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Properties of materials dedicated for the construction of isolation plugs-barriers in underground workings connecting an underground nuclear waste repository with a ground surface

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Vlastnosti materiálov určených pre konštrukciu izolačných poistných bariér v podzemnej bani prepojenej s podzemným skladom jadrového odpadu

The paper presents results of tests of basic properties of selected materials dedicated for the construction of artificial isolation barriers in underground workings, which connect an underground disposal site with a surface of the ground. The modified waste from coal fired power generation plants have been considered as a potentially useful materials for this application.

***Key words**: isolation plugs-barriers, underground nuclear waste repository, ground surface*

Introduction

The use of radioactive substances in the nuclear power generation, industry, medicine, science, etc., implicates a generation of radioactive waste. The management of radioactive waste can be divided into two main steps. The first step involves neutralization activities including a reduction of the volume of waste, solidification, binding, and packaging, the second step comprises a disposal of the remaining amount of waste in appropriate repositories [3].

In the case of radioactive substances it has been assumed that the best option for their storage are underground disposal sites located in deep geological strata [3].

The basic rule of disposing radioactive waste is to provide an effective protection of human beings and environment against a harmful influence of ionizing radiation being emitted by this waste. Additionally to the natural barriers, artificial isolation barriers can be used to eliminate any hazardous impacts of radioactive waste on the environment.

Characteristic of construction materials for isolation barriers; the methodology a range of tests

Fly ash – water slurries made from the fluidized bed ash with clay as a modifier have been the subject of this article.

The base material was fluidized bed ash from the "Jaworzno" power plant. Clay was provided by the building ceramics factory "Jopek" in Sierakowice. Before use, the clay was fractioned down to the maximal grain-size of 1 mm. The composition and description of the slurries considered in the tests is presented in Table 1.

Tab. .1. Composition and description of fly ash – water slurries considered in the tests.

Description of samples	Type of additive and its proportion (wt%) in the base material
JF-1	without modifier (ash 100 %)
JF-2	clay 10 % (ash 90 %)
JF-3	clay 30 % (ash 70 %)

The slurries were mixed with water in a proportion, which resulted in the constant value of spill radius (viscosity cup test) equal to 180 mm. By such a spill radius, the slurry meets the criteria of an effective hydraulic transportation of slurries in caving injection systems, together with a minimal amount of excessive water (bleeding) [4, 5]. The properties of fly ash – water slurries are described by the following parameters:

- compressive strength,
- soak resistance,
- toughness,
- coefficient of filtration.

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The measurements of the parameters listed above were undertaken according to standardized procedures. The toughness was determined as a value of the longitudinal strain (ε_z) by the boundary strength (R_c) [4]. The tests of toughness were made with the use of cylindrical samples of the diameter of 42 mm and the slenderness ratio of 2, after 100 days curing in an air-conditioned environment. All samples were cured at the temperature of 25 ºC and the relative humidity of 92 % to create conditions similar to those existing in mine shafts during their liquidation.

Analysis of results of basic properties of modified fly ash – water slurries

The boundary uniaxial compressive strength was tested after 7, 14, and 28 days of cure, and additionally, after 120 and 240 days of cure in the air-conditioned environment.

The results of boundary uniaxial compressive strength are listed in Table 2 and presented graphically in Fig. 1.

Tab. 2. Boundary uniaxial compressive strength of materials used in the tests.

Description of material	**Compressive strength** [MPa] **after:**				
	7 days	**14 days**	**28 days**	**120 days**	**240 days**
JF-1	2,79	5,62	7,54	4,33	2,47
JF-2	2,97	3,54	3,62	1,99	1,11
JF-3	1,12	1,49	1,44	0,54	0,30

On the basis of obtained results it can be stated that the compressive strength after the “standard” 28 days of cure time definitely decreases.

After 240 days of cure time, the compressive strength of fly ash – water mixtures changes in dependence of the modifier addition from 2,47 MPa (sample JF-1 – mixture without clay) up to 0,30 MPa (sample JF-5 – mixture with the addition of 30 % clay).

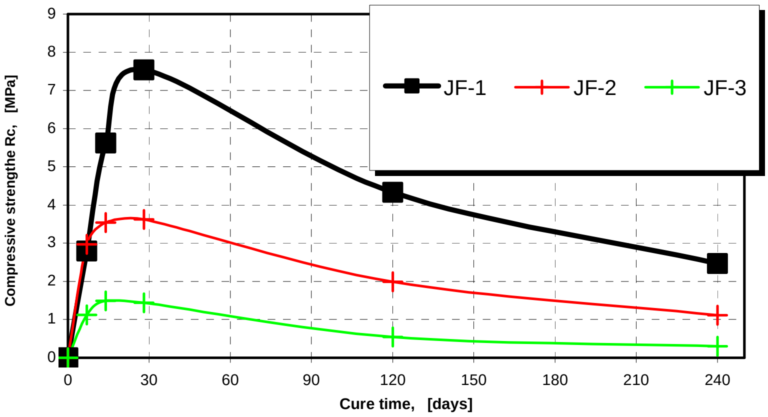

Fig. 1. Boundary uniaxial compressive strength of tested materials as a function of the cure time in the air-conditioned environment.

