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Hydraulic Conductivity And Porosity of Hardening Slurries with Fluidal Fly Ashes in Chemically Aggressive Environments

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Abstract

The article presents the results of hydraulic conductivity and porosity tests of hardening slurries prepared from Portland cement, betonite, water and fluidal fly ashes from combustion of hard and brown coal. In addition, the ashes were in two states of activation: non-activated and mechanically activated.

The slurries were exposed to persistent, 160-day filtration of chemically aggressive liquids: distilled water, 0.5% solution of nitric acid and 1% solution of sodium sulphate. A comparative base was composed of samples exposed to filtration of tap water.

The research was into relations between hydraulic conductivity and parameters characterizing the porosity structures in slurries, as well as into the influence of sample maturation periods, the state of activation and type of ashes, and the type of aggressive medium on porosity and conductivity of the material. The observed phenomena were typical of materials based on cement binders, and exposed to chemical aggression, e.g. sealing-up of porosity structures in response to sulphate corrosion and de-sealing in response to leaching corrosion, along with effects specific for slurries, such as a decrease of hydraulic conductivity in response to nitric acid solution. A favourable effect of fluidal fly ashes from brown coal was also noted.

Key words: hardening slurry, fluidal ashes, cut-off walls, hydraulic conductivity

1. Introduction

Poland's power industry is almost entirely based on the combustion of solid fuels. Combustion of hard or brown coal generates millions of tones of combustion by-products yearly. Some of them get utilized in industry but large amounts have to be disposed to overloaded waste dumps.

In recent years, a method 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 increased considerably.

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 (Havlica et al 2004). The special characteristics of fluidal fly ashes are: a higher content of calcium and sulphur compounds (as compared to conventional ashes), a higher content of unburnt coal elements, and a dissimilar crystallographic structure. These features limit possible applications of ashes in the construction industry.

In the search for new ways of utilising of fluidal ashes, research was undertaken to examine the possibilities of adding them to hardening slurries.

A hardening slurry is a mixture of water (the major constituent by volume), bentonite and cement, which in the liquid state has tixotropic characteristics (important in the case of liquids expanding trenches during excavation), and, after binding, characteristics of a construction material adequately durable and waterproof to be used, for instance, in cut-off walls. Since various additives and admixtures can be added to hardening slurries and thus modify their technological or functional properties, it is possible to design various formulae depending on the destination of the material.

Combustion wastes, including fluidal ashes, are rather special additives used in hardening slurries. They are mineral materials with binding characteristics. Therefore, they can act not only as fillers but also as additional binders (Kledyński at al 2004).

The favourable anticorrosive characteristic of ash additions from conventional coal combustion to cement concrete are well-known (Bastian 1980, Gruener 1983). Moreover, 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 (Kledyński 2004, Falaciński et al 2005). 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 (Kledyński et al 2004).

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 recognise the properties of hardening slurries with the addition of fluidal ashes functioning in a chemically aggressive water-ground environment, which takes place in cut-off walls in hydraulic structures used for environment protection (e.g. waste dumps or facilities protecting against pollution of underground water intakes, etc.).

The measure of leak tightness of hardening slurries is their hydraulic conductivity. 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.

This article presents 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 liquids chemically aggressive to cement binders. Also, results of porosity tests of slurries after long-time exposure to filtrating action of different liquids are discussed, as well as correlations between parameters characterizing the porosity of slurries, and hydraulic conductivity.

2. Formulae of Hardening Slurries

The tested slurries consisted of the following ingredients:

- sodium bentonite DYWONIT S;
- cement CEM I 32.5R "Ożarów";
- fluidal fly ash from hard coal (Katowice Thermal-electric Power Station);
- mechanically activated fluidal fly ash from hard coal (Katowice Thermal-electric Power Station);
- fluidal fly ash from brown coal (Turów Power Plant);
- mechanically activated fluidal fly ash from brown coal (Turów Power Plant).

The compositions of the tested slurries are presented in Table 1.

Mechanical activation of fly ash is a physical process conducted in specially constructed mechanical activators, which does not require the application of chemical reagents (Patent No. 180380). It involves a supply of the proper amount of mechanical energy to the comminuted material in a way that does not bring about a breakage of ash particles but induces a change in their internal energy and pore structure, as well as the creation of active centres on the particle surface which has been renewed by friction and collision of the particles.

3. Scope of Testing

Batches of slurries were prepared according to the formulae in Table 1. Their basic properties in liquid state were tested (Table 2), and samples for hydraulic conductivity tests were prepared.

