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UTILIZATION OF SLUDGE FROM MINE WATER TREATMENT PLANT IN THE SEGMENT OF THERMAL INSULATION MORTARS

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Abstract: The results from the experimental research are presented in the abstract. The experimental research involved utilization of the sludge from the mine water treatment plant of Coal Quarry ČSA/Czechoslovak Army/ (hereinafter "ČSA") and Coal Quarry Jana Švermy (hereinafter "JŠ") in the segment of thermal insulation mortars. The mine water treatment is described below including chemical and mineralogical sludge composition as the additional component of the binding material in the polyurethane thermal insulation mortars. Furthermore the composition of experimental mixtures of the thermal insulation polyurethane mortar is presented in the work and its physical-mechanical properties. The monitored elements included the strength characteristics, heat conductivity coefficient λ, and water vapour diffusion coefficient μ.

INTRODUCTION

Very interesting area of the experimental and applied research in the global scale are the issues related to the waste water treatment process, mine water treatment and subsequent utilization of the sludge originating from such processes. Results from the three-year experimental research dealing with the influence of the groundwater contamination with sludge from the waste water treatment, which was applied into the soil, are described in [1]. Issues regarding the utilization of the sludge from waste water treatment as a source of protein in the feed were published in [2]. Utilization of the sludge, which originates at the waste water treatment from refineries in the segment of infrastructure constructions, is described in [3]. Impact of the tailings used for the hydric reclamation of natural water-bearing subsidence troughs is described by the authors in [4].

The article describes the technology of treatment of mine water arising during brown coal mining in the Czech Republic, which can be used worldwide as a source of waste treated sludge used in combination with cement for the solidification of polyurethane foam at the end of its life cycle in the thermal insulation mortar segment. The solidification of polyurethane foam at the end of its life cycle in the cement matrix is described in [5]. The solidification of steel slag as artificial stone fr. 4/8 mm and fr. 8/16 mm in the cement matrix is described in [6], the utilization of finely ground blast furnace slag as a replacement of Portland cement in plain concrete is described in [7]. The production of concrete precast elements based on waste fine aggregate is described in [8].

Mine waters represent a significant problem during the mining process of the mineral raw materials. Their collection, retention and outlet belong to the basic conditions of the mining process. During the opencast coal-mining (brown coal in the case of our conditions) it is necessary to pay significant attention to these problems with respect to the area and topography of the coal quarries, which are very sensitive to the inlet of the surface water, groundwater and rain water. Therefore each quarry must have created the system of drainage objects for controlled drainage of the mine water from the quarry working area. The objective is to provide fluent and safe operation of the coal quarry.

Mine waters are defined in the Czech Republic by the "Mining Law" (Act No. 44/1998 Coll., on the Protection and Utilization of the Mineral Resources) as well as by the "Water Law" (Act No. 254/2001 Coll., on the Water and acts later amended). The acts are amended by other implementing regulations of the State Mining Authority and relevant local water institutes solving the safety and technical problems of the drainage as well as the protection of the groundwater and surface water.

Treatment process of the mine water from the Coal Quarry ČSA and Coal Quarry Jana Švermy consists of the following technological nodal points – neutralization, oxidation of heavy metals from aerations, precipitation of metal and manganese, thickening of the mine water sludge, its flocculation and drainage using the pressure filtration. Treated mine water from the mine water treatment plant of the Coal Quarries ČSA and Jana Švermy is discharged into recipient Bílina. The process diagram of the mine water treatment plant of the Coal Quarries ČSA and Jana Švermy is graphically represented in Figure 1. The values of the mine water contamination at the inlet into the water treatment plant are the following: pH (6.40–7.10), Fe (4.8–7.6 mg/l), Mn (1.6–2.30 mg/l), NL (40–60 mg/l), SO_4^{2-} (505–850 mg/l).

The values of the mine water contamination at the outlet from the mine water treatment plant (picture No. 1) are the following: pH (8.00–8.40), Fe (0.15–0.30 mg/l), Mn (0.18–0.38 mg/l), SO_4^{2-} (538–844 mg/l), NL (8.0–21.0 mg/l), RL_{105} (996–1661 mg/l) [9].

Results from the experimental research related to the issues of mine water desulphation with excess limit content of sulfates are described in [9, 10, 11]. Experimental research and its results regarding the issues of removing the manganese from the mine water are described in [12, 13].

