Minefill 2020-2021 – Hassani et al (eds)

The properties of the backfill mixtures based on own fine-grained waste

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SUMMARY: Backfilling and filling voids in Polish underground mines has mainly two faces: the classic hydraulic backfilling and caulking gobs with use fine-grained mixtures. The first type is backfilling, in which the main material is sand has over 100 years of tradition in Poland, but in recent years it has virtually disappeared in hard coal mines. There are used for almost 30 years other methods - caulking and filling voids caving mainly with mixtures based on different types of fly ash. Fine-grained hard coal waste is eagerly added to such mixtures, which is the cheapest way to manage it. In recent years there have been a number of changes on the ash market. Their price increased significantly due to widespread use in the construction sector. Coal mines wanting to use known and proven technology at a low level of costs, are forced to look for alternative mixtures, based more on their own waste. The article describes the properties of caulking mixtures based on own (mining) waste with the addition of parameters improving the parameters. The possibility of producing binder mixtures with higher mechanical properties was also assessed. The scope of research concerned the properties of mixtures in a liquid state, including rheological properties, as well as the properties of mixtures after hardening.

Keywords: backfill, suspension, mining waste, sediment, tailings

1 INTRODUCTION

Several types of hydraulic backfills have been used in Polish hard coal mining for years. In the twentieth century it dominated classic sand backfilling used as a way of filling goaf, providing support for the floor, and a significant reduction of the surface subsidence. From the beginning of the 21st century it was gradually withdrawn due to high costs and the need to limit exploitation in areas requiring special surface protection. From the late 1980s to the 1990s, another type of backfill began to gain popularity - mixtures based on fine-grained materials. For over 20 years they have been a permanent element of mining technologies. The basic component of such mixtures - suspensions are fly ash and water (most often saline water from mine dewatering), For this purpose, fly ash of various types can be used: from dust and fluidized bed boilers, whether or not containing flue gas desulphurization products. Suspensions are also an effective method of managing various types of fine-grained mining waste (Pomykała et al. 2015, Popczyk, Jendruś 2019). As their components, waste from on-going coal processing and enrichment is usually used: flotation waste and sludge waste from jigs. Suspensions of particulate materials are used as solidified backfill, for filling voids and working liquidation, but usually as a mixture to the sealing and caulking of gobs caving in longwall mining system. Such use is primarily aimed at fire and methane prevention - by cooling gobs and their internal insulation.

DOI: 10.1201/9781003205906-10

In the last 10 years there have been a number of changes on the ash market. First of all, its use in the construction sector has increased significantly - as a component of cements, concrete and building materials, road foundations. This resulted in a decrease in the availability of cheap ashes for mines, especially in summer, and an increase in their prices to levels difficult to accept by mines. This increased the pressure to look for materials that would allow partial or full replacement of fly ashes, while ensuring the current scope of use of suspensions as solidified backfill and mixtures for gobs caulking.

2 ALTERNATIVE MATERIALS

Among the materials for which methods of development are constantly sought are various fine-grained mining waste deposited in surface settling tanks. Such wastes are sludge (sediment) from treatment of mine water accumulated in the surface mine water settling ponds, where sedimentation of fine gangue and coal particles occurs Gruchot et al. 2015).

The possibility of increasing the proportion of tailing waste in suspensions so that they constitute the main component of mixtures is also considered. This applies to both wastes from current production and deposited in tailings ponds.

Bottom ashes from coal combustion are another type of waste that can be used to prepare suspensions. While bottom ashes from dust boilers are widely used in construction, geotechnics and engineering works, management of bottom ashes from fluidized bed boilers is difficult (Pomykała 2013). The main reason is their chemical composition, in particular the content of CaO and SO3. The presence of these components is associated with the flue gas desulphurization process carried out in the fluidized bed boiler. As properly managed waste is based on its recovery, new possibilities and directions of bottom ash management from fluidized bed boilers are sought. Their use for making suspensions due to their grain size is not possible. On the other hand, the separation of small fractions may enable such a development direction.

The article presents the results of research on the use of own waste from hard coal mines for the preparation of waste-water suspensions. Flotation waste from coal enrichment processes and sediment from underground water treatment deposited in settling tanks were used for the research. As an addition to such mixtures, fly ash from a fluidized bed boiler, separated bottom ash as well as cement were used, which allowed to obtain the required binding properties.

