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PARAMETERS OF BACK FILLING MATERIAL PREPARED FROM MINE TAILING, FLY ASH, AND MINE WATER

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Abstract. The article investigates the influence of mine tailing, fly ash, and mine water on strength parameters as mine paste filling material performing the strength tests on different recipes of mortar mixes with individual types of fillers and wastewater from extraction of mine tailings. Recipe is prepared in proportions corresponding to the standard mortar and compared with a reference recipe according to the fresh mortar consistency test using a shaking table according to ČSN EN 1015-3. Resulting measured values on $40 \times 40 \times 160$ mm solids samples for which the evaluation of the volume weight was carried out in the range of 2, 7, 14, 28, 56 and 90 days according to EN 1015-10 (722400). The results showed that that it is possible to prepare relatively fluid mixtures with extremely low binder dosage. And not only the water coefficient but also the granulometry of the raw material plays an important role in the long-term strengths of samples.

Keywords: Fly ash, mine water utilization, mine backfill mixture.

1. Introduction

The mining industry can be divided into two broad categories, namely metallic and non-metallic. Precious metals are extracted from mined ores following a well-defined series of mineral processing and metallurgical procedures. This series leads to the generation of large quantities of solid industrial wastes from mine development, such as fragmented waste rock and mined bedrock [1]. Another category of solid waste generated from mineral processing (separation of valuable minerals from ores) is called tailings. It follows that mining and mineral processing is associated with the generation of significant quantities of waste. Coal ash from thermal power plants during coal mining, tailings from precious metal mining and metallurgical slag from copper mining are significant waste streams generated [2, 3]. The generation of such a huge number of segregated tailings adversely affects the environment, including air, water, and soil [4, 5]. A vast area of surface land is subsequently required to adequately store and manage this waste in the form of segregated tailings. Underground disposal of these industrial wastes (tailings, fly ash cinders, red mud etc.) generated from mining and related activities in the form of mine backfill is an effective solution [6–8]. The voids created after ore extraction in underground mines can be refilled with specific waste material referred to as backfill [9]. Backfilling of mines helps to prevent subsidence, improves the stability of underground structures, and prevents ore grinding also increases the recoverability of the mined waste and as a result increases production with many other benefits [8–11]. Backfilling can be divided into two broad categories, the former being unconsolidated backfill and the latter being cemented reinforced backfill [12]. Unconsolidated backfill, waste is added without any binder. While in cemented backfill, a hydraulic binder is added, usually this binder is Portland cement which is added to the solid waste material to create background for mechanical properties of the paste [12, 13]. One form of cemented backfill used in underground mines is a paste with well-defined mechanical properties [12–15]. Paste backfill is widely applied worldwide because of its techno-economic and its technology success which is evident from the fact of increased demand over the last 40 years [14]. In recent years, several modifications and investigations have been made regarding improvements in the design and environmental friendliness of paste backfill. Significant progress in this area has been achieved using alternative binders, the use and modification of backfill materials, investigation of their strengths, rheology of leaching probability, and the economic use of other wastes. This work was devoted to the study of the basic mechanical properties and the effect of different mine waters used for the preparation of tailings backfill mixtures with binder in the form of fluidized fly ash activated by grinding [8–14].