MATERIALS AND METHODS

Mine Water Sludge

Mine water sludge involves the output product from the mine water treatment process of the Coal Quarries ČSA and Jana Švermy (see Figure 1). At present, the mine water sludge after the pressure filtration is transported to LH operations and subsequently placed

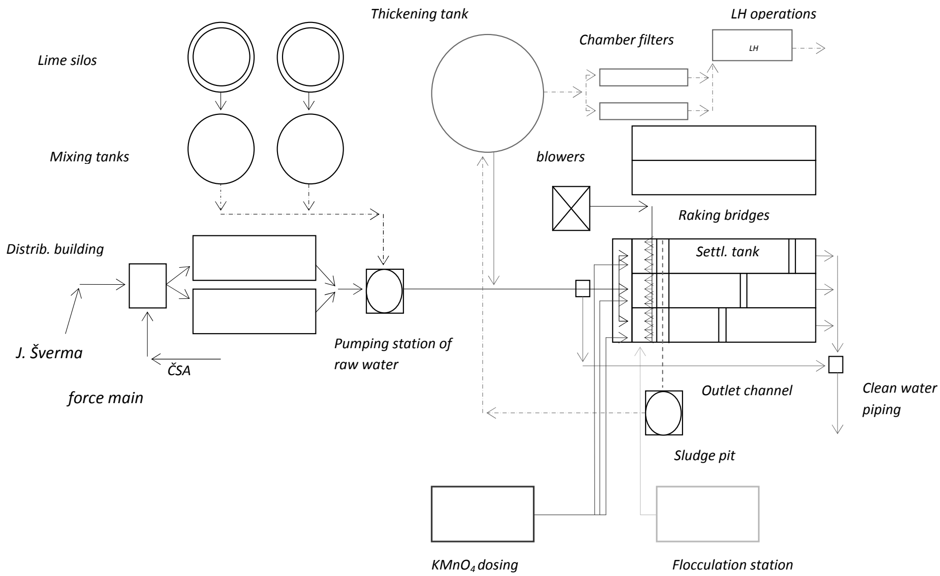

Fig. 1. Process diagram of the mine water treatment plant of the Coal Quarries ČSA and Jana Švermy [9]

on the hopper. For the own experimental research the sludge was taken away after the pressure filtration. The obtained sludge was treated in the following steps: 1) drying at the temperature of 105°C within 24 hours; 2) processing to the grain size max. 0.25 mm.

Such treated sludge was analyzed for the elements on the energy dispersion X-ray of the fluorescent spectrometer SPECTRO X-LAB (see Table 1), X-ray diffraction on fully automated diffractometer URD-6 and determination of the specific surface. The X-ray diffractation results showed that the mine water sludge composes of Portlandite – 98.74% ± 0.69% and silica – 1.26% ± 0.69%. The determination of the specific surface was provided by the instrument SORPTOMATIC 1990, which results from the method on the basis of Brunauer-Emmet-Teller (BET) equation. The value of specific surface of used and treated mine water sludge was 28.28 m^2/g.

Together with the hereinabove properties, the treated mine water sludge was tested to find out the density according to Czech Standard ČSN 72 2113 for determination of cement density. LE CHATERIER DENSITOMETER was used for the own density determination. The density value of treated mine water sludge was 2.60 g/cm^3. For determination of the mine water sludge granulometry there was used the laser analyzer Mastersizer 2000. The analysis results are presented in Table 2.

Polyurethane

As a filling agent in the thermal insulation mortar there is used crushed polyurethane foam after finished life cycle with density of 25–30 kg/m^3 with maximum grain sized 3 mm. It involves a new type of the artificial filling agent that has been used in the segment of thermal insulation mortars since the year 2008. A significant source of this filling agent is the recycling of white goods. Hereinabove recycled material was tested to find out its own characteristics. The results are presented in Table 3.

Table 1. Results from elements analysis of treated mine water sludge

Analyzed	**Unit**	**Sludge from UDV 105°C**	**Analyzed**	**Unit**	**Sludge from UDV 105°C**
annealing loss	weight %	41.4	**MnO**	weight %	1.18
MgO	weight %	0.89	**Fe_2O_3**	weight %	2.02
Al_2O_3	weight %	0.16	**V**	mg/kg	2.1
SiO_2	weight %	2.09	**Cr**	mg/kg	< 2
P_2O_5	weight %	< 0.05	**Ni**	mg/kg	1060
SO_3	weight %	0.75	**Zn**	mg/kg	960
K_2O	weight %	0.017	**Rb**	mg/kg	3.0
CaO	weight %	50.6	**Sr**	mg/kg	1050
TiO_2	weight %	0.026	**Ba**	mg/kg	75

Table 2. Results from mine water sludge granulometry

Name of sample	**d(0,1) [μm]**	**d(0,5) [μm]**	**d(0,9) [μm]**	**Mode= d50 [μm]**	**span**
Sludge from UDV 105°C	7.167	26.141	57.501	32.240	1.925

