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## POSSIBLE APPLICATIONS OF HARDENING SLURRIES WITH FLUIDAL ASHES IN ENVIRONMENT PROTECTION STRUCTURES

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**Keywords:** Fluidal ashes, hardening slurry, cut-off walls, hydraulic conductivity, eluate.

**Abstract:** This article presents ways of possible utilization and application of fluidal combustion wastes as active additives to hardening slurries which are used to seal environment protection structures, i.e. cut-off walls in waste dumps and wastewater treatment plants. Cut-off walls are often exposed to filtrating action of eluates – polluted (aggressive) waters.

Results of hydraulic conductivity tests of slurries after their long-term (210 days) filtration with eluates from a municipal waste dump and with tap water are presented. Porosity tests were also conducted to show the porosity structure of the filtered slurries. Additionally, compressive strength of slurries maturing in tap water and waste dump eluates was tested in parallel.

### INTRODUCTION

In recent years, repairs and upgrades of levees and environment protection structures (such as waste dump embankment seals) have been implemented in Poland on a rather large scale. This results, on the one hand, from the existing flood infrastructure having been considerably worked out (13% of levees are older than a hundred years, and 46% are 41100 years old), and from extensive omissions in the maintenance of these structures (of the 8 500 000 kilometers of embankments in Poland, as much as 60% require repairing), and, on the other, from limited and changing over time funding possibilities for such actions.

Investments in environment protection structures (waste dump embankments, underground water protection) are in turn forced by high requirements for such structures today (impact reduction, sustainability and reliability of the separation of environment pollution sources). The Polish *Environmental Protection Law* [15] and the *Waste Management Act* [17] in particular oblige local governments to establish new waste dumps and modernize existing ones. Varied location conditions of those structures (leak tightness of the soil for the most part) make it difficult to assess the present scope of use of cut-off walls, but the number of structures in which they will be applied may be assessed

at several hundred (of various scales). Estimations have it that in the years 2001–2007 some 4.5 million square meters of cut-off walls were completed, of which over a half in 2005–2007.

In the years 1998–2005 a total of 172 kilometers of cut-off walls with hardening slurries were constructed of which 25% using the Deep Soil Mixing (DSM) method, 52% using the WIPS method, and 23% using of cut-off walls method [3, 4, 7].

The above-mentioned technologies of trenching implementation all use mineral materials – usually modified cement slurries and hardening slurries [5, 12]. Indispensable ingredients of these slurries are betonite and waste materials from other industries (power industry, metallurgy, lime industry etc.). Also, dry ready-mixtures which develop into hardening slurries with the addition of water are now gaining in significance. These mixtures have technical approvals from either the Institute for Land Reclamation and Grassland Farming or the Building Research Institute.

Over the last few years in Poland a technology of solid fuel combustion in furnaces with a circular fluidal layer has been under development, usually associated with sulphur removal from combustion gases. The new combustion technology provides inter alia for a lower emission of noxious substances to the environment. Thus the amount of waste created in Poland as a result of fluidal combustion has considerably increased.

Due to a lower combustion temperature and a sorbent addition, ashes produced from fluidal boilers are significantly different from those created in conventional furnaces fired by pulverized fuel [9]. These features limit possible applications of ashes in the construction industry [8].

In the search for new ways of utilization of fluidal ashes, research was undertaken to examine the possibilities of adding them to hardening slurries. Research on hardening slurries with addition of ashes from conventional combustion has shown an improvement in the slurries' resistance to corrosion with some water environment aggressions, and in the conditions of diffusive capillary transport of aggressive substances [6, 8, 10, 18]. This is particularly significant where cut-off walls are used to separate underground waters from pollution sources.

In the light of the above, the response of slurries with fluidal fly ashes in conditions corrosive for cement binders was also tested, where contact with aggressive liquids was ensured by forcing their filtration through the porous structure of the material [6, 8].

The measure of leak tightness of hardening slurries is their hydraulic conductivity [2]. The latter is primarily conditioned by the porosity structure and the characteristics of the filtrating medium. Apart from the temperature and the physical features of the liquid (viscosity and density), its chemical characteristics are equally important, and in particular its capacity to react with slurry ingredients (corrosive processes). These processes can significantly change the structure of the material and its characteristics, including hydraulic conductivity [2, 10, 18].

Leak tightness is characterized by the filtration coefficient. Both natural and anthropogenic cut-off walls should have low hydraulic conductivity values [2].

The complicated nature of the chemical changes occurring in mineral binding materials and the characteristics of fluidal ashes call for a deeper insight into their application in hardening slurries. A special challenge is to recognize the properties of hardening slurries with the addition of fluidal ashes functioning in chemically aggressive water-ground environments, which takes place in cut-off walls functioning in hydraulic

structures used for environment protection (e.g. waste dumps or facilities protecting against pollution of underground water intakes, etc.).