The tests comprised determining the liquid slurries' density (ρ), conventional viscosity ratio (L), and 24h water setting (O_d). The volumetric density (ρ) of the

Table 1. Formulae of hardening slurries

Item	Component	PKN[1]	PKA[1]	PBN[1]	PBA[1]
1	2	3	4	5	6
1	Tap water [dm^3]	1000	1000	1000	1000
2	Bentonite Dywonit S [kg]	40	40	30	30
3	Fluidal fly ash from hard coal [kg]	323	0	0	0
4	Activated fluidal fly ash from hard coal [kg]	0	323	0	0
5	Fluidal fly ash from brown coal [kg]	0	0	326	0
6	Activated fluidal fly ash from brown coal [kg]	0	0	0	326
7	Cement CEM I 32.5R [kg]	163	163	170	170

1) symbol:
PKN – slurry with non-activated fluidal fly-ash from hard coal;
PKA – slurry with mechanically activated fluidal fly-ash from hard coal;
PBN – slurry with non-activated fluidal fly-ash from brown coal;
PBA – slurry with mechanically activated fluidal fly-ash from brown coal

Table 2. Properties of liquid hardening slurries

Item	Component	PKN[1]	PKA[1]	PBN[1]	PBA[1]
1	2	3	4	5	6
1	Volume density [g/cm^3]	1.305	1.315	1.300	1.300
2	Conventional viscosity ratio [s]	39	40	38	44
3	24h water setting [%]	3.5	2.0	5.0	2.0

1) symbol shown in Table 1

slurries was tested with *Barroid's balance*, and the conventional viscosity – using a viscometer (*Marsh's funnel*). The 24h water setting test can be described as determining the percentage share of spontaneously separating water in 1 dm^3 of liquid slurry after one day of standing in a measuring cylinder.

As for hardened slurries, only hydraulic conductivity and porosity were tested.

In conductivity tests the filtrating medium was tap water and liquids aggressive to cement binders.

From among typical aggressive environments, three were selected: leaching – distilled water, general acid – 0.5% solution of HNO_3, and sulphates – 1.0% solution of Na_2SO_4. The reference basis was constituted by test results of slurries exposed to filtrating action of tap water.

The slurries were exposed to filtration for 160 days. On the starting day of the research programme, the slurries were 65 days old. During the testing period, measurements of hydraulic conductivity were taken and trends in changes of this quantity were observed. After the exposure period, material for porosity tests was taken from the slurry samples, and thus distributions of pore sizes and characteristics of the pores were obtained.

4. Hydraulic Conductivity Tests

4.1. Methodology of Measurement and Calculation of Results. Apparatus

The hydraulic conductivity of hardening slurries is very low (similar to that of cohesive soils) and so the time needed to obtain a balance of supply and outflow of water from the sample 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):

$$k_T = \frac{a \times L}{A \times t} \ln\left(\frac{h_1}{h_2}\right), \tag{1}$$

k_T – hydraulic conductivity in temperature T [m/s],
a – cross-section area of the supplying tube [m^2],
L – length (height) of the sample [m],
A – cross-section area of the sample [m^2],
t – time between pressure measurements (h_1, h_2), $t = t_2 - t_1$ [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 action of the filtering media (tap water, distilled water and aggressive water solutions) on the tested sample was of gravitational nature. The measurements were performed with a decreasing initial hydraulic gradient.

The sample was placed in the apparatus (Fig. 1) and liquid poured over it up to the level which forced the maximum hydraulic gradient equal to 45 (hydraulic gradient is the quotient of water pressure measured in cm and height of investigated sample in cm).

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 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 was used:

$$k_{10} = \frac{k_T}{0.7 + 0.03T}. \tag{2}$$

The low concentrations of both the nitric acid – 0.5%, and the sodium suphate – 1.0%, entitles one to treat the two solutions as tap water, and thus ignore the influence of changes in their viscosity and density on hydraulic conductivity of the slurries.

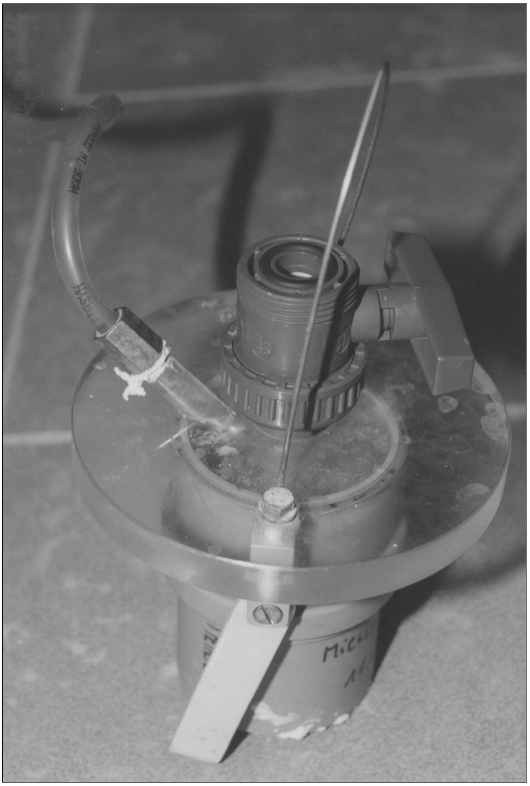

Fig. 1. Apparatus for testing hydraulic conductivity with a sample of hardening slurry, during the test