3 MATERIALS AND RESEARCH METHODOLOGY

For the preparation of suspensions, energy waste from coal combustion in a fluidized bed boiler was used: fly ash - designated FA, and separated bottom ash - designated BA. The bottom ash was separated on a 0.315 mm sieve. The 0-0.315 mm fraction was used for the tests. The selected size of distribution resulted from the grain composition of the bottom ash, ensuring the right amount of separated ash (about 40% of the waste was the 0-0.315 mm fraction). The larger the grain size, as well as their share, promotes sedimentation in the pipeline, it can also result in uneven material distribution in the binding mixture. Flotation waste from coal enrichment was used to prepare the mixtures - designated as FT and sediments (sludge) from the underground water sedimentation tank, designated as M. Due to the significant share of water in the mine's own waste (humidity FT 45% and M 39%) and to create greater opportunities for of underground water from the mine, CEM 32.5R cement was also used.

The use of suspensions in mining technologies requires that the suspensions meet the relevant requirements specified in PN-G-11011: 1998 - Materials for solidification backfill and mixtures to caulking gob. Requirements and test methods (Gruchot et al. 2015). The basic requirements for the materials themselves are to meet the limits in leaching of chemical impurities and radionuclide content (Pomykała 2013, Popczyk, Jendruś 2019).

An important role in the preparation of suspension formulas is played by several parameters: consistency (possibility and safety of transport as well as ability to penetrate voids) ability to bind water and solidify, setting time and compressive strength (also in the wetness test - after seasoning samples in water).

For each of the suspensions, a series of tests was performed, which allowed determining the variability of properties depending on the composition and determining the possibility of their use in mining for solidifying backfill or caulking mixture. The following properties of suspensions were tested: apparent density, fluidity, volume of supernatant water, setting time - beginning and end of setting using a Vicat apparatus. The fluidity measurement is carried out by spreading a given volume of suspension on a flat surface by lifting the standard cone into which the suspension has been previously poured. The Rheotest 4.1 cylindrical rheometer was used for testing rheological properties. Tests of the strength of mixtures for uniaxial compression were carried out after 14 days.

According to the assumption, mining waste was the main components of the suspensions. Mixtures prepared with the participation of sediment from water treatment were designated as M1-M6, while with the participation of flotation waste: FT1-FT5 (Table 1). The contents of individual ingredients were measured by mass. The compositions of suspensions were selected so as to obtain the smallest volume of supernatant water and at the same time the consistency enabling safe transport through the pipeline and flow along the outlet from the pipeline. As a result, in mixtures with sediment from underground water treatment, the ratio of the mass of components S (M + FA + BA + CEM) to water W was S/W = 1.2 and 1.5. Due to the higher water content in the flotation waste, more water-binding components were used in the mixtures with their participation. As a result, the S/W ratio for suspensions with FT was S/W = 1.38; 1.75 and 2.0.

4 TEST RESULTS

The sediment (M) from underground water treatment was first mixed with water in a 1: 1 weight ratio, and then fly ash was added in an amount of 0.5 sediment mass. A suspension M1 was obtained, the spreading rate of which was 140 mm. Because standard (Pomykała 2013) provides for the use of suspensions with a minimum fluidity of 180 mm, the next suspension was M3, in which half of the ash FA was replaced with cement. As a result, the fluidity of the suspension increased to 170 mm. By using separated BA bottom ash instead of FA fly ash,

Table 1. Composition of the suspensions.

	Share of ingredients by weight %					
	mine waste		ashes		cement	
Mixture	M	FT	FA	BA	CEM	S/W
M1	66.7	-	33.3	-	-	1.50
M2	80.0	-	20.0	-	-	1.25
M3	66.7	-	16.7	-	16.7	1.50
M4	80.0	-	10.0	-	10.0	1.25
M5	66.7	-	-	33.3	-	1.50
M6	66.7	-	-	16.7	16.7	1.50
M7	80.0	-	-	10.0	10.0	1.25
FT1	-	57.1	42.9	-	-	1.75
FT2	-	57.1	21.4	-	21.4	1.75
FT3	-	72.7	13.6	-	13.6	1.38
FT4	-	57.1	-	21.4	21.4	1.75
FT5	-	50.0	-	25.0	25.0	2.00

suspensions with higher fluidity properties of 150 mm (M5) and 190 mm (M6) were obtained. By reducing the proportion of S components in relation to water to the value of 1.25 and also by limiting the content of binding components (FA, BA and CEM), suspensions M2, M4 and M7, for which the spreading was 210-220 mm, were obtained (Table 2).

