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Possible Applications of Hardening Slurries with Fly Ash from Thermal Treatment of Municipal Sewage Sludge in Environmental Protection Structures

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Abstract

In Poland, in recent years, there has been a rapid accumulation of sewage sludge – a by-product in the treatment of urban wastewater. This has come about as a result of infrastructure renewal, specifically, the construction of modern sewage treatment plants. The more stringent regulations and strategic goals adopted for modern sewage management have necessitated the application of modern engineering methodology for the disposal of sewage sludge. One approach is incineration. As a consequence, the amount of fly ash resulting from the thermal treatment of municipal sewage sludge has grown significantly. Hence, intensive work is in progress for environmentally safe management of this type of waste.

The aim of the experiment was to evaluate the possibility of using the fly ash that results from municipal sewage sludge thermal treatment (SSTT) as an additive to hardening slurries. This type of hardening slurry with various types of additives, e.g. coal combustion products, is used in the construction of cut-off walls in hydraulic structures.

The article presents the technological and functional parameters of hardening slurries with an addition of fly ash obtained by SSTT. Moreover, the usefulness of these slurries is analysed on the basis of their basic properties, i.e. density, contractual viscosity, water separation, structural strength, volumetric density, hydraulic conductivity, compressive and tensile strength. The mandated requirements for slurries employed in the construction of cut-off walls in flood embankments are listed as a usefulness criteria.

The article presents the potential uses of fly ash from SSTT in hardening slurry technology. It also suggests directions for further research to fully identify other potential uses of this by-product in this field.

Key words: hardening slurry, cut-off walls, fly ash from thermal treatment of municipal sewage sludge, hydraulic conductivity

1. Introduction

After the Polish accession to the European Union (EU), the criteria and procedures concerning water and sewage management, as well as waste, have been significantly

Table 1. Methods of municipal sewage sludge disposal in 2008–2014 (CSOP 2014)

No.	years	total production of sewage sludge [1000 tons d.m.]	share of particular methods of municipal sewage sludge disposal [%]						
			used in agriculture	used in re-cultivation	used for compost production	thermal methods	landfill disposal	temporarily stored in wastewater treatment plants	other
1	2	3	4	5	6	7	8	9	10
1	2008	567.3	19.7	18.6	4.8	1.1	16.1	9.3	30.4
2	2009	563.1	21.9	13.8	4.2	1.6	14.5	12.9	31.1
3	2010	526.7	20.7	10.3	5.9	3.7	11.3	12.9	35.2
4	2011	519.2	22.4	10.5	5.9	8.0	9.9	10.2	33.1
5	2012	533.3	21.6	9.4	6.2	10.6	8.8	9.8	33.6
6	2013	540.3	19.5	5.4	6.0	13.5	5.9	12.9	36.8
7	2014	556.0	19.2	3.9	8.3	15.2	5.6	11.1	36.7

tightened. The National Programme for Urban Wastewater Treatment (KPOŚK) involves the construction of modern sewage treatment plants. From 2004 to 2014, a more that 14% increase in the number of municipal sewage treatment plants (from 2875 in 2004 to 3288 in 2014) was recorded (CSOP 2014). However, the rise in the number of highly efficient specialist facilities has resulted in a relatively fast increase in the amount of the major by-product of the sewage treatment process, i.e. municipal sewage sludge. According to the data from the Central Statistical Office of Poland (CSOP 2014), the amount of municipal sewage sludge produced in 2014 alone reached 556.0 thousand tonnes d.m. Thus, the steady annual increase in the amount of municipal sewage sludge at around $2.0 \div 2.5\%$, poses enormous problems for its safe management. Basic methods of municipal sewage sludge disposal practiced in Poland in the years 2008–2014 (CSOP 2014) are listed in Table 1. The table also contains figures for the total amount of sludge produced, together with the percentage share of different disposal approaches. These data clearly indicate a decrease in the amount of sludge stored in landfills (from about 16% in 2008, to about 5% in 2014) and an increase in the amount of sludge processed thermally (from about 1% in 2008, to about 15% in 2014). The above trends also match the goals set by the municipal sewage sludge management directives (UNWMP 2015). These are:

- reducing (or abandoning) sewage sludge storage,
- increasing the amount of municipal sewage sludge processed before re-introduction to the environment, as well as the amount of sludge recycled by thermal methods,
- maximizing the use of biogenic substances contained in the sludge, while meeting all the requirements related to health and chemical safety.

Still, experts in the field of waste agree on the current absence of a clear strategy for municipal sewage sludge management in Poland, as well as on the need for development and investments in modern thermal methods (Pająk 2014).

