	36	6	8.5	12.5	16.5

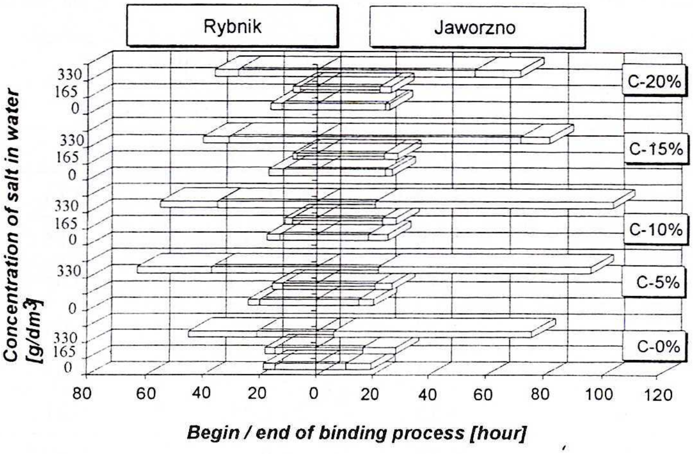

Fig. 7. Comparison of beginning and end of setting process of mixtures based on fly ashes from "Jaworzno" and "Rybnik" power stations

Rys. 7. Porównanie czasów rozpoczęcia i zakończenia procesu wiązania mieszanin sporządzonych z udziałem popiołów lotnych z elektrowni „Jaworzno" i „Rybnik"

The effect of adding a binding agent to mixtures containing brine with a salt concentration of 330 g/dm^3 is interesting. Increasing the quantity of cement added resulted in the prolongation of the completion of the setting process at low cement percentages and then a speeding-up of the process after a certain maximum value was achieved. The longest time to complete setting occurred when 10% of cement was added to mixtures containing fly ash from "Rybnik" power station and by an addition of 5% to mixtures containing fly ash from "Jaworzno" power station.

5.3. Measurements of load capacities of stabilised backfill mixtures

Values of the load capacity of the mixtures analysed are presented in Table 3 and Fig. 8. The load capacity of backfill samples was measured in order to obtain an expression of the compactness of the backfill. The load capacity of backfill samples after 6 hours of curing was within 0.03 to 0.05 MPa for mixtures based on fly ash from "Jaworzno" power station and from 0.07 to 0.5 for mixtures based on fly ash from "Rybnik" power station.

TABLE 3

Measurements results of load capacity of stabilised backfill mixtures based on fly ashes from "Jaworzno" and "Rybnik" power stations after 6 hours curing in relation to salt concentration in water

TABLICA 3

Wyniki pomiarów nośności mieszanin podsadzki zestalanej sporządzonej z udziałem popiołów lotnych z elektrowni „Jaworzno" i „Rybnik" po 6 godz. sezonowania w zależności od stężenia soli w wodzie

Number of mixture	Load capacity [MPa]		
	Salt concentration in water [g/dm^3]		
	330	165]	0
1	0.50	0.21	0.16
2	0.30	0.32	0.15
3	0.14	0.30	0.05
4	0.10	0.15	0.04
5	0.15	0.14	0.03
6	0.12	0.25	0.21
7	0.21	0.17	0.18
8	0.30	0.38	0.07
9	0.22	0.50	0.12
10	0.25	0.50	0.08