Mine tailings, which are deposited after the extraction of minerals, are the largest source of waste in the processing of mining raw materials. Worldwide, approximately 5-7 billion tons of waste are generated annually in the form of mined tailings [7, 8]. This waste has traditionally been disposed of in tailings ponds, repositories, which is associated with serious environmental, geotechnical, and economic problems [15–17]. Cement paste backfilling is increasingly used to fill excavated voids in underground spaces [6–8, 10]. Backfilling with cement paste recycles the processed tailings. into underground mine cavities, reducing the volume that needs to be deposited on the surface. This process reduces the potential environmental impacts associated with the issue [8, 18–21]. Material recycled in this way can act as a permanent support system or temporary working platform for others [15, 16]. Cement pastes treated in this way, in the form of a high-density slurry, consist of mined tailings, a low proportion of cement binder (3-7 %) and processed mine water to meet the design mechanical properties. To minimize the cost of the binder used, other alternative binders and materials are very often used, the most common being high temperature fly ash with pozzolanic activity and silica fume from the metallurgical industry. To achieve better pumpability and lower water coefficient while still maintaining good workability of these mixtures, superplasticizers are also very often used [1–3, 13–16]. The transport of backfill mixtures in underground mines is most often carried out by gravity or mediated by pumping through pipelines or boreholes. For this reason, the prepared slurry should be thickened to achieve a non-sedimentary character for easy pumping into mine cavities created during deep mining operations [11, 12, 19]. Hence, the fluidity of the paste backfill is an essential parameter in the design of cement slurry. The rheological properties (i.e., yield strength and viscosity) are related to the so-called amount of energy consumed to ensure fluidity. Mine backfill mixtures should be homogeneous, mobile, suitable for transport by pumping over distances of hundreds of meters, and workable for a minimum of 120 min. After curing, the strength should ideally reach at least 4 MPa after 90 days, however, in conditions without static function, a strength of about half, 2-3 MPa may be acceptable [18–22]. Several studies have been carried out in recent years to understand the rheological behavior of backfill pastes and their main influencing factors. These studies show that the rheological behavior is influenced by external (e.g., temperature and time) and internal (e.g., cement content, addition of slag, fly ash or superplasticizers, and type of water used) factors. Although the effects of these external and internal factors are widely documented in the literature, the reported results are not consistent because the physical, chemical, and mineralogical properties of tailings vary from mine to mine [8–14]. The aim of this research was to absolutely minimize the amount of binder component, which is only supposed to have the function of ensuring the cohesion of the cured composite. The use of fluidized power plant fly ash, which is not used at all to produce conventional concretes, is also interesting.

2. Material and methods

To create models of non-static landfill mixtures, residues after separation of heavy and light recoverable components from the Cínovec, Měděnec and Zlaté Hory landfills were used, for which specific weight tests were carried out, where the measured values of specific weights for the tailings are given in Table 1.

The cement paste binder has been completely replaced by a binder based on grinding-activated fly ash,

	Specific weight [$g\,cm^{-3}$]
Měděnec	3.56
Cínovec	2.74
Zlaté hory	2.82

Table 1. The resulting measured values of the specific weight of the separated tailings.

which is a dry, clinker-free hydraulic binder material commonly used as an active admixture in shotcrete. Composition of the fly ash used:

- above 50 % SiO2 with Al_2O_3
- up to 20 % free lime, CaO
- up to 8 % sulfur dioxide, SO_3

The specific weight of the fly ash was measured in the laboratory using a Helium pycnometer Accupyc 1340 (micromeritics gas pycnometer), which reached 2.78 $g\,cm^{-3}$. The specific weight is significantly lower than that of cement (3.1 $g\,cm^{-3}$). And its fineness of grinding was also measured similarly to cement according to ČSN EN 196-6 using the ZEB Pc-Blaine-Star instrument. Specific surface area of the fly ash came out to be 8 200 $cm^2\,g^{-1}$. On the contrary the specific surface area of the fly ash is significantly higher than that of cement (3 000 – 4 500 $cm^2\,g^{-1}$). Results are given in Table 2.

	Specific weight [$g\,cm^{-3}$]	**Specific surface area [$cm^2\,g^{-1}$]**
Fly Ash	2.78	8 200

Table 2. Determination of specific weight and specific surface area.

Furthermore, the normal consistency and the onset of hardening of the binder based on fly ash activated by grinding were determined similarly to cement according to EN 196-3 (722100), Determination of setting times and volume stability. The result is given in the following Table 3. and Table 4.

	Amount [g]	**Resulting consistency [mm]**
Demineralized water	215	3
Fly Ash	500	

Table 3. Determination of normal consistency.

In addition to the independent properties of the binder consisting of fly ash and filler, which were the tailings residues after heavy and light metal separation, the applicability of mine water for the production and subsequent observation of the durability of the tailings mixtures was tested. To study the influence

	Amount [g]	Beginning of hardening [min]
Demineralized water	215	40
Fly Ash	500	

Table 4. Determination of the beginning of hardening.

of mine water, water from the mining area of Cínovec and Zlaté Hory (acidic water and alkaline water) was used. The pH value was monitored with a AD8000 Professional Multi-Parameter pH – Bench Meter, with the resolution of 0.01 pH and accuracy of ±0.01 seen in Table 5. Seven mortar pastes based on fly ash binder were created to monitor the process of gaining their strengths. The mixture was always composed of 1 350 g of residues after separation of heavy and light usable components from landfills 225 g of Fly Ash and either demineralized water (reference) or mine water (Water Cínovec, Water Zlaté Hory acidic and Water Zlaté Hory alkaline).

	pH
Cínovec	8.5
Zlaté Hory Acidic	3.4
Zlaté Hory Alkaline	7.8

Table 5. resulting measured pH values for each water type.