This article continues its author's research into the matter. It describes a testing methodology and results for the basic – for application in cut-off walls – characteristic of hardening slurries, i.e. their hydraulic conductivity after persistent filtration over several months with tap water and waste dump eluates. Also, results of porosity tests of slurries are presented, as well as images of the microstructure of hardening slurries taken by a scanning microscope (SEM). In addition, compressive strength tests of hardening slurries were carried out.

## SELECTED CHARACTERISTICS OF HARDENING SLURRIES

Characteristics of hardening slurries fall into two groups:

- Characteristics of hardening slurries in the liquid state (technological),
- Characteristics of hardening slurries after hardening (functional).

The most important characteristics of hardening slurries in the liquid state include:

- density –  $\rho$  [ $\text{g}/\text{cm}^3$ ],
- conventional viscosity –  $L$  [s],
- 24 h water setting –  $O_d$  [%].

Slurry density  $\rho$  is usually determined in the process of ensuring stability of a trench or a hole in the ground. Density values sufficient for ensuring stability in average water-ground conditions range from  $1.12 \text{ g}/\text{cm}^3$  to  $1.59 \text{ g}/\text{cm}^3$ . Within that scope, slurries of lower density must demonstrate higher structural strength conditioned by relatively high content of betonite gel. Under electrostatic influences the latter generates the so-called filtration cake which stabilizes ground particles on the trench walls.

Density test results for liquid slurry have shown that a higher content of ash or cement significantly increases its density [10, 13]. Betonite in turn has little effect on changes in density values.

By determining the conventional viscosity ratio  $L$ , one can define flow conditions of hardening slurry in pipes as well as its ability to migrate in the trench during an excavation process.

Changes in conventional viscosity are predominantly influenced by betonite content [13]. Between the limits of cement content proportioning range, i.e. 60–80 kg per  $1000 \text{ dm}^3$  of water, conventional viscosity ratio increases by 3 seconds, while with the same modification of betonite content conventional viscosity ratio increases by 14 seconds. Hardening slurries are usually designed so as not to exceed conventional viscosity ratio of 50 seconds.

Low percentage of 24 h water setting  $O_d$  allows for eliminating heterogeneity of a slurry column after hardening, which could threaten the stability of an excavated trench during the period of binder hydration – before the time that the material has binded.

Excessive separation of water from slurry manifests either too low a concentration of clayey (colloidal) particles or adverse influence of coagulation agents. Acceptable – from the practical point of view – 24 h water setting values are up to 15%.

Test results show that 24 h water setting is most decreased by betonite [13] while binders (cement and ash) have no significant influence on it.

Hardening slurries used as material for cut-off walls in hydraulic engineering or environment protection structures have to meet a number of functional requirements and demonstrate appropriate durability in order to ensure safety of those structures.

The most important functional characteristics of hardening slurries include:

- compressive strength –  $f_c$  [MPa] and
- hydraulic conductivity –  $k_{10}$  [m/s].

Compressive strength of hardening slurry guarantees that a cut-off wall properly mates with the ground [10, 13]. It is important to design cut-off walls of appropriate rigidity, i.e. ones with correct  $f_c$  values.

Compressive strength of slurries primarily increases under the influence of binding materials, i.e. mainly cement but also ash and blast furnace slag. From the practical point of view, the compressive strength values of hardening slurries range from 0.3 to 2.0 MPa.

Hydraulic conductivity, which is the most important characteristic of cut-off wall material and notably affects the quality and durability of functioning cut-off walls, depends primarily on the material structure. According to the law [11], cut-off walls in waste dumps have to be practically impermeable, i.e. have hydraulic conductivity values of  $k < 1,0 \cdot 10^{-9}$  m/s.

Both technological and functional characteristics of hardening slurries significantly influence the scope and possible locations of their application.

#### PREPARATION OF HARDENING SLURRIES AND TESTS OF THEIR TECHNOLOGICAL CHARACTERISTICS

The tested slurries had been made out of the ingredients listed below. Two types of slurries were prepared: one with fluidal fly ash from hard coal (PK) and one with fluidal fly ash from brown coal (PB). The dosing of ingredients per 1000 dm<sup>3</sup> of water is given in brackets:

- sodium bentonite (40 kg for PK and 30 kg for PB);
- cement CEM I 32,5R "Ożarów" (160 kg for PK and PB);
- fluidal fly ash from hard coal (323 kg),
- fluidal fly ash from brown coal (326 kg).

The water-cement ratio  $w/c$  is in this case 6.25 while the water-binder ratio  $w/s$  is 2.07 for fluidal ash from hard coal and 2.06 for fluidal ash from brown coal.