Table 3. Properties of the polyurethane foam afterwards finished life cycle

Monitored Property	***Testing Method***	***Unit***	***Value***
Maximum grain size	ČSN EN 933-2	mm	3
Density	ČSN EN 1602	kg/m^3	29
Equilibrium moisture at 28/30	ČSN EN 12429	%	max.12
Determination of permeability for water vapor – factor of diffusion resistance μ	ČSN EN 12086	–	1.5
Thermal conductivity	ČSN 72 7306 ČSN 72 7012-2,3 ČSN EN 12664 ČSN EN 12667	W/m·K	0.038

Cement

Portland cement CEM I 42.5 R was used from the cement mill Hranice na Moravě as the basic binding material for thermal insulation mortar.

Hydrated Lime

As the second binding material in the thermal insulation mortar there was used hydrated lime prepared from the oxide calcium CL80, produced by DOLLVAP s.r.o., using the following method: 170 g of oxide calcium CL80 was stirred in 510 ml of potable water. Lime mixture was stirred for 13 minutes, maximum temperature reached at the lime slaking was 74°C in 11 min. Lime mixture was then poured over to the specific cylinder and stabilized for 15 days. Sediment height i.e lime capacity was 660 ml. Such prepared lime hydrate was used as the reference sample for replacement of the lime component in the thermal insulation mortar.

Vinyl Acetate Copolymer

It involves the powder admixture with the trade name Wacker 8034H improving the mixture rheology, increasing the strength and decreasing the absorption of insulation mortar.

EXPERIMENTAL PROCEDURES

The main objective of the experimental research consisted in the cement hydrate replacement with treated mine water sludge in the thermal insulation mortar, where polyurethane foam was used as the filling agent. Polyurethane foam is the secondary recycled product. It has suitable density, excellent thermal insulation properties and is chemically and volume stable. At disintegration of the waste polyurethane and subsequent sorting it is possible to create the thermal insulation mortars with respect to the optimum granularity of the thermal insulation plaster. Considering that the individual polyurethane grains have the open surface, than they are optimally composed in the thermal insulation mortars from the viewpoint of segregation of the volume of different components.

Furthermore, the open surface of the polyurethane grains is partially moisture--absorbing so the thermal insulation mortars at the own application are not demanding on the exact quantity of the batch water.

Experimental Prescriptions

In the framework of the basic experimental research there were proposed in total 4 experimental prescriptions of the thermal insulation mortar. Prescription 1 is the comparing prescription, where cement is used as the binding material in the quantity of 35% (m/m) from the binding material and cement hydrate in the amount of 65% (m/m). In the case of prescription 2, cement hydrate is replaced with treated mine water sludge in comparison with the previous prescription. In the prescription 3 there is the same quantity of cement (50% (m/m)) and treated mine water sludge (50 (m/m)). For prescription 4, the cement hydrate is replaced with treated mine water sludge comparing to the first prescription in the quantity of 35% (m/m) and cement amounting to 65% (m/m) from the total volume of the binding materials. Mine water sludge was dosed in the form of pulp that was prepared using the following method: 670 g of treated mine water sludge was stirred in 1000 ml of potable water.

Exact representation of individual components in the prescriptions is mentioned in Table 4 below.

Physical Mechanical Characteristics of Thermal Insulation Mortar

Strength characteristics of the thermal insulation mortar experimental prescriptions were determined according to standard ČSN EN 1015-11 [14] on the test specimen sized 40×40×160 mm. The results are presented in Figure 2.

Table 4. Composition of experimental mixtures of the thermal insulation mortar on the basis of treated mine water sludge

Component	Prescription 1		Prescription 2		Prescription 3		Prescription 4	
	for 0.9 dm^3 in (g)	for 1 m^3 in (kg)	for 0.9 dm^3 in (g)	for 1 m^3 in (kg)	for 0.9 dm^3 in (g)	for 1 m^3 in (kg)	for 0.9 dm^3 in (g)	for 1 m^3 in (kg)
PUR fr.0/3 mm	42.1	46.8	42.1	46.8	42.1	46.8	42.1	46.8
Cement CEM I 42.5 Hranice	142	157.8	142	157.8	205.3	228.1	268.6	298.4
Sludge from UDV in form of pulp	–	–	268.6	298.4	205.3	228.1	142	157.8
Lime hydrate	268.6	298.4	–	–	–	–	–	–
Water	182	203	211	234	198	221	174	194
Vinyl acetate copolymer Wacker 8034H	3.5	3.9	3.5	3.9	3.5	3.9	3.5	3.9