The sewage sludge thermal treatment technique (SSTT) makes it possible to change the chemical and biological composition of sludge, to reduce the heavy metal content, to neutralise pathogens and to significantly decrease the weight or volume of sludge. The thermal methods of dealing with municipal sewage sludge include incineration, co-incineration and other processes, such as wet oxidation, pyrolysis, gasification and vitrification (Pająk 2014). Over the last years, the use of these methods has increased in Poland, and therefore the amount of coal combustion products (CCP), such as ash, has increased. Unfortunately, the sewage sludge incineration process does not eliminate the high content of phosphorous and heavy metals in sewage sludge. Therefore, research continues to develop effective, environmentally safe methods of managing/using ash from the thermal treatment of sewage sludge. A popular solution processing of fly ash from SSTT is their use in the ceramic industry or construction, eg.: solidification of concrete blocks or sintering to a granulated form (Rutkowska & Iwaszko 2015). The main purpose of these methods is a safe and economical immobilization of hazardous compounds within the obtained material structure.

This paper presents research on the possibility of using the fly ash resulting from SSTT, as a constituent of hardening slurries used for fabricating cut-off walls (anti-filtration barriers) in hydraulic structures and environmental protection structures. It should be noted that research on hardening slurries containing other types of coal combustion products, e.g.: conventional ash resulting from fluidised bed combustion, showed an improvement in the hydraulic conductivity of hardening slurries under both capillary and diffusive conditions (Falaciński 2012).

2. Types and Properties of Hardening Slurries

In hydraulic structures, cut-off walls are normally constructed by way of narrow (trench) spatial excavations. The excavations are first expanded by the addition of bentonite and water slurries, and are then filled with cohesive soil, modified local soils, concrete, as well as loam-concrete or so-called hardening slurries.

A hardening slurry is defined as a slurry which hardens over time and contains cement or another binder and additional materials, such as loam (bentonite), granulated blast furnace slag or fly ash, fillers and admixtures (PN-EN 1538 2015).

If chemical admixtures are excluded from the slurry compositions, the remaining components are of a mineral character. Some of these are by-products of certain waste technology processes.

The slurries used or tested in Poland can be classified in terms of the types of their components (Kledyński & Rafalski 2009). These are:

- cement-bentonite-water,
- cement-bentonite-water with chemical admixtures,
- cement-bentonite-water with additives, such as sand, hard or lignite coal ash, hard or lignite coal fluidised bed combustion ash, blast furnace slag,
- bentonite-water with additives, such as lignite coal ash, hard coal ash, lime,
- cement-bentonite-water with additives, the so-called “company mixes”.

Table 2. Selected properties of hardening slurries used in the fabrication of cut-off walls in flood embankments (Borys 2012, Kłosiński 2003)

No.	properties	unit	value	marked by
1	2	3	4	5
properties of hardening slurries in the liquid state (technological)				
1	density			
2	– deep soil mixing method (DSM)	g/cm^3	1.30–1.50	(BN-90/1785-01 1990)
3	– vibro injected thin-wall method (WIPS)	g/cm^3	1.50–1.60	(BN-90/1785-01 1990)
4	– narrow spatial excavation method	g/cm^3	1.15–1.40	(BN-90/1785-01 1990)
5	conventional viscosity (the time of flow from Marsh funnel)	s	max. 50	(BN-90/1785-01 1990)
6	24h water setting	%	max. 4	(PN-85/G-02320 1985)
7 8	structural strength – after 10 min	Pa	1.4–10.0	(BN-90/1785-01 1990)
properties of hardening slurries after hardening (functional)				
9	uniaxial compressive strength after 28 days of curing	MPa	0.5–2.0	(PN-EN 12390-3 2011)
10	hydraulic conductivity after 28 days of curing	m/s	$\leq 10^{-8}$	laboratory methods, as for cohesive soil (Twardowski & Drożdżak 2007)

Information on the properties of the above-mentioned slurries can be found in Borys (2012) and Kledyński & Rafalski (2009). Information on the of ready mixes can be found in technical approvals issued for these products (ITP 2011) (Table 2).

The values of the selected properties of hardening slurries presented in Table 2 characterized by requirements for cut-off wall construction (by various ways) in flood embankments. In relation to sealings (cut-off walls) used in other specialised hydraulic structures (bunds in sewage treatment plants or in landfills), the requirements for this type of construction are determined (specified) individually, depending on the design requirements.

3. Characteristics of Ash from Thermal Treatment of Sewage Sludge Used in the Experiment

Sewage sludge ash is produced by the incineration of sewage sludge at a high temperature (about 600 ÷ 920°C), most often in the fluidised bed process. This process ensures a considerable reduction in the volume of material, while the yield of thermal energy, which results in ash with specific characteristics, not found among the by-products of coal combustion.The ash produced in the process has unique characteristics that are not found in other coal combustion products. Owing to the high content of organic substances in sewage sludge, ash from the thermal treatment of sewage sludge may contain 0.3 ÷ 1.5% of total phosphorus (Łukawska 2014), which negatively affects (prolongs) the delay of the cement hydration process in concrete based on this additive (Małolepszy & Tkaczewska 2006). The relatively high content of heavy metals is also problematic, so it is necessary to immobilise them (e.g. in hardening slurries).