Batches of hardening slurries were prepared, and their basic properties in liquid state were tested (Tab. 1).

Tests were performed to determine density ( $\rho$ ) of the liquid slurries, their conventional viscosity ratio ( $L$ ), and 24 h water setting ( $O_d$ ). Volumetric density ( $\rho$ ) of the slurries was

Table 1. Properties of liquid slurries

Item	Parameter	PK	PB
1	2	3	4
1	Volume density $\rho$ [g/cm <sup>3</sup> ]	1,27	1,29
2	Conventional viscosity ratio $L$ [s]	38	37
3	24 h water setting $O_d$ [%]	2,0	4,0

tested with Barroid's balance, and the conventional viscosity – using a viscometer (Marsh's funnel). The 24 h water setting test can be described as determining the percentage share of the volume of spontaneously separating water in 1.0 dm<sup>3</sup> of liquid slurry after one day of it standing in a measuring cylinder.

### TESTS OF HARDENED SLURRIES

Regarding the nature of the application of cut-off walls, tests of hardened slurries were limited to hydraulic conductivity, porosity and compressive strength.

The 'utilitarian' purpose of the hydraulic conductivity tests was to demonstrate slurry usefulness for the construction of cut-off walls.

In conductivity tests the filtrating medium were eluates sampled from a ferroconcrete settler (retention reservoir) in a waste dump. Due to their chemical composition, eluates are hazardous to the environment. Table 2 juxtaposes parameter values determined for eluates sampled from the waste dump, and admissible values specified in an applicable regulation of the Polish Minister of Environment [16]. Comparing the two sets of values one can observe that the values for eluates clearly exceed admissible limits of most parameters by several dozen or even several hundred times. These parameters are marked in Table 2 – they are mainly nitrogen, phosphorus and chloride compounds, as well as BZT<sub>5</sub> and CHZT. In addition, the eluates contain heavy metals such as nickel, lead and zinc. Therefore, it is essential that the cut-off walls constructed around waste dumps stop eluates from infiltrating to underground waters.

Table 2. Physical and chemical parameters of eluates from a municipal waste dump and admissible values of compounds in waste effluents according to Journal of Laws no. 137, item 984 of 2006 [16]

Item	Indicator	Units	Admissible values	Indicator in eluate
1	2	3	4	5
1	Reaction	-	6,5 – 9,0	7,71
2	BZT <sub>5</sub>	mg O <sub>2</sub> / dm <sup>3</sup>	25 – 50	<b>4850</b>
3	CHZT	mg O <sub>2</sub> / dm <sup>3</sup>	125 – 250	<b>13136</b>
4	General nitrogen (N)	mg N / dm <sup>3</sup>	30,0	<b>884</b>
5	Ammonia nitrogen (NH <sub>4</sub> )	mg NH <sub>4</sub> / dm <sup>3</sup>	10 – 20	<b>763</b>
6	General phosphorus (P)	mg P / dm <sup>3</sup>	2 – 10	<b>78,4</b>
7	Chloride (Cl)	mg / dm <sup>3</sup>	1000	<b>1597</b>
8	Sulphates (SO <sub>4</sub> )	mg / dm <sup>3</sup>	500	37,5
9	∑ Cl, SO <sub>4</sub>	mg / dm <sup>3</sup>	1500	<b>1634,5</b>
10	Lead (Pb)	mg Pb / dm <sup>3</sup>	0,1 – 0,5	<b>4,25</b>
11	Copper (Cu)	mg Cu / dm <sup>3</sup>	0,1 – 0,5	0,336
12	Zinc (Zn)	mg Zn / dm <sup>3</sup>	2,0	0,808
13	Nickel (Ni)	mg Ni / dm <sup>3</sup>	0,1 – 0,5	0,394
14	General slurry	mg / dm <sup>3</sup>	35 – 150	<b>6774</b>

The reference basis was constituted by test results of slurries exposed to filtrating action of tap water, and of slurry samples statically maturing in tap water and not exposed to persistent filtration (standard samples).

The slurries were exposed to filtration for 120 days. On the starting day of the research program, the slurries were 60 days old. During the testing period, measurements of hydraulic conductivity were taken and trends in changes of this quantity were observed. Also taken were measurements of hydraulic conductivity of the standard samples (which had matured for 210 days in tap water). These tests were conducted only once and in the same way as those of slurries exposed to persistent filtration.

After the exposure period (210 days), material for porosity tests was taken from the slurry samples, and thus distributions of pore sizes as well as pore characteristics were obtained. Analysis of the porosity structures of the standard samples was also conducted, and a number of microstructure photographs were taken using a scanning electron microscope (SEM).