4.2. Test Results

The test results are shown in time function in Figures 2 and 3 (hardening slurries with fluidal fly ash from hard coal), and Figures 4 and 5 (hardening slurries with fluidal fly ash from brown coal). The diagrams show trends (matching lines) for the series of individual hardening slurries (formulae) exposed to filtering tap water, distilled water, and the solution of nitric acid and sodium sulphate. For each day of the hydraulic conductivity test, four repeated measurements were used with a gradually decreasing initial gradient (the first and the last measurement in the series were rejected). Earlier, the influence of hydraulic gradient on the result of conductivity measurements had been tested – in the applied range of gradients there was no

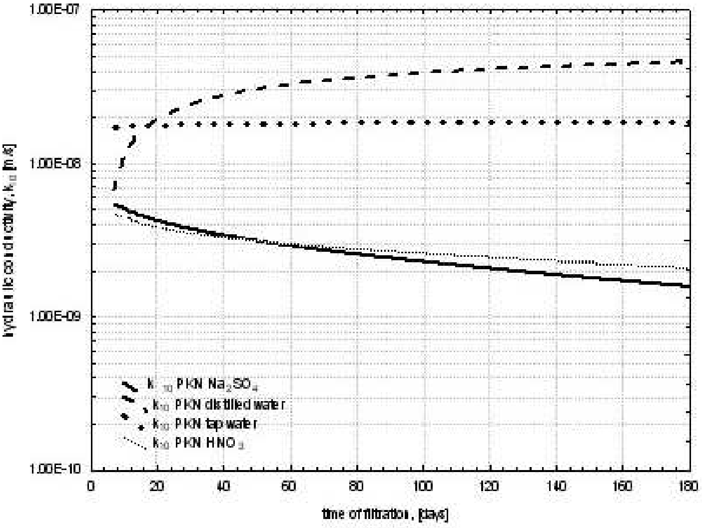

Fig. 2. Hydraulic conductivity of hardening slurry with addition of non-activated fluidal ash from hard coal (PKN) as a function of time and type of filtrating liquid

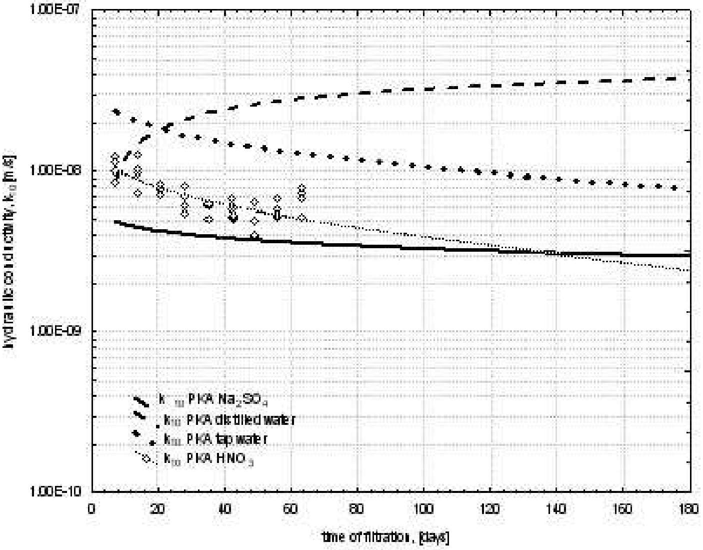

Fig. 3. Hydraulic conductivity of hardening slurry with addition of mechanically activated fluidal ash from hard coal (PKA) as a function of time and type of filtrating liquid

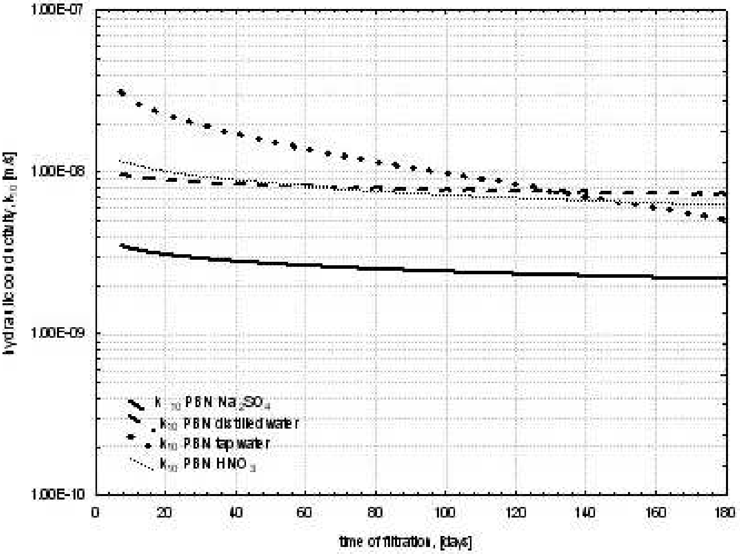

Fig. 4. Hydraulic conductivity of hardening slurry with addition of non-activated fluidal ash from brown coal (PBN) as a function of time and type of filtrating liquid