The ash examined here came from a large municipal sewage treatment plant equipped with a Sewage Sludge Thermal Utilization (SSTU) Station. Sewage sludge mixed with screenings and fats is pumped onto a fluidised bed of sand, where it is incinerated. The by-products of this process are: slag, ash and the products of the dry flue gas cleaning.

The ash used in the present study was produced in the Sewage Sludge Thermal Utilization Station between April and November 2015. Selected physical properties of this ash are presented in Table 3. The ash was characterised by various size distribution, as evidenced by the specific surfaces, varying in the range of 2560 ÷ 3670 cm^2/g (variability of about 30% for 3 batches).

Table 3. Selected physical properties of ash from the thermal treatment of municipal sewage sludge (Szarek 2016)

No.	properties	unit	value
1	2	3	4
1	specific surface area	cm^2/g	2560–3670
2	density	Mg/m^3	2260–2360
3	fineness	% mass	47.0–62.5
4	water demand	%	129–132
5	compressive strength	MPa	30.1 – 30.7
6	activity index	%	54.0–66.5
7	initial setting time	min.	400 – 410

The results of a compressive strength test (30.1 ÷ 30.7 MPa) of a mortar based on ash (binder: 75% CEM I 42.5R, 25% ash, w/s = 0.5), compared to the values (55.7 MPa) for a comparative mortar (binder: 100% CEM I 42.5R, w/s = 0.5), show a negative impact of the ash additive on the mechanical properties of mortar. The sample compressive strength derivatives include the activity ratio values (54.0 ÷ 66.5% in relation to the comparative cement CEM I 42.5R), marked after 28 days of curing, which indicate the lack of the pozzolanic activity of the material.

The initial setting time of grouts (400 ÷ 410 min.) based on SSTT ash (25% of ash, 75% CEM I 42.5R) is, on average, twice as long as the initial setting time of grouts (200 min.) composed of 100% of a comparative cement (CEM I 42.5R). This test confirmed the negative impact of the ash additive on the cement setting time.

The test results presented in Table 3 and the phosphorus content (Łukawska 2014) indicate a very limited suitability of SSTT ash for the construction industry, and particularly for the current concrete technology. Moreover, the high water demand and low pozzolanic activity of this ash preclude its use as an additive in concrete. However, these properties open up the possibility of using it in hardening slurries, in which the ratio of w/s (water/dry components) and the resulting strength are subject to other assessment criteria.

4. Formulae of Hardening Slurries

The hardening slurries used in this study were prepared from the following ingredients: tap water, sodium bentonite, Portland cement CEM I 32.5R and SSTT fly ash.

Table 4 shows the composition of these slurries (percentages of components in 1.0 m^3 of the slurry), For each formulae (from R1 to R6), the water/cement ratio (w/c) and water/dry ingredients ratio (w/s) are listed.

Table 4. Formulae of hardening slurries (as the percentages of components in 1.0 m^3 of the slurry)

No.	formula	water	bentonite	ash	cement	w/c	w/s
1	2	3	4	5	6	7	8
1	R1	59.9	2.4	26.9	10.8	5.56	1.49
2	R2	54.6	2.2	32.2	10.9	5.00	1.20
3	R3	50.5	1.5	25.3	22.7	2.22	1.02
4	R4	50.5	1.5	27.8	20.2	2.50	1.02
5	R5	49.5	1.0	27.2	22.3	2.22	0.98
6	R6	49.5	1.0	24.8	24.8	2.00	0.98

5. Scope of Testing

5.1. Tests of Technological Properties

Tests were performed to determine the density (ρ) of the liquid slurries, their conventional viscosity ratio (L), 24h water setting (O_d) and structural strength (t).

The volumetric density (ρ) of the slurries was tested by Barroid's balance (BN-90/1785-01 1990), and their conventional viscosity (L) was measured with a viscometer (*Marsh's funnel*) (BN-90/1785-01 1990). The 24h water setting (O_d) test determines the percentage share of the volume of spontaneously separating water in 1.0 dm^3 of a liquid slurry after the slurry had remained in a measuring cylinder for one day (PN-85/G-02320 1985). Finally, the structural strength (t) of the slurries was tested by Szirometer apparatus (BN-90/1785-01 1990). The readings of structural strength (in [Pa]) were carried out at 1.0 and 10.0 minute intervals.

5.2. Preparation of Samples for Testing after Hardening

Hardening slurry test cylinders were prepared in PVC and steel moulds (cylinder) of 8 cm in diameter and 8 cm in height. Before the slurry set, the samples were kept under a foil covering in the laboratory. After 2–3 days, the samples were submerged in water at a temperature of +18°C ± 2°C. They were left under water until measurement.