Independently from hydraulic conductivity tests, compressive strength tests of slurries were performed. The tested samples had matured (for 28 and 90 days) in tap water and in waste dump eluates.

### ***Hydraulic conductivity tests***

The hydraulic conductivity of hardening slurries is very low (similar to that of cohesive soils) and so the time needed to obtain the balance of supply and outflow of water from the sample in tests with a constant hydraulic gradient is quite low. In such cases, conductivity tests are performed with a variable hydraulic gradient. This method consists of determining, in established times  $t_1$ ,  $t_2$ , etc., the values of water pressure  $h_1$ ,  $h_2$ , etc. in the supply tube of cross-section area  $a$ , during the liquid's flow through the sample of length (height)  $L$  and cross-section area  $A$ . In this case the hydraulic conductivity is calculated with the following formula (Eq. 1):

$$k_T = \frac{a \cdot L}{A \cdot \Delta t} \ln \frac{h_1}{h_2} \quad (1)$$

$k_T$  – hydraulic conductivity in temperature  $T$ , [m/s];  $a$  – cross-section area of the supplying tube, [m<sup>2</sup>];  $L$  – length (height) of the sample, [m];  $A$  – cross-section area of the sample, [m<sup>2</sup>];  $\Delta t$  – time between pressure measurements  $h_1$  and  $h_2$ ,  $\Delta t = t_2 - t_1$ , [s];

$h_{1,2}$  – values of water pressures at times  $t_1$  and  $t_2$ , [m].

The main advantage of this testing method is the possibility it offers of measuring small water flows and forcing high water pressures.

The hydraulic conductivity tests using tap water and eluates were conducted in specially produced chemical-resistant plastic (plexiform and polyvinyl chloride) apparatus [6]. The action of the filtering media (tap water and waste dump eluates) on the tested sample was of gravitational nature. The measurements were performed with a decreasing initial hydraulic gradient.

Once a week measurements of hydraulic conductivity of the slurries were taken.

The range of hydraulic gradients acting on the samples was from 20 to 45, and gradients lower than 45 were only acting on the days of the hydraulic conductivity measurements (once a week) for no longer than 4 hours.

The hydraulic conductivity calculated with formula (Eq. 1) does not take account of the influence of the temperature of the filtering liquids. The  $k_T$  values obtained during the tests (at temperature T) were recalculated into  $k_{10}$  values corresponding to the temperature of +10°C. The following formula (Eq. 2) was used:

$$k_{10} = \frac{k_T}{0,7 + 0,03T} \quad (2)$$

The water solution character of waste dump eluates entitles one to treat them as tap water in  $k_{10}$  calculations, and thus ignore the influence of changes in their viscosity and density on hydraulic conductivity of the slurries.

The results of hydraulic conductivity test of hardening slurries in the conditions of filtering transport of the media are shown in time function in Figure 1 (slurries with fluidal fly ash from hard coal – PK), and in Figure 2 (slurries with fluidal fly ash from brown coal – PB). The diagrams show matching lines (trends) for the series of individual hardening slurries (formulae) exposed to filtering tap water and eluates.

Table 3 shows the final hydraulic conductivity values for the hardening slurry samples after exposure to persistent filtration (210 days) – as estimated on the basis of the diagrams.

The influence of hydraulic gradient on the result of the conductivity measurements was also tested – in the applied range of gradients there was no relationship between these results.

### ***Porosity tests of slurries***

Numerous factors influence hydraulic conductivity which is the primary characteristic of the hardening slurry as a construction material in cut-off walls. It needs to be stressed, however, that the conductivity of slurry depends mostly (and directly) on its structure. And the structure of a material is in turn inseparably connected to its porosity and pore structure [1, 18].

The greatest influence on a liquid's filtration through a slurry structure is that of continuous capillary pores (mesopores). Tests show [6, 8] that the structure of these pores is particularly affected by the water-binder ratio w/s (w/c), as well as the ratio and time of cement hydration.

The porosity structures of slurries were tested in a mercury porosimeter. The test was performed on samples of hardening slurry with addition of fluidal fly-ashes (PK and PB), after their long-term exposure (210 days) to filtrating action of tap water and dump waste

Table 3. Final hydraulic conductivity values of the tested slurries after their long-term filtration (210 days)

Item	Type of solution	PK	PB
		$k_{10}$ [m/s]	
1	2	3	4
1	tap water	$9,0 \cdot 10^{-10}$	$5,5 \cdot 10^{-10}$
2	eluate	$4,0 \cdot 10^{-10}$	$2,0 \cdot 10^{-10}$
3	standard	$2,5 \cdot 10^{-11}$	$1,6 \cdot 10^{-11}$