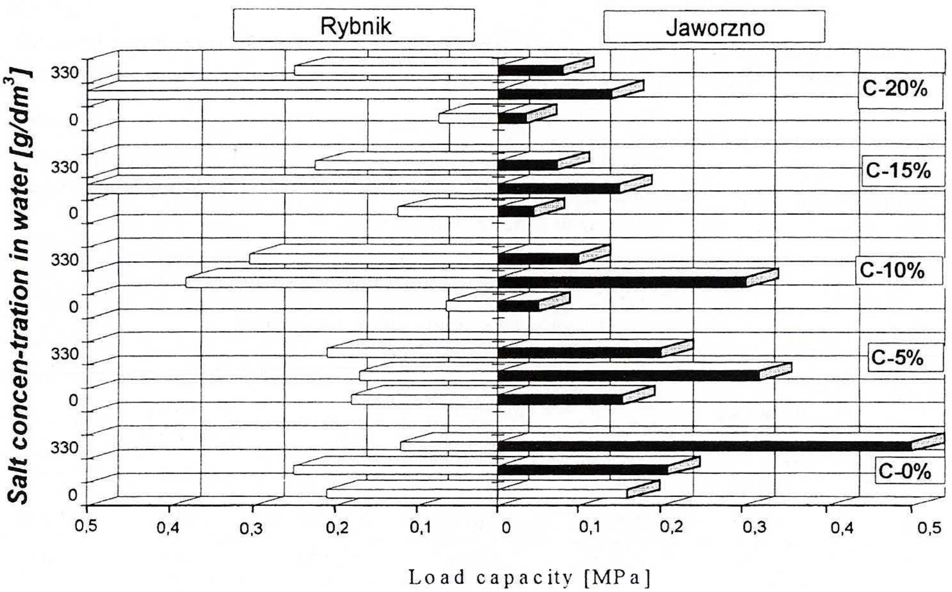

Fig. 8. Comparison of load capacities of mixtures based on fly ashes from "Jaworzno" and "Rybnik" power stations in relation to salt concentration in water, after 6 hours curing

Rys. 8. Porównanie nośności mieszanin sporządzonych z udziałem popiołów lotnych z elektrowni „Jaworzno" i „Rybnik" po 6 godzinach sezonowania w zależności od koncentracji soli w wodzie

The salt concentration of water did not reduce the load capacity in most cases, and even a positive influence was sometimes observed. In most cases the highest load capacity was achieved with mixtures containing saline water with a 165 g/dm^3 concentration of salt. All mixtures tested were able to sustain some loads even before the binding process started.

5.4. Measurements of compressive strength of stabilised backfill mixtures

The results of Uni-directional compressive strength measurements of stabilised backfill mixtures are presented in Table 4 and Fig. 9.

The compressive strength of samples cured for 28 days in air dry conditions ranged from 0.12 to 18.80 MPa for mixtures based on fly ash from "Jaworzno" power station and from 0.77 to 6.95 MPa for mixtures based on fly ash from "Rybnik" power station.

For samples cured in an air washer the measured compressive strengths ranged between 0.42÷17.38 MPa for fly ashes from "Jaworzno" power station and 1.08÷14.85 MPa for fly ashes from "Rybnik" power station. In most cases the highest compressive strengths were achieved with mixtures made with saline water containing 165 g/dm^3 of salt.

TABLE 4

The results of compressive strength measurements of mixtures based on fly ashes from "Jaworzno" and "Rybnik" power stations after 28 days curing in air-dry conditions and in an air washer

TABLICA 4

Wyniki pomiarów wytrzymałości na ściskanie mieszanin sporządzonych z popiołów lotnych z elektrowni „Jaworzno" i „Rybnik" po 28 dobach sezonowania w warunkach powietrzno-suchych oraz w komorze klimatycznej

Number of mixture sample	Compressive strength [MPa] after 28 days of seasoning					
	Salt concentration in water [g/dm^3]					
	330		165		0	
	air-drying conditions	air washer	air-drying conditions	air washer	air-drying conditions	air washer
1	0.226	0.423	0.121	0.439	0.307	0.596
2	1.480	2.050	3.610	3.075	2.910	2.015
3	6.478	6.074	8.690	10.270	5.682	5.652
4	6.952	9.006	18.802	13.746	6.320	6.794
5	8.058	12.166	17.538	17.380	6.636	10.902
6	0.770	1.085	2.265	4.505	2.880	2.935
7	1.495	2.545	2.905	9.638	4.120	3.861
8	2.360	2.780	3.025	10.902	4.898	4.210
9	2.950	3.645	6.925	14.852	5.372	5.668
10	3.940	5.846	7.742	11.850	5.688	6.952

The compressive strength increases with increased additions of cement. The highest strengths were recorded for samples containing 15% cement and were equal to 18.8 MPa for fly ash from "Jaworzno" power station and seasoned in air-drying conditions and 14.85 MPa for fly ashes from "Rybnik" power station and seasoned in an air washer.