5.3. Tests of Functional Properties

Hydraulic conductivity tests

The hydraulic conductivity of hardening slurries is very low (similar to that of cohesive soils), 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 in determining, at specific times t_1, t_2, etc., the values of water pressure h_1, h_2, etc. in the supply tube of cross-sectional area a during the liquid's flow through the sample of length (height) L and cross-sectional area A. In this case, hydraulic conductivity is calculated by the following formula (Eq. 1):

$$k_T = \frac{a \cdot L_p}{A \cdot \Delta t} \ln \frac{h1}{h2} \quad [\mathrm{m/s}], \tag{1}$$

where:

k_T	–	hydraulic conductivity at temperature T, [m/s],
a	–	cross-sectional area of the supply tube, [m^2],
L	–	length (height) of the sample, [m],
A	–	cross-sectional area of the sample, [m^2],
Δt	–	time between pressure measurements h_1 and h_2, $\Delta t = t_2 - t_1$, [s],
$h1, 2$	–	values of water pressure at times t_1 and t_2, [m].

The main advantage of this testing method is the possibility it offers of measuring minute water flow, as well as the forcing of high water pressures. The hydraulic conductivity tests with tap water were conducted in an apparatus specially built of chemical-resistant plastic (plexiform and polyvinyl chloride) (Falaciński 2011). The action of the infiltrating medium (tap water) on the tested sample was of gravitational, and the measurements were performed with a decreasing initial hydraulic gradient. All tests were performed after 28 days of slurry maturation. Three samples of the slurry were tested in one series. The hydraulic gradients acting on the samples ranged from 20 to 45, and gradients lower than 45 acted on the samples for no longer than 4 hours on the days of the hydraulic conductivity measurements. The hydraulic conductivity calculated by Eq. 1 does not take account of the influence of the temperature of the infiltrating liquids. The k_T values obtained during the tests (at temperature T) were recalculated into k_{10} values corresponding to a temperature of +10°C. The following formula (Eq. 2) was used:

$$k_{10} = \frac{k_T}{0.7 + 0.03T} \quad [\mathrm{m/s}]. \tag{2}$$

Density of hardened slurry

The density of the hardened slurry r_o was determined for cylindrical samples made in steel moulds (PN-EN 12390-7 2011). These tests were performed after 28 days of slurry maturation. After a sample had been taken out of the container (filled with water), it was left to dry for several minutes. It was then weighed, and its diameter and height were measured. After the volume of the sample had been calculated, the following formula was used to determine its density (Eq. 3):

$$\rho_o = \frac{m}{V} \quad [\mathrm{kg/m^3}], \tag{3}$$

where:

ρ_o – density of the sample, [kg/m^3],
m – mass of the sample, [kg],
V – volume of the sample, [m^3].

Compressive strength tests

Compressive strength values f_c were determined for cylindrical samples made in steel moulds (PN-EN 12390-3 2011). The tests were performed after 28 days of slurry maturation. The samples matured under laboratory conditions in tap water. After a sample had been taken out of the container (filled with water), it was left to dry for several minutes. Its upper surface (and the lower if uneven) was then smoothed to fit the surface of the sample precisely to the heads of the testing machine. Compressive strength measurements were performed with a testing machine ZD 20. Each sample was compressed with a stress gain of 0.04–0.06 MPa/s until destruction. Three samples were compressed in one series. The following formula was used to calculate the compressive strength (Eq. 4):

$$f_c = \frac{P}{A} \quad [\mathrm{MPa}], \tag{4}$$

where:

P – stress force destroying the sample, [N],
A – cross-sectional area of the cylindrical sample, [mm^2].

Tensile splitting strength tests

Tensile splitting strength values f_{ct} were determined for cylindrical samples made in steel moulds (PN-EN 12390-6 2011). The samples matured under laboratory conditions in tap water. After a sample had been taken out of the container (filled with water), it was left to dry for several minutes. The tests were performed after 28 days of slurry maturation. The tensile splitting strength measurements were performed with a testing machine ZD 20. Each sample was placed on the cylinder surface (side surface) on a disc machine, and then exposed to load-induced tension (with a stress gain of 0.04–0.06 MPa/s) until destruction. Three samples of the slurry were tested in one series. The following formula was used to calculate the tensile splitting strength (Eq. 5):

$$f_{ct} = \frac{2P}{\Pi d^2} \quad \text{[MPa]}, \tag{5}$$

where:

- P – stress force destroying the sample, [N],
- d – diameter of the cylindrical sample, [mm²].

6. Tests Results for Technological Properties of Liquid Slurries

Tests results for the aforementioned technological properties of liquid slurries are shown in Table 5.