The results of soak resistance measurements are shown in Fig. 2. The soak resistance of tested materials changes from 10,7 % for the mixture with the addition of 10 % clay (sample JF-2) up to 17,7 % for the mixture without the addition of clay (sample JF-1).

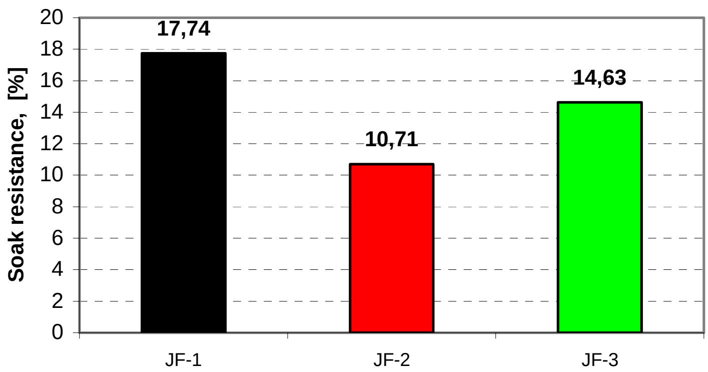

Fig. 2. Soak resistance of tested materials..

The results of toughness measurements are presented in Fig. 3. The measured values of the toughness range between 0,9 % for the mixture without the addition of clay (JF-1) and 2,1 % for the mixture with the addition of 30 % clay (JF-5).

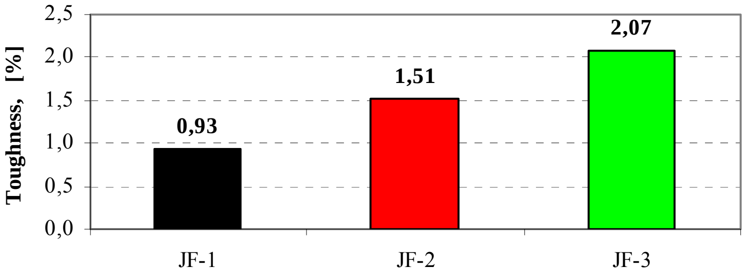

Fig. 3. Toughness of tested materials.

The results of filtration measurements are shown in Fig. 4.

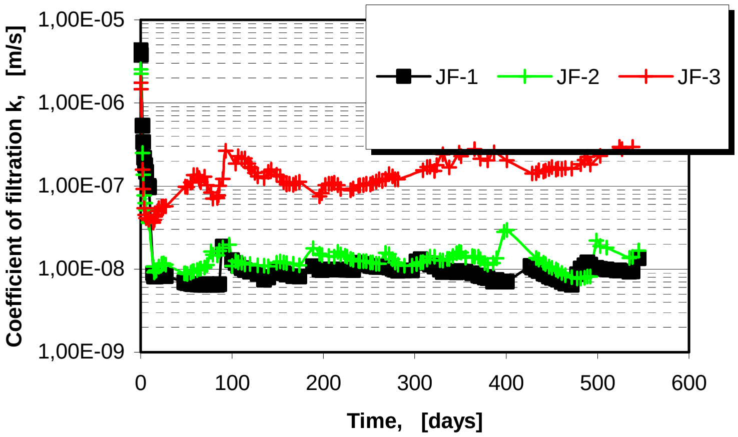

Fig. 4. Volatility of the coefficient of filtration during the cure time for tested materials.

The measurements of coefficient of filtration, which lasted 570 days show that the coefficient of filtration was stabilized after 60 days of cure time. After 570 days, tested mixtures achieved the following values of coefficient of filtration:

- JF-1 (100 % ash) – $9{,}0 \cdot 10^{-9}$ m/s,
- JF-2 (addition 10 % clay) – $1{,}5 \cdot 10^{-8}$ m/s,
- JF-3 (addition 30 % clay) – $3{,}0 \cdot 10^{-7}$ m/s.

Numerical calculations of stability of shaft fill comprising of a highly thickened mixture of slag, fly ash and cement

The closure of a shaft poses a serious technical and technological problem in the case of lack of revetment walls and a partial flooding of the abandoned shaft.