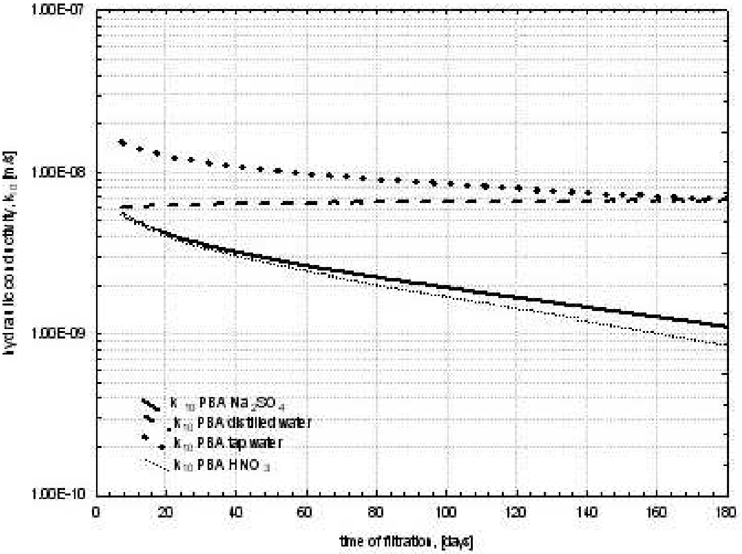

Fig. 5. Hydraulic conductivity of hardening slurry with addition of mechanically activated fluidal ash from brown coal (PBA) as a function of time and type of filtrating liquid

relationship between these results. After about 60 days of testing, the sample of slurry with activated ash from hard coal, exposed to the action of acid, de-sealed in the area of contact with the mould so the test was discontinued. In Figure 3 the test results of this sample are shown as experimental points and a trend curve extrapolated until the end of the analysed period.

Table 3 shows results of the hydraulic conductivity tests – the final values, i.e. after the 160-day exposure period, complemented by results of analogous tests performed on samples of slurries matured statically in tap water over a period of 28 days.

Table 3. Values of hydraulic conductivity k_{10} [m/s] of hardening slurries matured statically in tap water over a period of 28 days and those after exposure to persistent filtration (160 days) with tap water and aggressive liquids

Item	Type of slurry	Hydraulic conductivity k_{10} [m/s]				
		Filtration with tap water after 28 days of maturing samples	Persistent filtration of tap water	Persistent filtration of Na_2SO_4 solution	Persistent filtration of distilled water	Persistent filtration of HNO_3 solution
1	2	3	4	5	6	7
1	PKN$^{1)}$	2.0×10^{-8}	2.0×10^{-8}	1.5×10^{-9}	4.5×10^{-8}	2.0×10^{-9}
2	PKA$^{1)}$	2.4×10^{-9}	8.0×10^{-9}	3.0×10^{-9}	4.0×10^{-8}	2.5×10^{-9}
3	PBN$^{1)}$	1.4×10^{-8}	6.0×10^{-9}	2.0×10^{-9}	7.5×10^{-9}	6.0×10^{-9}
4	PBA$^{1)}$	1.0×10^{-8}	7.0×10^{-9}	1.0×10^{-9}	7.0×10^{-9}	8.0×10^{-10}
$^{1)}$ symbols as in Table 1						

5. Porosity Tests of Slurries

The porosity structures of slurries were tested in a mercury porosimeter. The test was performed on samples of hardening slurries with addition of fluidal fly-ashes (PKN, PKA, PBN and PBA), after their long-term exposure to filtrating action of tap water and liquids chemically aggressive toward cement binders, as well as on samples of slurries which had matured for 28 days in tap water. Results of the porosity tests are presented in the form of distributions of pore sizes, exemplified in Figure 6. On the basis of the diagram, parameters of the microstructures of the tested samples were determined. These values are illustrated in Figure 6 and compiled in Table 4 where the following symbols are used:

$d_{\max}$ – maximum diameter of pores [μm],
$v_p < 0.2$ – volume of pores of diameters smaller than 0.2 μm,
$v_p > 0.2$ – volume of pores of diameters larger than 0.2 μm,
Pc – total porosity of sample [–].