Table 5. Technological parameters of liquid slurries

No.	parameter		R1	R2	R3	R4	R5	R6
1	2		3	4	5	6	7	8
1	volumetric density	[g/cm^3]	1.36	1.41	1.48	1.47	1.50	1.50
2	conventional viscosity	[s]	46	79	48	50	43	46
3	water setting (2h)	[%]	5.0	3.0	3.5	4.0	4.0	4.0
4	water setting (24h)	[%]	11.0	6.0	5.0	5.0	4.0	4.0
5	structural strength after 1 minute	[Pa]	2.02	1.63	1.78	1.68	1.68	2.78
6	structural strengthafter 10 minutes	[Pa]	1.97	1.87	3.31	3.36	2.35	4.08

7. Tests Results for Functional Properties of Hardened Slurries

The averaged values of the functional properties after hardening are shown in Table 6.

Table 6. Functional parameters of hardening slurries after hardening

No.	parameter	R1	R2	R3	R4	R5	R6
1	2	3	4	5	6	7	8
1	density ρ_o [kg/m^3]	1.374	1.398	1.504	1.488	1.516	1.514
2	hydraulic conductivity k_{10} [m/s]	1.07×10^{-6}	8.84×10^{-7}	3.88×10^{-8}	8.87×10^{-8}	5.17×10^{-8}	1.54×10^{-8}
3	compressive strength f_c [MPa]	0.20	0.21	1.11	0.94	1.20	1.26
4	tensile splitting strength f_{ct} [MPa]	0.04	0.09	0.22	0.17	0.18	0.32
5	brittleness f_{ct}/f_c [-]	0.20	0.43	0.20	0.18	0.15	0.25

8. Test Result Analysis

The obtained values of the parameters were compared with the requirements for hardening slurries used in fabricating cut-off walls in flood embankments presented in Table 2. It should be noted that the density of all hardening slurries tested in this study, shown in Table 3, is sufficient to ensure drilling excavation stability (except of WIPS method). These slurries show a density increase in accordance with the theoretical assumptions of Kledyński & Rafalski (2009), as well as a decrease in the w/c and a w/s ratios (Fig. 1).

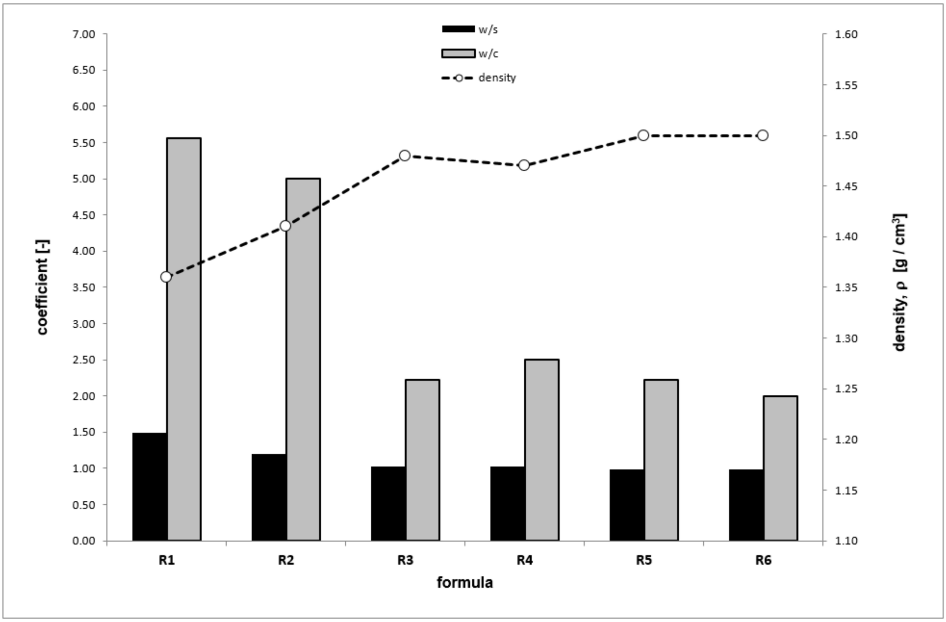

Fig. 1. Relationship between density and the w/s and w/c ratios

It should be underlined that the conventional viscosity of the R2 formula exceeds the limit values (estimated at max. 50 s) because of the hydraulic transport of the slurry at the construction site, as well as its movement in the drilled excavation. Furthermore, there is no clear trend in the variability of the conventional viscosity values in relation to the w/c and w/s ratios (Fig. 2).

The values of water setting after two hours meet the assumed criteria (max. 4.0%) for all the formulas except R1 (Fig. 3). However, in the case of water setting determined after 24 hours (daily), the limit value was met only by the R5 and R6 formulas (Fig. 3). It should be noted that a higher value of this parameter can result in a lack of uniformity of any wall made of such a slurry. The decrease in the value of water setting after 2 and 24 hours is (generally) proportional to the decrease in the w/s and w/c ratios.