In such a case, a plug can be constructed in the abandoned shaft at a station level, from highly thickened solidifying slurry comprising slag, fly ash, cement and water. However, filing the shaft pipe with a solidifying material results in a different distribution of vertical and horizontal stresses acting on the shaft lining than in the case when the filling is done by a loose material. The solidifying fill material provides a high resistance to the radial forces and a high friction against the shaft lining only if it is properly cured and achieves an adequate compressive strength. In such conditions, the analytical method of shaft stability assessment based on the Jansen's conditions does not take into consideration a number of facts, which could result in an underestimating of the stability of material filing the shaft.

These facts are:

- construction of a plug in the flooded part of the shaft,
- large depth of the shaft,
- limited possibilities to control the quality of plug construction.

A methodology of the fill column stability assessment using the finite element numerical method can be described as follows:

- constructing a model,
- calculating the stability coefficient with the use of the shear strength reduction method.

For these reasons, when assessing the stability of a shaft fill, the column priority should be given to the use of numerical methods (Fig. 4).

In the example presented here, calculations were done for two slurries comprising slag, fly ash, cement and water, one of them containing 15 and the other 30 wt % of cement. Additionally, an assumption was made that the plug at the shaft station will be constructed using the slurry with the 30 % cement content. The results of laboratory measurements of strength and strain properties of highly thickened solidifying slurries were used in the calculations. The dependence of the calculated shaft fill stability coefficient from the loads resulting from placing subsequent batches of fill slurry and its strength related to the curing time is presented in Tables 4. and 5.

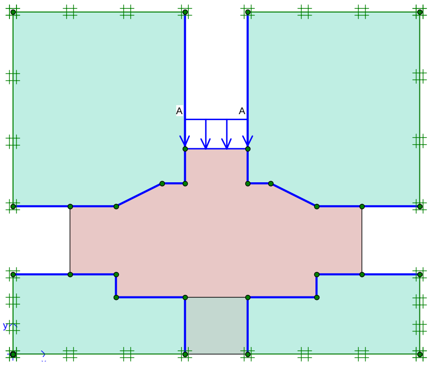

Fig. 4. Geometry of the plug constructed at a shaft station adopted for the numerical calculations.

Tab. 4. Shaft fill stability coefficient for the slurry strength obtained after 1 day of curing.

Coefficient of binding the solidifying slurry with the shaft walling *k*							
0.01		**0.25**		**0.50**		**1.00**	
Load [MPa]	**Stability index**	**Load** [MPa]	**Stability index**	**Load** [MPa]	**Stability index**	**Load** [MPa]	**Stability index**
0.0	2,25	0.0	12,94	0.0	13,27	0.0	13,97
0.1	1,02	0.1	10,92	0.1	12,64	0.1	14,44
1.0	unstable	1.0	4,98	1.0	5,72	1.0	6,80
		2.0	3,66	2.0	4,29	2.0	2,15
		3.0	3,14	3.0	3,58	3.0	1,84
		4.0	2,84	4.0	3,08	4.0	1,23

The calculations were done for characteristic states of stresses on the fill slurry- shaft lining contact surface, described by the coefficient of bond k.

Tab. 5. Shaft fill stability coefficient for the slurry strength obtained after 14 days of curing.

Coefficient of binding the solidifying slurry with the shaft walling *k*							
0.01		**0.05**		**0.1**		**0.25**	
Load [MPa]	**Stability index**	**Load** [MPa]	**Stability index**	**Load [MPa]**	**Stability index**	**Load** [MPa]	**Stability index**
0.0	10.55	0.0	21.76	0.0	41.34	0.0	41.49
0.1	9.84	0.1	14.36	0.1	12.51	0.1	42.41
1.0	unstable	1.0	10.16	1.0	10.66	1.0	12.47
		2.0	5.72	2.0	6.93	2.0	8.03
		3.0	4.48	3.0	5.13	3.0	6.20
		4.0	3.33	4.0	4.43	4.0	5.47
						5.0	4.86
						6.0	4.44
						7.0	4.03
						10.0	3.63

The values of coefficient k are equal to:

- k = 0.01, for the state that occurs directly after the placement of a batch of fill slurry into the shaft (material is plastic, wet, there is no binding with the shaft lining, etc.);
- k = 0.1, for the initial curing time of the fill material;
- k = 0.25, for the advanced state of curing of the fill material;
- k = 0.5-1.0, for the final strength of the solidified fill material.

From the results of the calculations it can be seen that for law values of the coefficient of bond between the solidifying slurry and the shaft lining (k = 0.01), i.e. for the state occurring directly after pouring the fill material into the shaft, a loss of the stability is caused by loads as small as approximately 0.2 MPa acting on the plug.

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