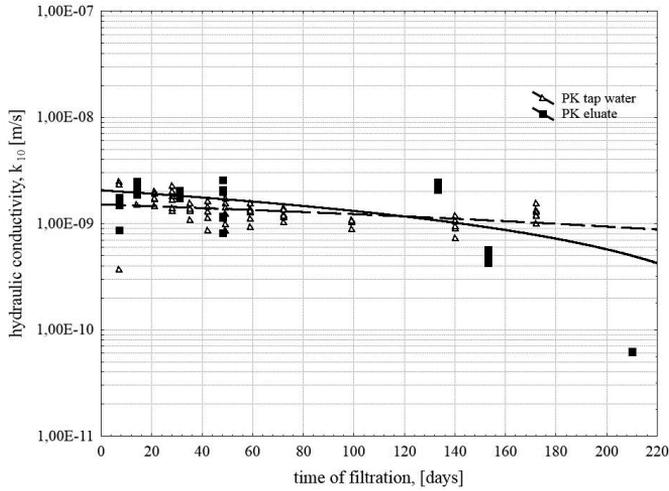


Fig. 1. Hydraulic conductivity of hardening slurry with addition of fluidal ash from hard (PK) coal in time function (trend lines)

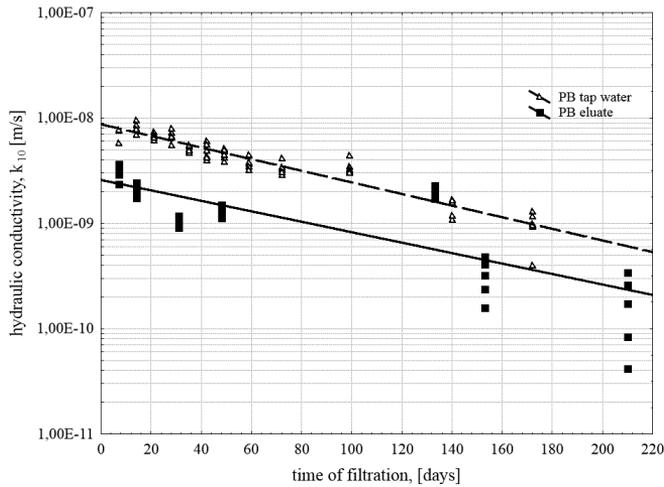


Fig. 2. Hydraulic conductivity of hardening slurry with addition of fluidal ash from brown (PB) coal in time function (trend lines)

eluates. The reference base was constituted by standard samples which had matured for 210 days in tap water and were then subject to a single filtration test.

Results of the porosity tests are presented in the form of pore size distributions. On the basis of the diagram, parameters of the microstructures of the tested samples were determined. These values are compiled in Table 4 where the following symbols are used:

$A_p$  – total pore area, [ $m^2/g$ ];  $v_p < 0,2$  – volume of pores of diameters smaller than  $0,2 \mu m$ ;  $v_p > 0,2$  – volume of pores of diameters larger than  $0,2 \mu m$ ;  $P_c$  – total porosity of sample, [-];  $d_{max}$  – maximum diameter of pores, [ $\mu m$ ].

Table 4. Specification of microstructure parameters of the tested hardening slurries

Item	Type of solution	PK	PB	PK	PB	PK	PB	PK	PB	PK	PB
		$A_p$ [m <sup>2</sup> /g]		$v_p > 0,2$ μm [%]		$v_p < 0,2$ μm [%]		$P_c$ [%]		$d_{max}$ [μm]	
1	2	3	4	5	6	7	8	9	10	11	12
1	tap water	99,5	100,9	66	69	34	31	76,2	75,9	4,0	7,0
2	eluate	94,4	85,7	71	68	29	32	73,9	72,1	3,0	4,0
3	standard	189,6	169,1	38	35	62	65	74,0	73,0	1,5	1,5

### Compressive strength tests

Compressive strength values  $f_c$  were determined for cylindrical samples from steel moulds ( $d = h = 80$  mm). The tests were performed twice: after 28 and 90 days of slurry maturation. The investigated samples matured in laboratory conditions in both tap water and waste dump eluates.

After a sample was taken out of the container (filled with water or eluate), it was left to dry for several minutes. Then its upper surface (and the lower one if uneven) was smoothed, the point of which was to fit the surface of the sample precisely to the heads of the testing machine. The compressive strength measurements were performed in a testing machine type ZD 20.

The sample was compressed with stress gain between 0.0026 and 0.0020 MPa/s, until it was destroyed. Three samples of slurry were compressed in one series. The following formula was used to calculate compressive strength  $f_c$ :

$$f_c = \frac{P}{A} [MPa] \quad (3)$$

where:

$P$  – stress force destroying the sample, [N],

$A$  – cross-section area of the cylindrical sample, [mm<sup>2</sup>].