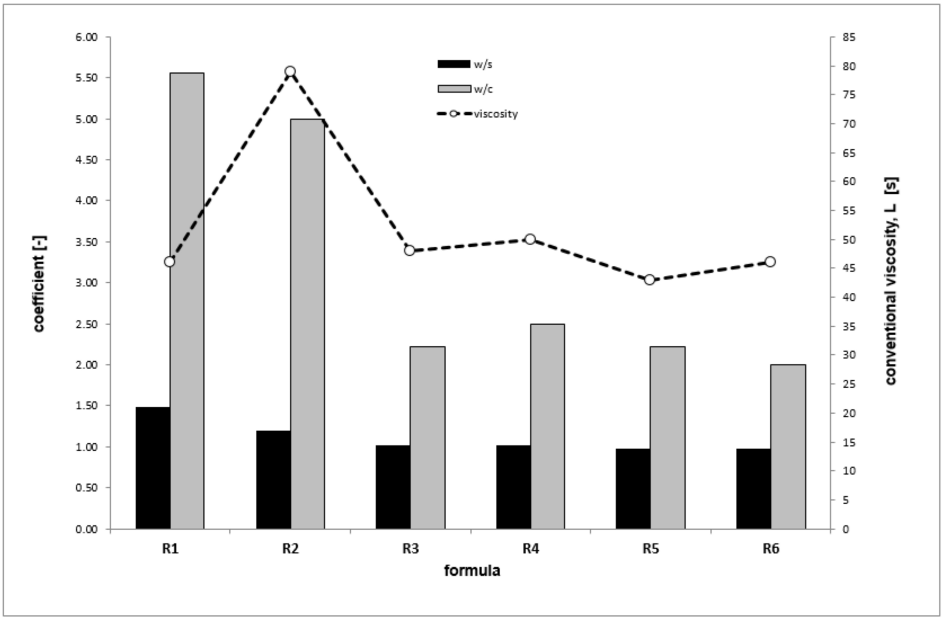

Fig. 2. Relationship between conventional viscosity and the w/s and w/c ratios

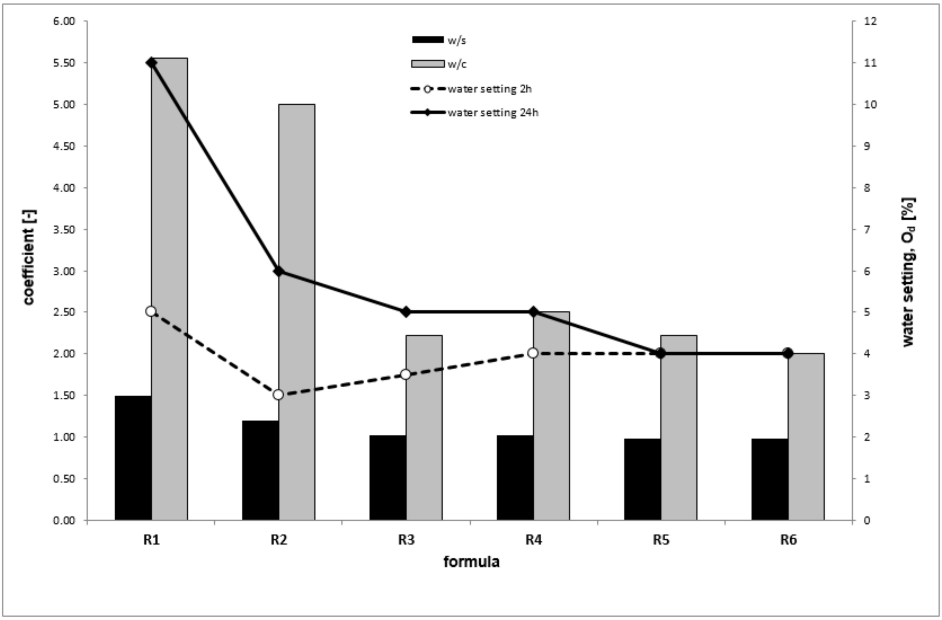

Fig. 3. Relationship between water setting and the w/s and w/c ratios