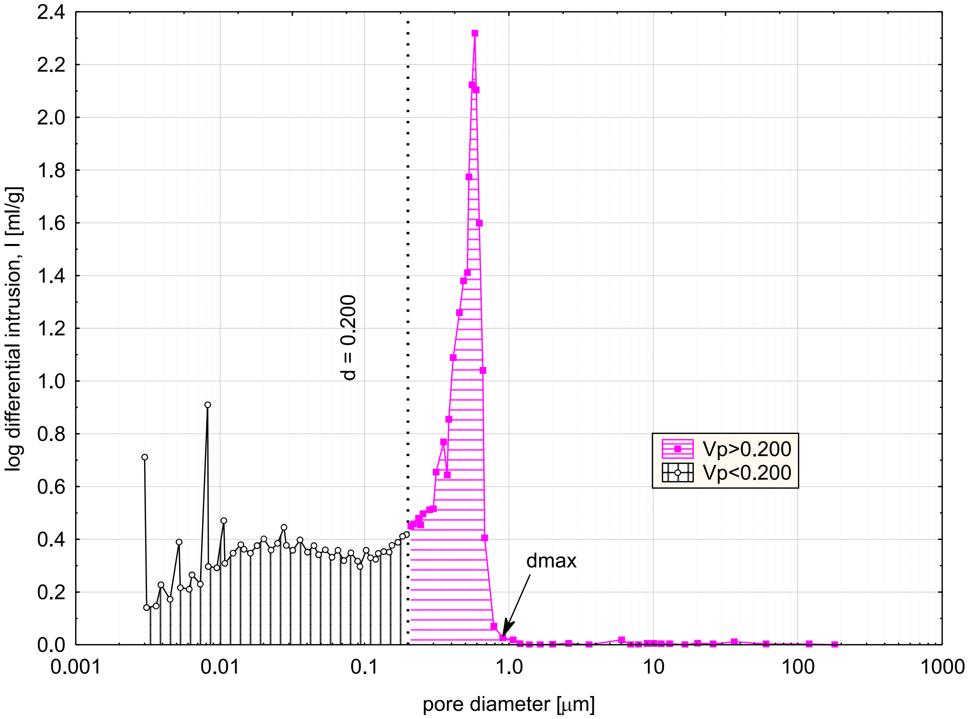

Fig. 6. Distributions of pore sizes in hardening slurry with activated fluidal ash from hard coal (PKA) after filtration of HNO_3solution

6. Analysis of Test Results

Having analysed the changeable results of the slurries' hydraulic conductivity tests, performed over a period of 160 days' exposure to filtration with various liquids (change trends of this quantity are presented in Figs. 2÷5), one can draw the following conclusions:

- The samples of slurries with addition of fluidal fly-ashes from hard coal exposed to persistent filtration with potable water demonstrate either stable values of hydraulic conductivity (ca. 2.0×10^{-8} m/s) in the case of addition of non-activated ash to the slurry, or a drop in hydraulic conductivity from ca. 2.5×10^{-8} m/s to ca. 8.0×10^{-9} m/s in the case of activated ash;
- Under the influence of filtrating tap water, samples of slurries with addition of fluidal fly-ashes from brown coal demonstrated a tendency to seal up – both in the case of activated and non-activated ash decreases of hydraulic conductivity occurred. With addition of non-activated ash, the value of hydraulic conductivity decreased from ca. 3.0×10^{-8} m/s to ca. 5.0×10^{-9} m/s, and with activated ash – from 1.5×10^{-8} m/s to ca. 7.0×10^{-9} m/s;

Table 4. Specification of microstructure parameters of hardening slurries under test

Item	Type of slurry	After exposure to 160 days' filtration with 1.0% Na_2SO_4				After exposure to 160 days' filtration with distilled water			
		$d_{\max}$ [μm]	v_p < 0.2	v_p > 0.2	P_c [–]	$d_{\max}$ [μm]	v_p < 0.2	v_p > 0.2	P_c [%]
1	2	3	4	5	6	7	8	9	10
1	PKN[1)]	1.0	0.620	0.51	0.73	4.5	0.650	0.91	0.79
2	PKA[1)]	2.0	0.630	0.690	0.76	2.5	0.670	0.710	0.76
3	PBN[1)]	0.8	0.561	0.48	0.72	3.0	0.732	0.650	0.76
4	PBA[1)]	1.5	0.621	0.48	0.72	2.5	0.690	0.640	0.76
Item	Type of slurry	After exposure to 160 days' filtration with 0.5% HNO_3				After exposure to 160 days' filtration with distilled water			
		$d_{\max}$ [μm]	v_p < 0.2	v_p > 0.2	P_c [–]	$d_{\max}$ [μm]	v_p < 0.2	v_p > 0.2	P_c [–]
11	12	13	14	15	16	17	18	19	20
1	PKN[1)]	–	–	–	–	2.5	0.675	0.63	0.75
2	PKA[1)]	0.8	0.580	0.56	0.72	0.9	0.724	0.36	0.72
3	PBN[1)]	0.8	0.743	0.30	0.74	2.0	0.725	0.40	0.72
4	PBA[1)]	1.5	0.642	0.56	0.74	2.5	0.763	0.61	0.77
Item	Type of slurry	After 28 days of maturing in tap water							
		$d_{\max}$ [μm]	v_p < 0.2	v_p > 0.2	P_c [–]				
21	22	23	24	25	26				
1	PKN[1)]	4.5	0.461	0.92	0.77				
2	PKA[1)]	3.5	0.154	1.16	0.76				
3	PBN[1)]	5.0	0.462	0.85	0.76				
4	PBA[1)]	4.0	0.533	0.91	0.77				

[1)] symbol shown in Table 1

- Persistent filtration of distilled water through hardening slurries with addition of fluidal fly-ash from hard coal (activated (PKN) and non-activated (PKA)) definitely de-sealed the structure of the material. The value of hydraulic conductivity k_{10} increased from ca. 7.0×10^{-9} m/s to ca. 4.5×10^{-8} m/s with addition of non-activated ash (PKN), and from ca. 1.0×10^{-8} m/s to ca. 4.0×10^{-8} m/s in the case of activated ash. The de-sealing of the slurry structure resulted from the leaching of soluble calcium compounds (Kledyński et al 2004);