A small amount of supernatant water, up to 1.5%, was noted for mixtures with the sediment. According to the standard (Pomykala 2013), in solidified backfill only max. 7% of supernatant water content is allowed, and for caulking gobs mixtures - max. 15%. Such a small amount is very beneficial because there is no danger due to the formation of water reservoirs at the bottom in the mine, and pumping costs will be relatively low. It also allows reducing the costs associated with the discharge of saline water into surface watercourses.

The results of the early compressive strength test indicate that some suspensions (M1, M3 and M6) already after 14 days showed higher strength than required for solidified backfill (min. 0.5 MPa). Compressive strength depends on the proportion of binding components and their ratio to water. Similarly as in the case of building materials - slurries, mortars or concretes (Pomykała et al. 2013). In addition, suspensions with fly ash (FA) showed higher compressive strength than with separated bottom ash (BA).

Flotation waste (FT) was also mixed with water in a 1: 1 mass ratio before preparing the suspensions. Next, binding components were added, but in an amount greater than in the case of M1-M7 suspensions, because the humidity of FT was higher than M. As a result, FT1-FT5 suspensions were prepared, in which the mass ratio of all solids to water was S/W = 1.38 (FT3), 1.75 (FT1, FT2, FT4) and 2.0 (FT7). The fluidity of these suspensions ranged from 210 mm to 290 mm. The base suspension made of FA (FT1) had a fluidity rate of 210 mm (FT1). Replacing half of the FA ash with cement increased the fluidity to 230 mm (FT2). In turn, the use of BA instead of FA caused a further increase in fluidity to 270 mm (FT4).

Start of suspensions setting was varied depending on the type and content of individual binding components in relation to water and solids content. In general, fly ash suspensions started to set sooner than suspensions with separated bottom ash. The use of cement instead of some fly ash or separated bottom ash accelerated the setting of suspensions.

Early uniaxial compression strength (after 14 days) for all suspensions prepared with post-flotation waste was higher than 0.5 MPa, ranging from 0.61 MPa (FT3) to 2.16 MPa (FT1). The highest strength was found for suspensions with the proportion of cement, the smallest - with separated bottom ash (Table 2).

The results of testing the rheological properties of the tested suspensions are presented in Figures 1 and 2 in the form of flow curves.

Table 2. Suspension properties.

Mixture	Properties of liquid suspensions: density [Mg/m^3]	fluidity [mm]	Supernatant water [%]	Start setting time [day]	Finish setting time [day]	Compression strength after 14days [MPa]
M1	1.31	140	1.0	3	5	0.57
M2	1.23	220	1.5	9	11	0.34
M3	1.32	170	1.0	2	4	1.09
M4	1.27	220	1.0	4	7	0.45
M5	1.30	150	0.4	9	12	0.37
M6	1.29	190	0.0	2	6	0.56
M7	1.24	210	0.0	5	10	0.24
FT1	1.34	210	0.0	3	4	1.66
FT2	1.33	230	0.3	3	4	2.16
FT3	1.23	290	1.8	4	8	0.61
FT4	1.34	270	6.9	4	6	0.65
FT5	1.34	250	7.3	3	5	2.71

Source: own study

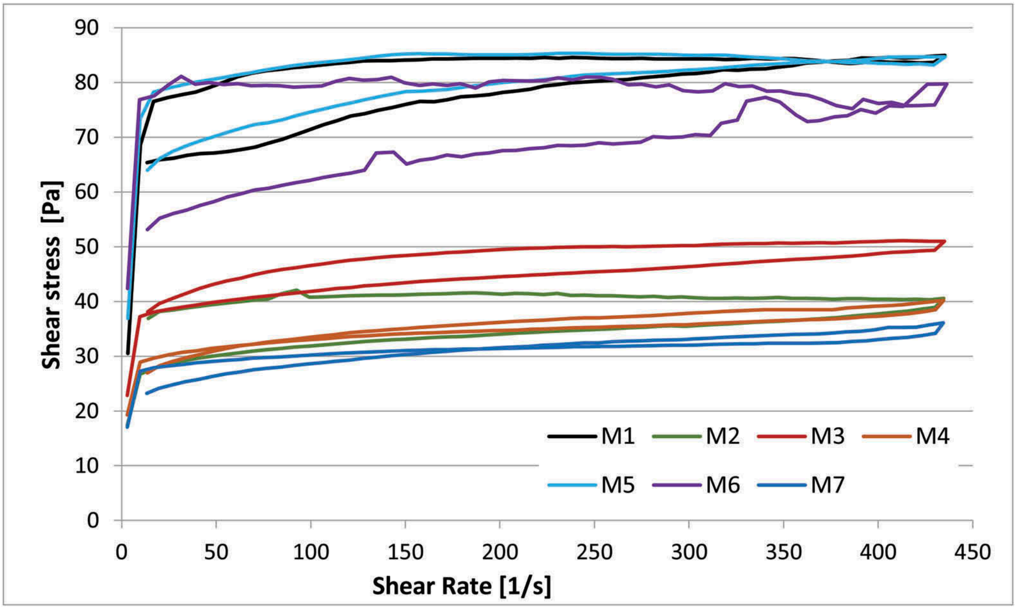

Figure 1. Flow curves of suspensions with sediment (M).