The lowest strengths occurred in mixtures without the addition of binding agent. Among the mixtures containing fly ashes from "Jaworzno" power station the lowest compressive strength, 0.12 MPa, was observed in a mixture with saline water of salt concentration 165 g/dm^3 after seasoning in air-drying conditions. In case of mixtures based on fly ashes from "Rybnik" power station the lowest compressive strength, equal to 0.77 MPa, obtained appeared in a mixture containing brine of salt concentration 330 g/dm^3, also after seasoning in air-drying conditions.

All mixtures based on "Rybnik" power station fly ash achieved compressive strengths above 1 MPa without cement addition and with brine of 330 g/dm^3 salt concentration except the above mentioned sample, which, after seasoning in air dry conditions, achieved a strength of 0.77 MPa.

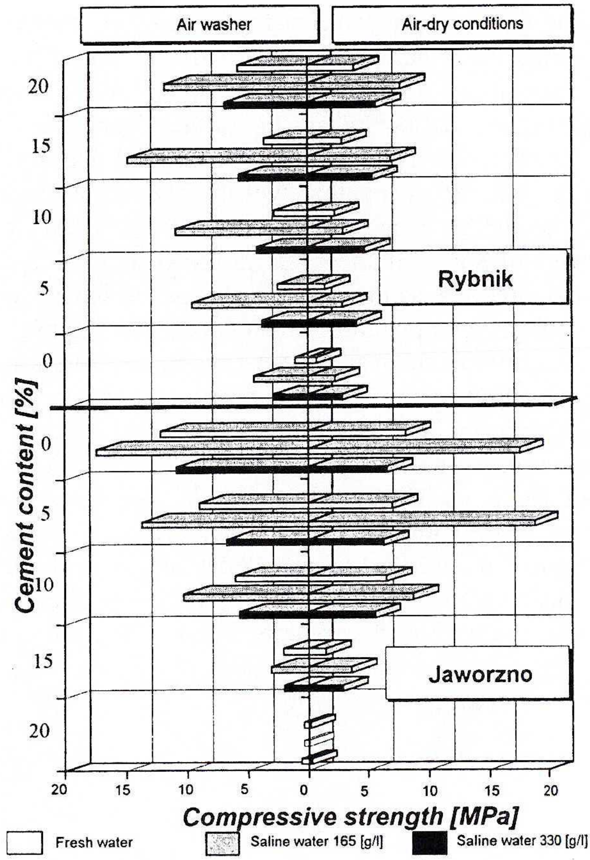

Fig. 9. Compressive strength comparison of mixtures based on "Rybnik" and "Jaworzno" power station wastes after 28 days of curing in air-drying conditions and in an air washer

Rys. 9. Wytrzymałość na ściskanie mieszanin sporządzonych z popiołów lotnych z elektrowni „Jaworzno" i „Rybnik" po 28 dobach sezonowania w warunkach powietrzno-suchych i w komorze klimatycznej

Mixtures based on "Jaworzno" power station fly ash obtained compressive strengths in excess of 1 MPa only by the addition of binding agent.

6. Summary

Utilisation of industrial waste, especially fly ashes from coal-based power generation plants and mine waste such as waste rock, flotation tailings, and highly saline mine waters is one of the great environmental problems faced by the industry of the Upper Silesian Coal Basin. The permanent demand for heat and electric power from the industry necessitates the burning of large amounts of coal in the power plants. This is connected with the need to locate new places for dumping or otherwise disposing of the ashes, dusts and saline waters that are the by-product of coal of production.