- Slurries with addition of fluidal fly-ashes from brown coal (PBN and PBA) demonstrated a decrease in or stability of hydraulic conductivity when exposed to filtration with distilled water. This is shown in the decrease of conductivity values from ca. 1.0×10^{-8} m/s to ca. 7.5×10^{-9} m/s in the case of (PBN) slurries, and their being practically stable ($6 \div 7 \times 10^{-9}$ m/s) with addition of activated ash (PBA);

- Nitric acid solution and sodium sulphate acted in similar ways on each slurry, in spite of quantitative differences, and regardless of the type (origin) of ash or its activation. The process of long-term filtration with these solutions did not de-seal the structure of any of the tested slurries exposed to their action. This is confirmed by the hydraulic conductivity values, which remained at the practically stable level of $2 \div 3 \times 10^{-9}$ m/s for the slurries (PKN and PKA) exposed to filtration with nitric acid solution, or showed a decrease from ca. 1.5×10^{-8} m/s to ca. 6.0×10^{-9} m/s in the case of (PBN) slurry, and from ca. 5.5×10^{-9} m/s to ca. 8.0×10^{-10} m/s in the case of (PBA) slurry. The values of hydraulic conductivity of the slurries exposed to filtration with sodium sulphate solution were again practically constant – $1.5 \div 3 \times 10^{-9}$ m/s for (PKN and PKA) slurries, and demonstrated a slight decrease from ca. 3.5×10^{-9} m/s to ca. 2.0×10^{-9} m/s in the case of (PBN) slurry, and from ca. 5.5×10^{-9} m/s to ca. 1.0×10^{-9} m/s for (PBA) slurry.

  It is worth noting that the values of hydraulic conductivity of the slurries exposed to acid and sulphate aggressions are similar and change over the testing period in a similar way (especially in the case of the slurry with non-activated ash). This is in spite of differences in the chemical processes of sealing of the structure of the materials. With sulphate aggression, complex hydrated sulphate salts are formed (Kledyński 2004), and in the case of acid aggression it is possible to reseal the material with amorphous products (gel) of C-S-H phase decay in an acid environment (Falaciński and Kledyński 2007).

Another step in the analysis was to look for a relation between hydraulic conductivity values and the values characterizing the microstructures of hardening slurries, which were obtained after 160 days of exposure. Also, the influence of maturation time on the porosity structure of the hardening slurries with addition of fluidal fly-ashes was analysed. Such correlations could explain the observed changes in hydraulic conductivity during long-term filtration with the liquids in question.

Correlation analysis of hydraulic conductivity (values specified in Table 3) and quantities characterizing microstructures of slurries (given in Table 4) was conducted. Apart from obvious correlations resulting from mutual, often mathematical, connections between some of the quantities, the following can be considered statistically significant (at 5% significance level): the correlation of hydraulic conductivity k_{10} and the maximum diameter $d_{\max}$ (correlation coefficient 0.53) and the correlation of hydraulic conductivity and total porosity P_c of slurries (correlation coefficient 0.60).

Moreover, a correlation of quantities P_c and $d_{\max}$ was noted (correlation coefficient 0.82). As total porosity is a standard result obtained from the mecury porosimetry measurement method, and the quantity $d_{\max}$ – being the extreme characteristic of pore sizes distribution – is burdened with considerable estimation unreliability (low reproducibility of measurement), further analysis will be limited to the k_{10} (P_c) correlation.

Figures 6 ÷ 8 present experimental points (P_c, k_{10}), the location of which confirms a positive correlation of the tested quantities.

Pairs of points between which changes in the analysed values occurred were linked with dotted (Fig. 7), thick continuous (Fig. 8) and thin continuous (Fig. 9) lines. The dotted arrowed lines illustrate transitions from younger to older samples or contrariwise (Fig. 7). The older samples of slurry with addition of ash from brown coal, sealed up (a drop of conductivity) after exposure to persistent filtration, whereas in the samples with addition of ash from hard coal, hydraulic conductivity did not improve (the slurry with non-activated ash maintained its original conductivity, and that with activated ash saw an increase).

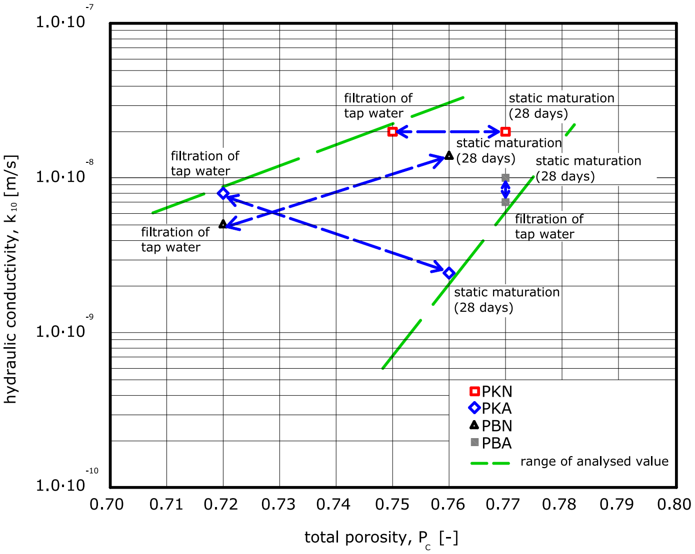

Fig. 7. Test results for slurries (PKN, PKA, PBN and PBA) in contact with tap water – static contact over the maturation period, and filtration contact during hydraulic conductivity research – influence of maturation time (age) of slurries