Results of the compressive strength  $f_c$  tests of samples of slurry PK and PB maturing in tap water and waste dump eluates are illustrated in Figure 3. Because of its small values, the parameter  $f_c$  is presented in [kPa].

### Microstructure tests of hardening slurries by a scanning microscope (SEM)

The microstructures of the hardening slurries were tested with a scanning microscope (SEM). The tests were performed on the slurry material exposed for a long time (210 days) to filtrating action of tap water and eluates, and on standard slurry. The selected images of the microstructures are shown in Figure 5.

## ANALYSIS OF TEST RESULTS

Having analysed the changeable results of the slurries' hydraulic conductivity tests performed over a period of 210 days' exposure to filtration with various liquids (change trends of this quantity are presented in Figures 1 and 2), one can present the following observations:

- Both the PK and PB samples exposed to long-lasting action of tap water demonstrated drops of hydraulic conductivity over the whole testing period: from ca.  $1.5 \cdot 10^{-9}$  m/s

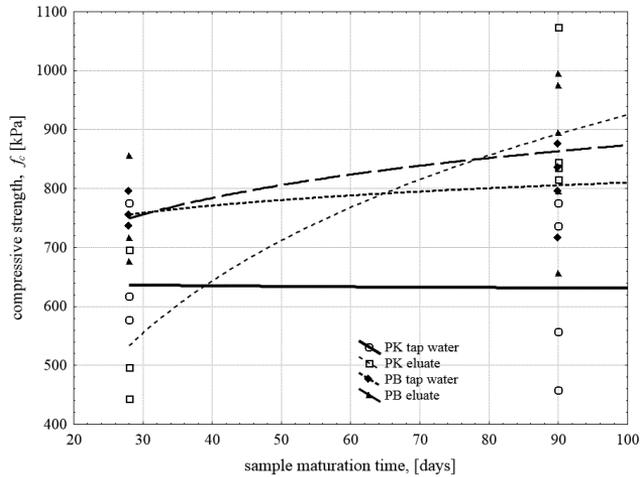


Fig. 3. Compressive strength of hardening slurry samples, in time function

to ca.  $9,0 \cdot 10^{-10}$  m/s for the PK sample, and from ca.  $9,0 \cdot 10^{-9}$  m/s to ca.  $5,5 \cdot 10^{-10}$  m/s for the PB sample;

- The exposure of slurries to filtration with waste dump eluates generally resulted in sealing up of the samples, i.e. the values of hydraulic conductivity of both types of slurry decreased: from ca.  $2,0 \cdot 10^{-9}$  m/s to  $4,0 \cdot 10^{-10}$  m/s for PK, and from ca.  $2,5 \cdot 10^{-9}$  m/s to  $2,0 \cdot 10^{-10}$  m/s for PB.

When examining the matching lines for the hydraulic conductivity values of all the slurry types and filtrating media, one finds that the slurry structure seals-up. In the case of tap water filtration, this correlation was already observed in the previous research project [6], however the sealing up of the slurry structure under the influence of aggressive waste dump eluate is also interesting. It confirms corrosion resistance of this material in an aggressive environment (as referred to a cement matrix). Such behaviour allows for a wider application of slurries in vertical cut-off walls which seal environment protection structures such as municipal waste dumps.

Furthermore, it is clear that all the final  $k_{10}$  results (after 210 days of filtration) for the tested slurry types (PK and PB) and the analysed filtrating media (tap water and waste dump eluates) are lower than  $k = 1,0 \cdot 10^{-9}$ , which means that they meet the requirements for the materials used in cut-off walls. This also implies that the eluates which are hazardous to the environment (ground waters and living organisms) will be retained at the cut-off wall, and will not infiltrate beyond the waste dump area.

Analysis of parameters characterizing the microstructure of hardening slurries exposed to filtration of tap water and waste dump eluates, as compared to samples statically maturing in tap water, shows a significant impact of mezopores ( $v_p > 0,2 \mu\text{m}$ ), which was confirmed in earlier experiments [6, 8]. Due to similar hydraulic conductivity values of the samples (both PK and PB, exposed to filtration of both tap water and eluates), the percentage shares of mezopores and micropores are also comparable.

The total area of pores ( $A_p$ ) in the standard samples (statically maturing in tap water) is definitely larger than that in the samples exposed to filtration, however a reverse

proportion of mezopores ( $v_p > 0.2 \mu m$ ) and micropores ( $v_p < 0.2 \mu m$ ) should be noted. Specification of the microstructure parameters of hardening slurries ( $v_p > 0.2 \mu m$  and  $A_p$ ), which distinctly affect their hydraulic conductivity ( $k_{10}$ ) is contained in Figure 4.