Discharging saline waters into rivers as well as the open storage of residues from coal-fired power-generation stations means the further degradation of an environment which has been already seriously damaged by industrial activity. By putting waste resulting from power generation together with highly saline waters in underground workings and voids creates a chance for environmental problems to be reduced.

The measurements of some of the basic physical and mechanical properties of differently composed mixtures, as presented in this paper, have been carried out, with the aim of determining a composition which meets the requirements of stabilised backfill. The most decisive factor was the determination of the proportion of binding agent needed in relation to the concentration of salt in the water, which is an important factor in its suitability for application in mining practices.

The results obtained prove that it is possible to make a stabilised backfill on the basis of fly ash and flotation tailings. The best properties were demonstrated by a slurry made from 48% fly ash, 48% flotation tailings, and 4% cement. Such a mixture achieved a compressive strength of about 3.2 MPa after 28 days curing with a decrease to 2.6 MPa after 3 days immersion in water. The compressibility results of the selected slurries are within the values required by Polish standards. The load capacity varies over a period from about 1 day up to 7 days, the exact values and times being related to the fly ash/tailing ratio and the addition of cement.

REFERENCES

Lazarevic L.T., 1996: Handling of 2 600 000 tons per month of slimes and backfilling at Vaal Reefs exploration and mining company limited. 13th Intenational Conference on Slurry Handling and Pipeline Transport HYDROPTRANSPORT 13, Johannesburg, South Africa.

Mazurkiewicz M., 1997: Fin-friction Suspensions as Void-Filling and Brine-Binding Agents in Salt Mine, Archiwum Górnictwa vol. 42, i. 4.

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

Palarski J., 1998: Design and use of backfill for support in polish coal mines. Sixth Intl. Symp. on Mining with Backfill, Brisbane, Australia.

Palarski J., 1997: Fill transportation and sedimentation mechanisms for stope filling. 9th Intl. Conf. on Transport & Sedimentation of Solid Particles, Sept. 2–5, Kraków, Poland.

Palarski J., 1998: Use and design of backfill in Polish coal mines. Asia — Pacific Workshop on Coal Mining Technology Tokyo'98, Proceedings J. Coal, Japan.

Palarski J., 1998: Multi-slice longwalling with backfill. Underground coal mining. The challenges and the future, Sydney.

Plewa F., 1996: Application of coal fired power generation waste in the process of utilisation of saline mine waters. Intl. Conf. Workshop on Waste Management in Coal Mining and The Coal Fired Thermal Power Sector, Szczyrk.

Plewa F., Radzikowski W., 1996: Możliwości odzysku niektórych metali oraz stopów niemagnetycznych z odpadów przemysłowych. Materiały konferencji: Problemy zagospodarowania odpadów, Wisła.

Plewa F., Mysłek Z., 1996: Możliwości zagospodarowania słonych wód dołowych w podsadzce zestalanej. Materiały konferencji: Problemy zagospodarowania odpadów, Wisła.

Plewa F., Babczyński W., Popczyk M., 1996: Możliwości zagospodarowania wód silnie zasolonych w podsadzce samo zestalającej. Materiały konferencji: Problemy zagospodarowania odpadów, Wisła.

Sobota J., 1998: Hydraulika przepływu mieszanin newtonowskich w rurociągach, Prace i Studia 50, PAN, Komitet Inżynierii Środowiska, Wyd. Ossolineum.

Sobota J., 1996: A procedure for the prediction of pressure drops for polyfractional mixture flow. 13th International Conference Hydrotransport 13, Johannesburg, South Africa.

Sobota J., 1987: Badania globalnych i lokalnych charakterystyk przepływu mieszaniny popiołowo-wodnej w rurociągu poziomym. Archiwum Hydrotechniki t. XXXIV, z. 3–4.

REVIEW BY: PROF. DR HAB. INŻ. MACIEJ MAZURKIEWICZ, KRAKÓW

Received: 29 May 2000