Górnictwo i Geoinżynieria • Rok 29 • Zeszyt 3/2 • 2005

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APPLICATION OF STABILIZING HIGHLY THICKENED SLURRIES FOR FILLING OF FLOODED SHAFTS

1. Introduction

Closure of mining workings, especially shafts, is a complex problem, particularly when water and gas hazards exist. The method of shaft closure depends in the first place on the actual condition of the working and its equipment, existing connections to horizontal workings and water conditions.

The most significant problem is to ensure stability of the fill column. This can be achieved through selection of appropriate material for filling the shaft and construction of revetment walls at shaft stations.

In the case of an abandoned shaft, which is partially filled with water, the fill material or mixture of materials should possess the ability to solidify in a water environment, and after solidification must be proof against soaking and secondary liquefaction.

The solidified fill material should also remain stable under the loads resulting from subsequent batches of fill material placed in the shaft. The paper presents the results of laboratory research and numerical analyses on the use of highly thickened slurries for filling abandoned shafts.

2. General strength and strain properties of highly thickened slurries being transported through a shaft filled with water

When working out the composition of the mixture for filling an abandoned, partially flooded shaft, under the assumption that the filling will be carried out by free-falling material, the following issues should be taken into consideration:

— the multi-component slurry must possess highest possible cohesion, to prevent the slurry from disintegration and separation into fractions with different grain size and weight during its free fall down the shaft;

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— cohesion of the slurry must be high enough to prevent complete disintegration of the material at the moment of it hitting the water surface;

— the slurry must be characterized by adequate resistance to washout by water, which could take place during the material sinking in the flooded part of the shaft.

Laboratory research tests were conducted for highly thickened slurry placed in a flooded underground mining working.

The slurry was composed from the following materials:

— fly ash with the by-products of semi-dry flue gas desulphurisation process;

— slag from fluidisation bed boiler;

— portland cement type cem IA 42.5.

The results of the laboratory measurements of compressive and tensile strengths of highly thickened slurries in relation to their cure times and proportions of the components by mass were presented on Figures 1 and 2.

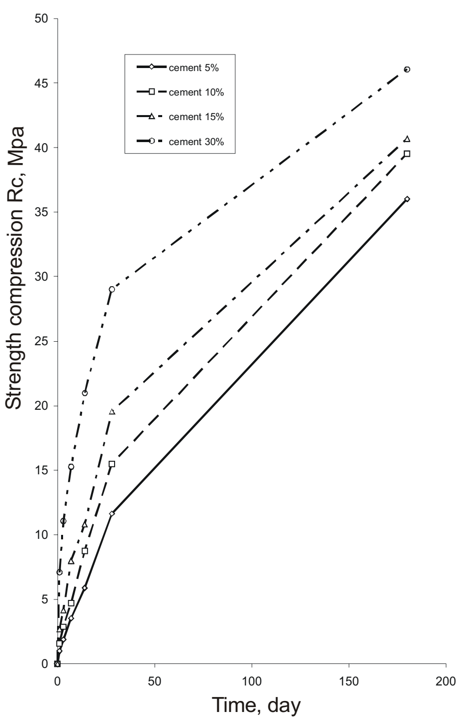

Fig. 1. Compressive strength *Rc* of highly thickened solidifying slurries as a function of cure time and cement percentage

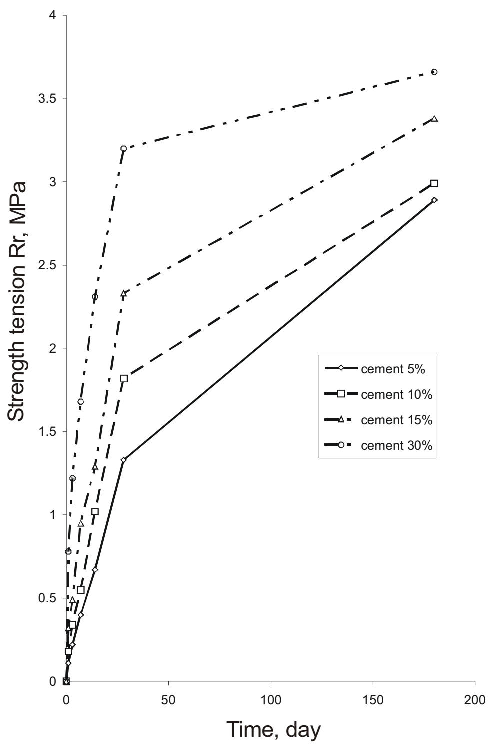

Fig. 2. Tensile strength *Rr* of highly thickened solidifying slurries as a function of cure time and cement percentage

The diagrams presented on Figures 1 and 2 show high usefulness of the highly thickened slurries for stabilization of a shaft fill.