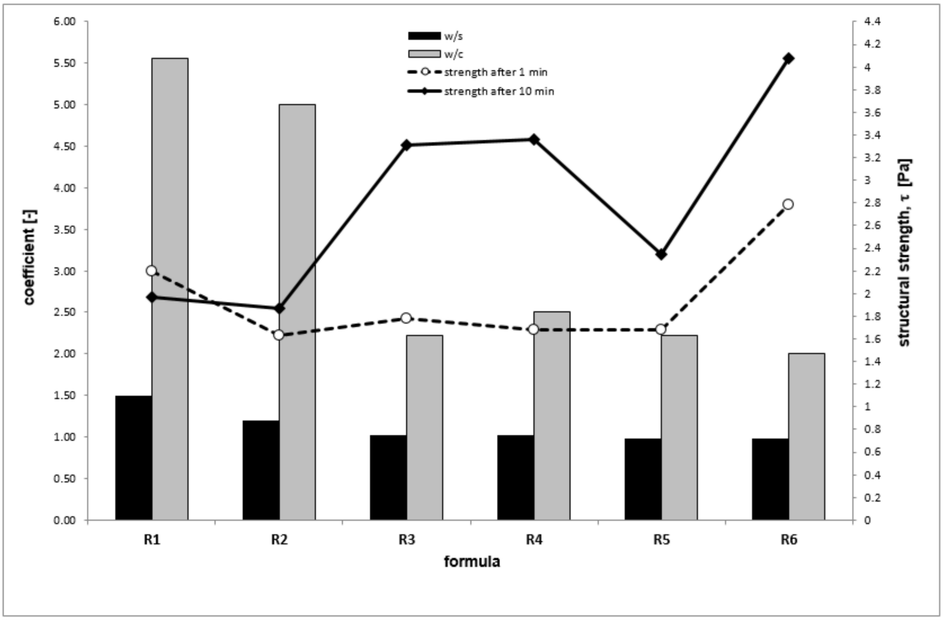

Fig. 4. Relationship between structural strength and the w/s and w/c ratios

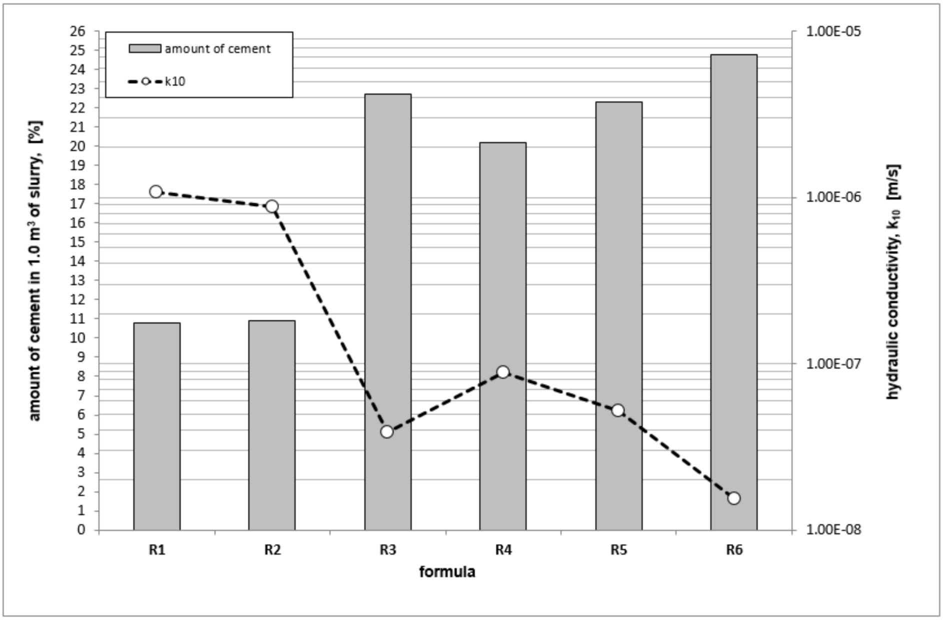

Fig. 5. Hydraulic conductivity as a function of the amount of cement in 1.0 m^3 of the slurry