Images of the microstructures of hardening slurries presented in Figure 5 confirm earlier observations.

Analysis of the compressive strength test results (Figure 3) for PK samples maturing in tap water proves that their  $f_c$  values are constant – practically identical after 28 and 90 days of maturing – and remaining at the level of ca. 640 kPa. On the other hand,  $f_c$  values of PK samples maturing in waste dump eluates are lower in the first test round, i.e. after 28 days, than for those maturing in tap water. The former only reach the level of ca. 540 kPa. Conversely, compressive strength values of the samples maturing in eluates visibly increase with the final value (after 90 days) of ca. 890 kPa (+ 65%), thus exceeding the  $f_c$  values of the samples maturing in tap water by 250 kPa (+ 39%).

Similar correlations can be observed in the case of the  $f_c$  test results for PB samples. A small increase of  $f_c$  value was observed in the slurry maturing in tap water – ca. 760 kPa after 28 days and ca. 810 kPa (+ 6%) after 90 days. By all means most considerable increase in  $f_c$  values was registered for PB slurry samples maturing in waste dump eluates. In the first testing phase (28 days), its  $f_c$  value amounted to ca. 750 kPa, while the final  $f_c$  value (after 90 days) was ca. 870 kPa (+ 16%). The final compressive strength values of the samples maturing in waste dump eluates are higher by ca. 7.4% than those of the slurry samples maturing in tap water.

The results obtained in this project confirm the present knowledge on a delayed gain in strength of cement composites with fluidal ashes (delayed hydration). Particularly interesting is, however, the larger gain in strength in the (PK and PB) samples maturing in aggressive eluates from a municipal waste dump. This increase can be explained by the formation of a tighter C-S-H matrix (Figure 5 c, d), which may be caused by the process of additional hydration, as well as by carbonatization.

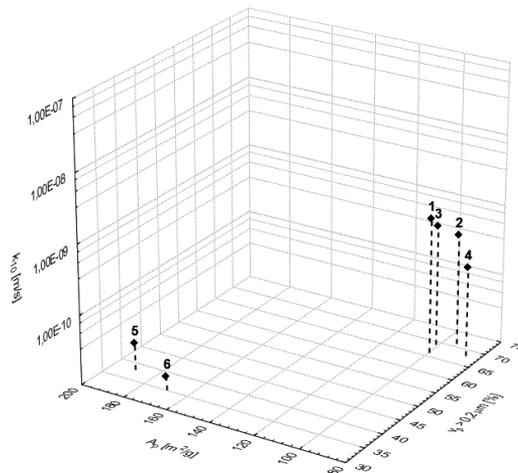


Fig. 4. Hydraulic conductivity of hardening slurries in the function of their microstructure parameters:  $k_{10} = f(v_p > 0.2; A_p)$ , 1 – PK tap water, 2 – PK eluate, 3 – PB tap water, 4 – PB eluate, 5 – PK standard, 6 – PB standard

The above-mentioned results corroborate with the author's earlier research on the high structural resistance of the slurry material to aggressive environments.

All the  $f_c$  results obtained for the analyzed types of ash (PK and PB) and media (tap water and waste dump eluates) stay within the limits of practical applicability (0.3–2.0 MPa).