The thick continuous arrowed lines illustrate the influence of mechanical activation of the ashes, i.e. transitions from samples with non-activated fluidal ashes to slurries with activated ashes (Fig. 8). Activation of ash from hard coal caused a decrease of hydraulic conductivity of the slurries, despite their age and exposure to filtration. In the case of ash from brown coal, activation produced a slight drop in conductivity of the slurry matured in water, and a slight increase of conductivity after 160-days' exposure to tap water filtration.

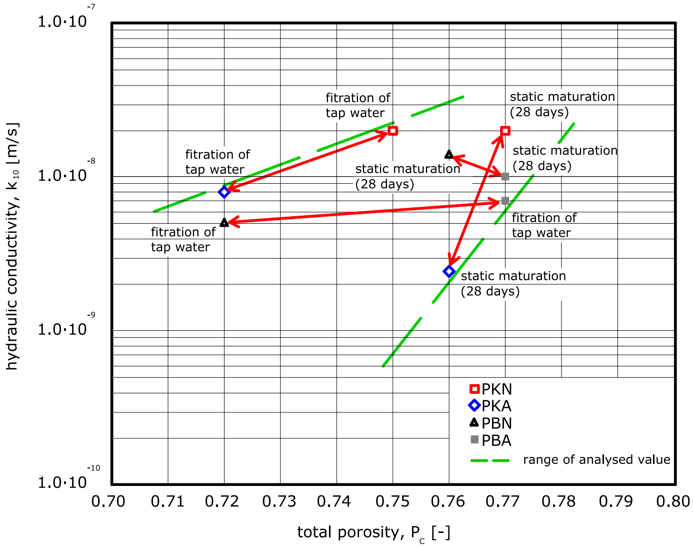

Fig. 8. Test results for slurries (PKN, PKA, PBN and PBA) in contact with tap water – static contact over the maturation period, and filtration contact during hydraulic conductivity research – influence of activation of ashes

The thin continuous arrowed lines illustrate relations between samples of slurries with fluidal ashes from hard coal and samples of slurries with fluidal ashes from brown coal (Fig. 9), i.e. the effects of ash types. The slurries with addition of non activated ash from brown coal are more leak tight than the slurries with addition of non activated ash from hard coal, despite age and exposure, whereas in the case of activated ashes, these relations are reversed, i.e. the slurries with addition of activated ash from brown coal are less leak tight than the slurries with addition of activated ash from hard coal, despite their age and exposure.

Figure 10 illustrates test results for slurries (PKN, PKA, PBN and PBA) exposed to filtration of aggressive media: distilled water, 0.5% solution of nitric acid, and 1.0% solution of sodium sulphate. It shows experimental points (P_c, k_{10}). Influence on hydraulic conductivity of the origin of the ashes and the state of their activation, as well as of the type of filtering medium were analysed.

The arrowed lines (dotted and continuous) link points between which changes in the analysed values occurred.

The dotted lines illustrate transitions from samples with non-activated ashes to those with activated ashes. Activation of ashes from brown coal caused sealing up of the samples of slurries in each type of aggression, while activation of ashes from hard coal did not result in any specifically directed changes of conductivity.

The continuous lines illustrate relations between samples of slurries with ashes from hard coal and samples of slurries with ashes from brown coal. The slurries with addition of ashes from brown coal are generally more leak tight than those

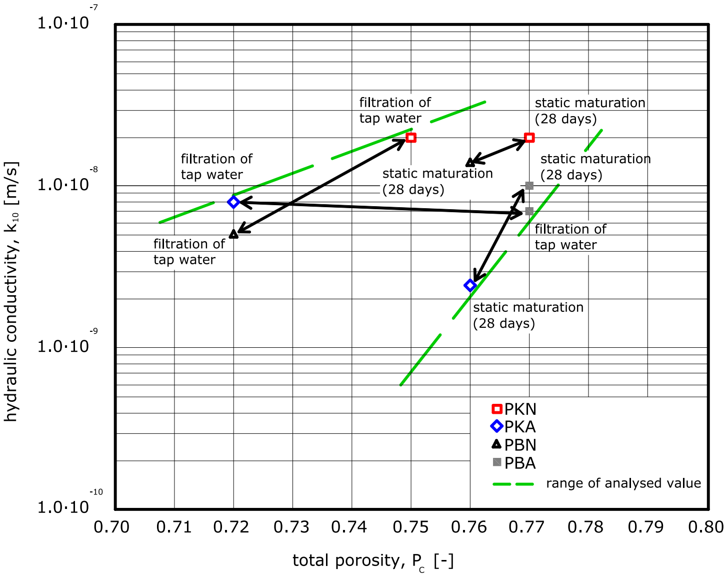

Fig. 9. Test results for slurries (PKN, PKA, PBN and PBA) in contact with tap water – static contact over the maturation period, and filtration contact during hydraulic conductivity research – influence of type (origin) of ashes

with addition of ashes from hard coal, despite the activation of ash or the type of aggression.