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

Closure of a shaft poses a serious technical and technological problem in the case of lack of revetment walls and partial flooding of the abandoned shaft. The choice of an appropriate closure method is of great importance especially in the presence of potential methane hazard and the need to protect methane drainage pipelines, which are often left in abandoned shafts.

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, filling a shaft pipe with a solidifying material results in different distribution of vertical and horizontal stresses acting on the shaft lining than in the case when the filling is done by loose material. The solidifying fill material provides high resistance to radial forces and high friction against the shaft lining only after it properly cured and achieved adequate compressive strength. In such conditions the analytical method of shaft stability assessment based on Jansen's conditions does not take into consideration a number of facts, which could result in underestimating the stability of the fill material filling 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.

For these reasons, when assessing stability of a shaft fill column priority should be given to the use of numerical methods (Fig. 3).

A methodology of fill column stability assessment with the use of 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.

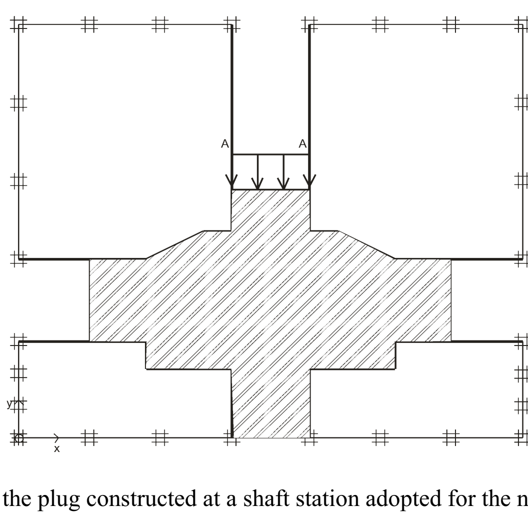

Fig. 3. Geometry of the plug constructed at a shaft station adopted for the numerical calculations

In the example presented here the calculations were done for two slurries comprising slag, fly ash, cement and water, one of them containing 15 and the other 30% of cement by mass. Additionally an assumption was made that the plug at the shaft station will be constructed using the slurry with 30% cement content.

The results of the laboratory measurements of strength and strain properties of highly thickened solidifying slurries have been used in the calculations.

Dependence of the calculated shaft fill stability coefficient from the loads resulting from placing subsequent batches of fill slurry and its strength related to curing time were presented in Tables 1, 2, 3 and 4.

TABLE 1

Shaft fill stability coefficient for slurry strength obtained after 1 day of curing

Coefficient of binding the solidifying slurry with 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

TABLE 2

Shaft fill stability coefficient for slurry strength obtained after 3 days of curing

Coefficient of binding the solidifying slurry with shaft walling $k = 0.01$	
Load, [MPa]	Stability index
0.0	7.59
0.1	5.61
1.0	unstable

TABLE 3

Shaft fill stability coefficient for slurry strength obtained after 7 days of curing

Coefficient of binding the solidifying slurry with shaft walling $k = 0.01$	
Load, [MPa]	Stability index
0.0	9.69
0.1	5.63
1.0	unstable

TABLE 4

Shaft fill stability coefficient for slurry strength obtained after 14 days of curing

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

The values of coefficient k are equal to:

— $k = 0.01$, for the state that occurs directly after 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 can be seen that for a low value 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, loss of stability is caused by loads as small as approximately 0.2 MPa acting on the plug.

With increasing strength of the plug material and increasing values of the coefficient of bond, stability of the shaft fill column increases as well. It can be accepted that stability of the revetment plug is assured when the value of shaft fill stability index is equal to 5.0.

4. Summary

The laboratory test results and analyses showed that strength and strain parameters of the fill material depend not only on the composition of the mixture, but also on the way of transport (transport in stagnant water) and the curing environment — water or dry air environment.

The numerical calculations of the stress and strain state in the shaft plug acting as a revetment plug done for increasing strengths of fill material and increasing loads on the plug from the thickening column of fill material in the shaft, allowed to determine:

— stability of the revetment plug in the shaft in relation to its strength,
— maximum allowed load of fill material on the revetment plug,
— maximum allowed volume of one batch of solidifying fill material.

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