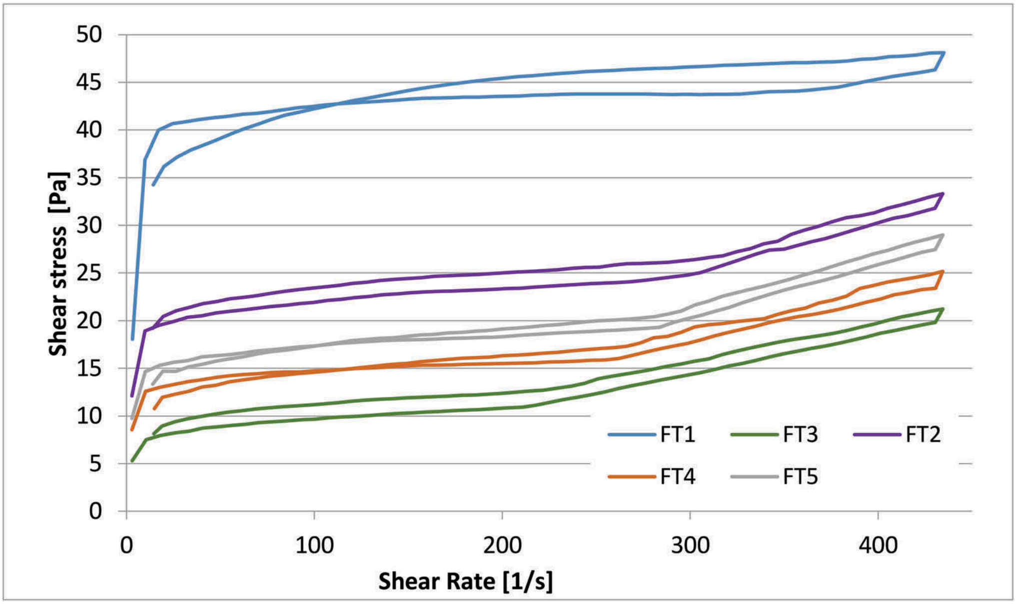

Figure 2. Flow curves of suspensions with flotation waste (FT).

All tested wastes have a clear flow limit, and at the same time, as the shear rate increases, the increase in viscosity is relatively small. This shape of the flow curves indicates a large role of plastic properties, and is typical for flotation wastes from hard coal processing. The highest shear stress values were obtained for suspensions with fly ash. In the case of suspensions with the participation of sediment (M) a constant flow curve is observed in a wide range of share rates. In the case of suspended solids with flotation waste (FT), an increase in share stress is observed after exceeding the shear rate of 250 [1/s].

5 SUMMARY

The article presents the results of tests on the properties of suspensions, in which the main component was fine-grained mining waste in the form of sediment from underground water treatment and flotation waste from hard coal processing. In order to bind water and solidify the mixtures, the following ingredients were added to them: fly ash and separated bottom ash with a fraction of 0-0.315 mm, from coal combustion in a fluidized bed boiler, as well as cement.

One of the main objectives of the research was to indicate whether and to what extent separated bottom ash can replace fly ash in such suspensions, as well as whether and to what extent the addition of cement allows to increase the share of fine-grained mining waste. As the results of the research have shown, it is possible to select the appropriate composition of suspensions, in which the main component will be waste in the form of sludge from underground water settlers or flotation waste. This can increase the possibility of using this type of difficult material, which is often landfilled. In addition, the use of separated bottom ash from coal combustion can complement the shortage of fly ash, especially in summer.

Replacement of fly ash with other materials cannot take place without prior analysis. The use of bottom ashes, even their separated fractions, involves the risk of sedimentation in the pipeline and its failure. This involves the need for more complex planning of transport parameters in the pipeline. In turn, the addition of cement raises the costs of the filling itself. Nevertheless, increasing the amount of fine-grained mining waste used in mining technologies is now a necessity due to the limited possibilities of depositing it on the surface.

ACKNOWLEDGEMENTS

The tests were carried out based on statutory works No. 11.11. 100 482.

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