It is clear from Figure 10 that as regards hydraulic conductivity in aggressive leaching environment (distilled water), slurries with addition of ashes from brown coal perform better (in any state of activation of ashes, they are tighter than the slurries with hard coal ashes).

In an acid environment and in that of sulphate ions, leak tightness of the slurries with addition of activated ash from brown coal improved in comparison with the slurries with addition of non-activated ash, which cannot be said about the slurries with addition of ashes from hard coal.

Comparing Figures 7, 8, 9 and 10 – while having adopted as the reference level characteristics of the slurries contacting tap water – confirms that the contact of slurries with distilled water brings about an increase of their total porosity and hydraulic conductivity, and the filtration with solutions of nitric acid or sodium sulphate generally results in improved leak tightness of the slurries' structures and fundamentally decreases their porosity. While the influence of sulphates is identical to their effect on concretes, an acid solution makes the leak tightness of concretes deteriorate. The different responses of hardening slurries with fluidal fly ashes call for further research, including chemical research and research into phase composition of corrosion products.

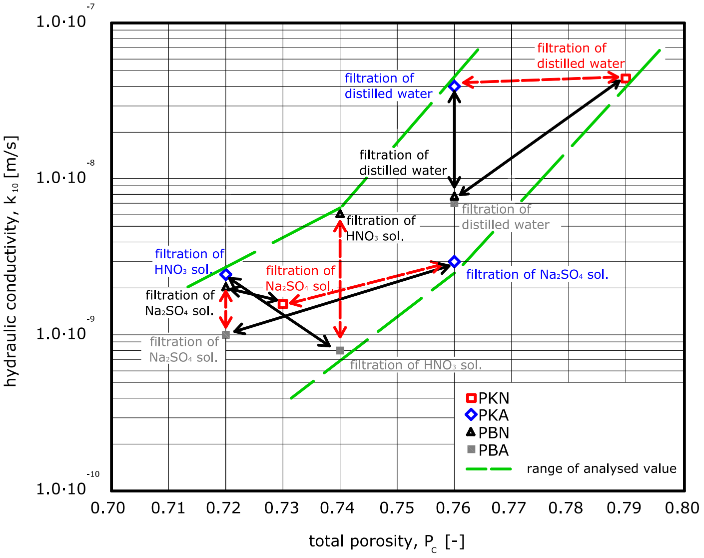

Fig. 10. Test results for slurries (PKN, PKA, PBN and PBA) exposed to filtration of aggressive media: distilled water, 0.5% solution of nitric acid (HNO_3), and 1.0% solution of sodium sulphate (Na_2SO_4); experimental points (P_c and k_{10}) are shown

7. Conclusions

Result analysis of the tests of hydraulic conductivity and porosity of hardening slurries with addition of fluidal fly-ashes allows of the flowing conclusions:

1. Slurries exposed to filtration with distilled water de-sealed in comparison with the slurries tested with tap water, while the slurries filtered through by aggressive solutions (of nitric acid and sodium suphate) demonstrated – generally speaking – a sealing up as compared to the slurries exposed to filtration with tap water.
2. Mechanical activation of fluidal fly-ash from brown coal results in a sealing up of the slurries exposed to filtrating action of solutions aggressive towards cement binders.
3. Mechanical activation of fluidal fly-ash from hard coal does not cause any significant, directed and explicit changes of hydraulic conductivity in the slurries exposed to filtration with aggressive solutions.
4. Slurries with addition of fluidal fly-ashes from brown coal exposed to filtration with aggressive solutions demonstrate greater leak tightness of their structures than the slurries with addition of fluidal fly-ashes from hard coal, independently from the activation of ash and the type of aggressive medium. This can result from an increased content of calcium compounds in these ashes.
5. There exists a relation between the porosity structures and hydraulic conductivity of hardening slurries with addition of fluidal fly-ashes. It is expressed by

a correlation of conductivity and total porosity of the slurries, as well as the maximum diameters of pores.

6. The age of slurries, i.e. their maturation period, has an influence on the decreasing porosity of the material, which is accompanied – statistically speaking – by lower hydraulic conductivity values. It is an effect of hydration of the binder, favoured by the supply of filtrating water to the structure of the material (insides of samples).
7. With regard to differences in the behaviour of hardening slurries with fluidal fly ashes towards cement mortars and concretes in chemically aggressive environments, and in particular in contact with general acid aggression, it would be expedient to continue specialist research aimed at a total explication of the corrosion processes occurring in hardening slurries.

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