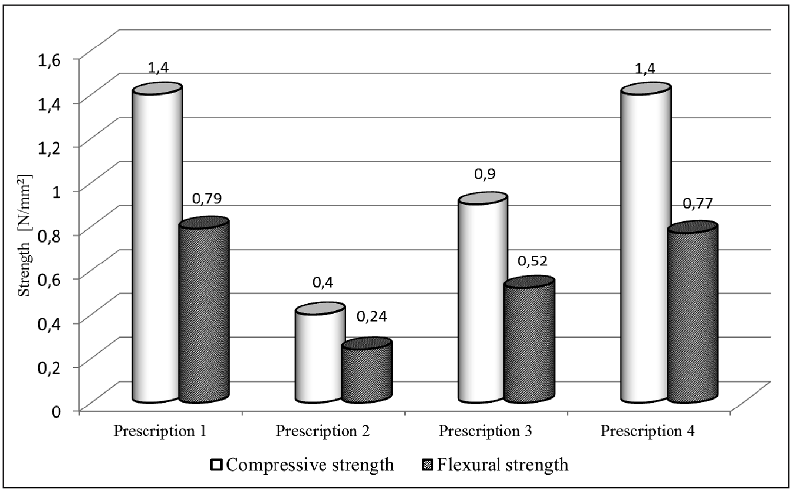

Fig. 2. Graphical representation of strength characteristics of the experimental prescriptions

From Figure 2 it is evident that replacement of cement hydrate with treated mine water sludge is possible in the quantity of 35% (m/m) (prescription 4) from the total binding material at keeping the strength characteristics in comparison with comparing prescription (prescription 1).

Prescription 4 was selected for the further experimental research, which involved testing of other physical mechanical properties. Tested properties and their values are mentioned in Table 5.

Table 5. Physical mechanical properties of thermal insulation mortar on the basis of PUR and sludge from UDV

Technical parameters	***Value***
Density of matured mortar	350–550 kg/m^3
Polyurethane granularity	0.125–4 mm
Compressive strength	1.4 MPa
Flexural strength	0.77 MPa
Mortar adhesiveness to the sublayer – porous concrete	0.038 MPa
Mortar adhesiveness to the sublayer – brick	0.044 MPa
Water vapor diffusion μ	4.6
Water consumption	0.85 l/kg
Heat conductivity factor λ	0.080 W/m.K
Efficiency in case of 10 mm layer	4.5 kg/m^2
Spreadable time	50 min
Maximum thickness of one layer application	30 mm
Maximum plaster thickness	80 mm
Minimum temperature of sublayer, air and plaster	5°C

DISCUSSION

In order to verify the replacement of hydrate using modified waste treated sludge in the segment of thermal insulation mortars based on polyurethane, four basic experimental prescriptions have been prepared, with the first formula being a comparative one (without waste treated sludge). All the experimental prescriptions have been subjected to tests of the strength characteristics (strength in compression and strength in tension in deflection). The performed tests show that prescription 4 has achieved the same values as the comparative prescription, with 35% replacement of the binding agent using waste treated sludge. The other important parameters of the tested formula 4 include thermal conductivity coefficient $\lambda = 0.080$ W/m.K and water vapour diffusion $\mu = 4.6$. These values correspond to the values of thermal insulation mortar in which the polyurethane grains were solidified only in the cement matrix, without the addition of waste treated sludge. It is therefore a highly porous mortar with very good heat insulation effect, especially suitable for use in heat and humidity redevelopment of buildings.

CONCLUSION

The experimental research proved that replacement of lime hydrate with treated sludge from the mine water treatment from Coal Quarry ČSA and JŠ is possible in the thermal insulation mortar on the basis of polyurethane foam after finished life cycle. Novelty of the results from the experimental research consists in the proof of the binding effects of the treated sludge from the mine water treatment in the light mortars; in this case it involves the polyurethane filling agent in the thermal insulation mortar. Experimental research has shown the new utilization of the sludge from the mine water treatment plant, which is being currently placed as a waste on the dump. The output from the experimental research is the functional sample called "Thermal insulation mortar on the basis of polyurethane with calcific sludge after the mine water treatment" [15]. The following part of experimental research will be dedicated to optimization of the capillary active properties of mortars based on polyurethane and waste treated sludge, especially from the point of view of pore size and mortar hydrophobization.

List of abbreviations:

ČSA – Coal Quarry Československé armády
JŠ – Coal Quarry Jana Švermy
UDV – Mine water treatment
RTG – powder X-ray diffraction analysis

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