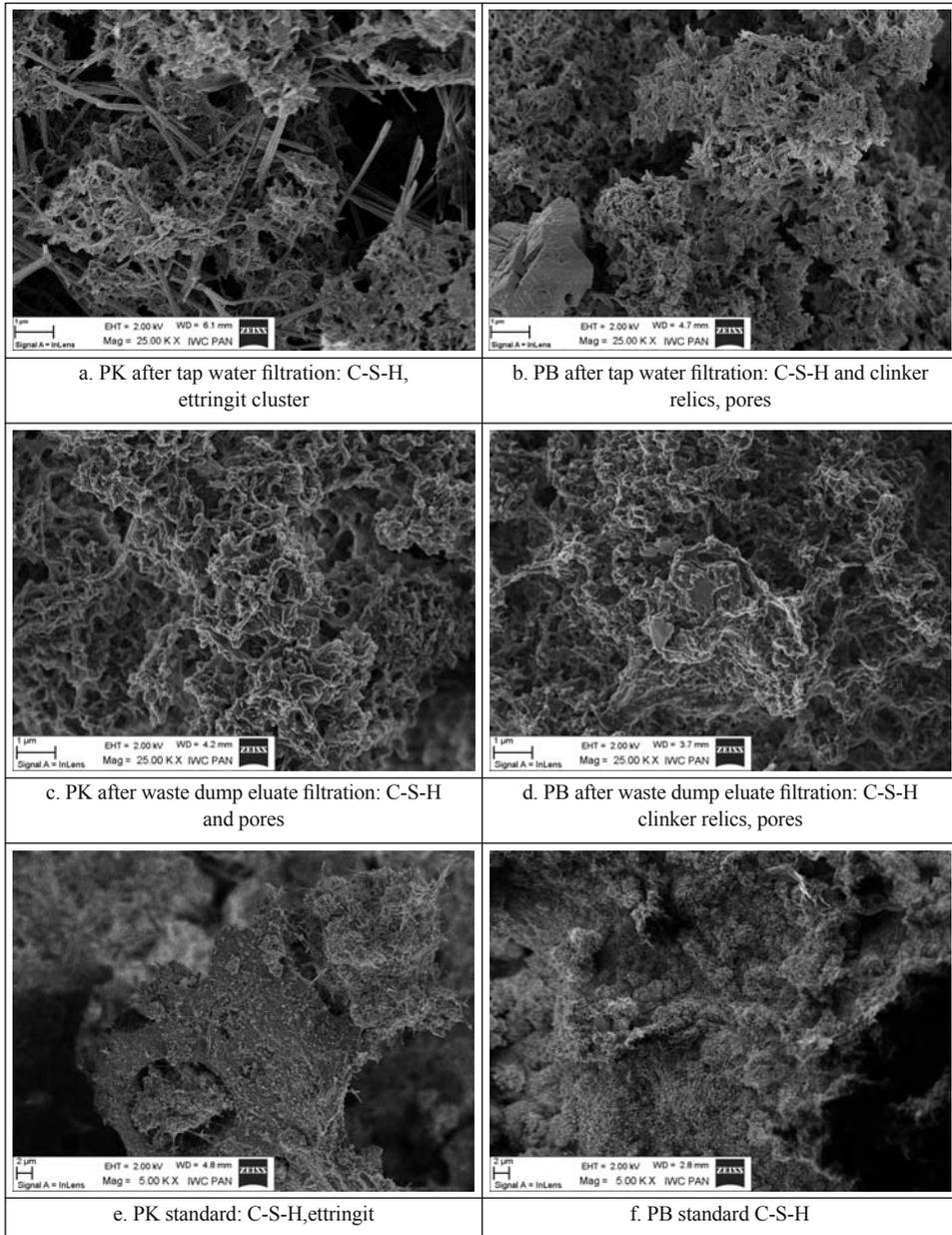


Fig. 5. Selected microstructure images of investigated hardening slurries (SEM)

## CONCLUSIONS

Result analysis of the tests of hardening slurries with fluidal ashes (from hard and brown coal) concerning their hydraulic conductivity, porosity and compressive strength allows of the following conclusions:

1. Slurries exposed to filtration with waste dump eluates were not corrosively destroyed, and, moreover, they sealed up (a decrease in hydraulic conductivity) as compared to the slurries tested with tap water.
2. The tests conducted in this research project have also demonstrated a gain in the strength parameter, i.e. compressive strength of hardening slurries maturing in aggressive eluates from a municipal waste dump.
3. Hydraulic conductivity values of the hardening slurries used in this experiment were always  $k < 1.0 \cdot 10^{-9}$ , regardless of the type of added fluidal ash and the type of the filtrating medium, which means that the slurries meet the requirements for materials used in cut-off walls.
4. The project confirms high structural resistance of hardening slurries with fluidal ashes (from both hard and brown coal) to the aggressive environment of waste dump eluates.
5. The hardening slurries with fluidal fly-ashes from hard and brown coal can be a high-quality material to be used for cut-off walls in environment protection structures.

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#### MOŻLIWOŚCI STOSOWANIA ZAWIESIN TWARDNIEJĄCYCH Z POPIOŁAMI FLUIDALNYMI W OBIEKTACH OCHRONY ŚRODOWISKA

Artykuł przedstawia możliwości zagospodarowania oraz wykorzystania odpadów ze spalania fluidalnego, jako aktywnego dodatku do zawiesin twardniejących podczas realizacji uszczelnień w obiektach ochrony środowiska, tj.: przesłon przeciwfiltracyjnych na składowiskach odpadów komunalnych, oczyszczalniach ścieków. Przesłony przeciwfiltracyjne często pracują w warunkach filtracyjnego oddziaływania odcieków – wód zanieczyszczonych (agresywnych).

Przedstawiono wyniki badań przepuszczalności hydraulicznej zawiesin poddanych długotrwałej (210 dni) filtracji odcieków ze składowiska odpadów komunalnych oraz wody wodociągowej. Wykonano badania porozymetryczne przedstawiające strukturę porowatości filtrowanych zawiesin. Niezależnie od tych badań przeprowadzono testy wytrzymałości na ściskanie zawiesin dojrzewających w wodzie wodociągowej oraz w odciekach ze składowiska.