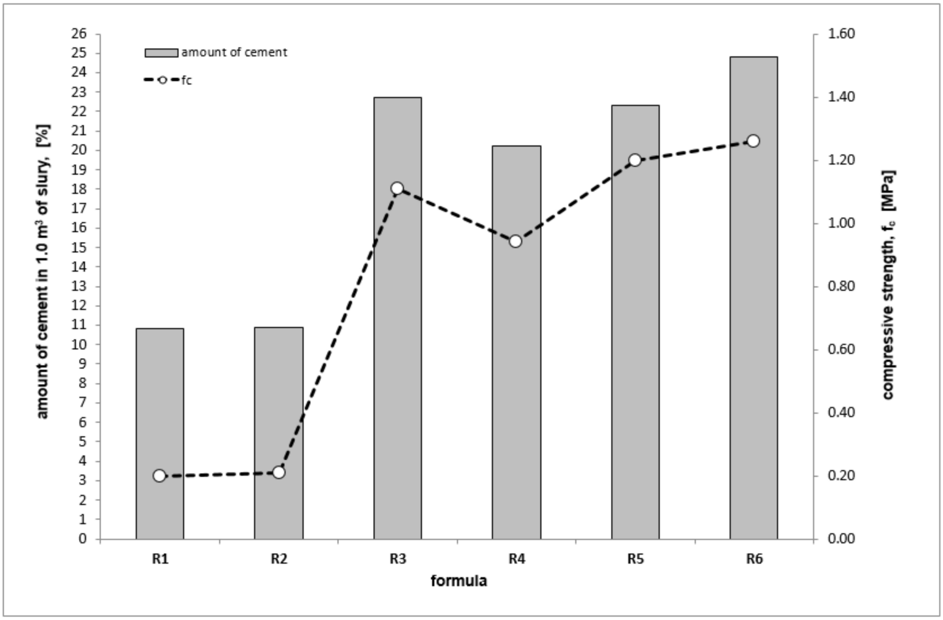

Fig. 6. Compressive strength as a function of the amount of cement in 1.0 m^3 of the slurry

The structural strength, also defined as the gel strength, describes the thixotropic properties of the slurry (PN-EN 12390-3 2011). The appropriate structural strength value is conductive to the stability of excavation walls, as it protects them from soil particle run-in and ensures the required stability of slurries contaminated by excavated soil (therefore, soil particles remain suspended in the slurry weight and do not settle out). The values determined during the experiment (Fig. 4) meet the acceptable criteria (a value above 1.4 Pa as stated by Kłosiński 2003). The volumetric density values presented in Table 6 show that the volumetric density after hardening is at an acceptable level for all the formulas, and the increase in this parameter is (generally) inversely proportional to the increase in the w/s and w/c ratios. The hydraulic conductivity of the slurries as a function of the quantity of the binder (cement) is presented in Figure 5. The hydraulic conductivity limit value for hardening slurries used for fabricating cut-off walls in flood embankments is $k_{10} \leq 1.0 \times 10^{-8}$ (Table 2), which ensures an appropriate tightness of the flood embankment. For all hardening slurry formulas tested in this study, k_{10} values above the limit value were obtained. In the case of the R6 formula, the k_{10} value (1.54×10^{-8}) was only slightly above the limit value.

In the analysed hardening formulas, a clear correlation can be observed between the hydraulic conductivity values and the quantity of the binder (cement) (Fig. 5) in 1.0 m^3 of the slurry. With regard to hardening slurries used for fabricating cut-off walls in flood embankments, the compressive strength values are designed to be at a level of 0.5 to 2.0 MPa. It is worth noting that, because of the lacking hydraulic and pozzolanic properties of the ash used in this study, the binder (cement) affects the strength parameters. The compressive strength values of the slurries as a function of the quantity of the binder (cement) is therefore presented in Figure. 6. The f_c values obtained during the tests confirm the usefulness of the R3–R6 formulas.

Because of the need to maintain the continuity of any structure made of hardening slurries, it is necessary to know the appropriate f_{ct} tensile splitting strength. For the slurries investigated here, this value was about 30% of the compressive strength value (Kledyński & Rafalski 2009). The quotient of the tensile splitting strength (f_{ct}) and the compressive strength (f_c) is a measure of the material's fragility. For the slurry formulas tested here, this parameter ranged from 0.15 to 0.43, which is over twice as high as the fragility of a mortar and cement concrete (below 0.125). This is due to the presence of bentonite, as well as the high porosity and moisture of slurries, and, consequently, it ensures a good cooperation of structures made of hardening slurries with their ground base.

9. Conclusion

Considering all technological and performance parameters analysed above, it should be noted that the R6 formula met most of the criteria qualifying hardening slurries as a material for cut-off walls in flood embankments. Only a slight excess of the acceptable hydraulic conductivity value was recorded ($k_{10} = 1.54 \times 10^{-8}$). It must be pointed out that, owing to the lack of hydraulic and pozzolanic properties in the ash utilized in this study, the proportion of the binder has to be increased to improve the slurry matrix tightness. This binder can be cement (as in this experiment) or another type of binder, e.g. ground blast furnace slag or fly ash resulting from the combustion of hard or lignite coal (additional Coal Combustion Products).

The results obtained show the potential of the fly ash resulting from thermal treatment of municipal sewage sludge to be used as an additive to hardening slurries. Such a utilization of fly ash can be a new field in the management of this type of industrial waste. The values of slurry properties recorded in this study confirm the safe bounding of ash in the slurry matrix. Tests for the leaching of heavy metals and other substances from the slurry matrix are the next stage in research on the safe use of this fly ash.

The proposed experiment in the direction of the use of fly ash from thermal treatment of municipal sewage sludge is part of a broader policy of sustainable development.

The test results presented in the paper are a basis for further studies on the potential use of ash from the thermal treatment of sewage sludge as a component of hardening slurries used in fabricating cut-off walls in environmental protection structures or in other civil structures, e.g. for mining damage recovery and site restoration.

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