To perform the strength tests, the recipes of mortar mixes for individual types of fillers and wastewater from the extraction of tailings were designed and compared with a reference recipe prepared in proportions corresponding to the standard mortar according to the fresh mortar consistency test using a shaking table according to ČSN EN 1015-3. The monitored parameters were:

- Volumetric weight of fresh mortar according to EN 1015-10 (722400),
- Flexural tensile strength and compressive strength at curing times of 2, 7, 14, 28, 56 and 90 days according to EN 1015-11 (722400), determination of flexural and compressive strength of hardened mortars.

Due to the requirement for flowability of the mixes, the consistency of fresh mortar was chosen using a shaking table and levelling them to a 180 mm spillage. To achieve a 180 mm spillage, more water had to be added to the mixes than for normal consistency due to wetting of the separated aggregate. The proposed formulations of the stockpile mixes and the reference mixes are shown in Table 6, Table 7 and Table 8.

3. Results and discussion

Resulting measured values on 40 × 40 × 160 mm solids samples for which the evaluation of the volume weight was carried out in the range of 2, 7 14 and 28 days according to EN 1015-10 (722400), Test methods for mortars for masonry – Part 10: Determination of volume weight of dry hardened mortar. The values obtained for the volume weights are summarized in Table 9 and then evaluated in the bar graph in Figure 1 for each individual mixture consisting of the residues after separation from the respective mine deposit together with the respective water and a fly ash-based binder activated by grinding.

Resulting measured values on 40 × 40 × 160 mm solids samples for which the strength tests were evaluated in the time intervals 2, 7 14, 28, 56 and 90 days according to EN 1015-11 (722400), Test methods for mortars for masonry – Part 11: Determination of tensile flexural and compressive strength of hardened mortars. The achieved strength test values are summarized in Table 10 and Table 11 and then evaluated in the bar charts in Figure 2 and Figure 3 for each individual mix consisting of the residue after separation from the respective mine deposit together with the respective water and a fluidized fly ash-based binder activated by grinding.

The results of the fundamental mechanical properties of the backfill mixtures, determined on selected formulations with very high-water coefficient, showed that it is possible to prepare relatively fluid mixtures with extremely low binder dosage. Not only the water coefficient but also the granulometry of the raw material plays an important role in the long-term strengths. Here, the flotation waste is in principle significantly handicapped, however, at least minimum strengths were achieved here as well. The fluidity was ensured only by the water coefficient without the addition of thickening or plasticizing additives. These agents were deliberately not used here, as they would have made the whole technology significantly more expensive. The effect of the acidic mixing water on the mechanical properties did not show any significant effect and for this reason can be considered suitable

	Amount [g]	Resulting consistency [mm]
CEN Standard Sand EN 196-1	1 350	
Demineralized water	250	Spillage 180/180
Fly Ash	225	

Table 6. Proposed reference recipe for the mortar mixture.

	Cínovec [g]	Zlaté Hory [g]
Tailings	1 350	1 350
Demineralized water	420	580
Fly Ash	225	225

Table 7. Proposed recipes for the mortar mixture with demineralized water.

	Měděnec [g]	Cínovec [g]	Zlaté Hory [g]
Tailings	1 350	1 350	1 350
Fly Ash	225	225	225
Demineralized water	420 (Water Cínovec)	420 (Water Cínovec)	620 (ZH Acidic) 620 (ZH Alkaline)

Table 8. Proposed recipes for the mortar mixture with the use of post-mining water.

	After 2 Days	After 7 Days	After 14 Days	After 28 Days
Reference	1 900	1 950	1 970	1 990
Cínovec + Demi.W.	1 700	1 730	1 800	1 810
Zlaté Hory + Demi.W.	1 620	1 760	1 750	1 770
Cínovec	1 780	1 690	1 730	1 750
Měděnec	2 040	2 170	2 110	2 150
Zlaté Hory + Acidic W.	1 770	1 760	1 720	1 750
Zlaté Hory + Alkaline W.	1 850	1 850	1 790	1 860

Table 9. Achieved volumetric weights of given recipes.

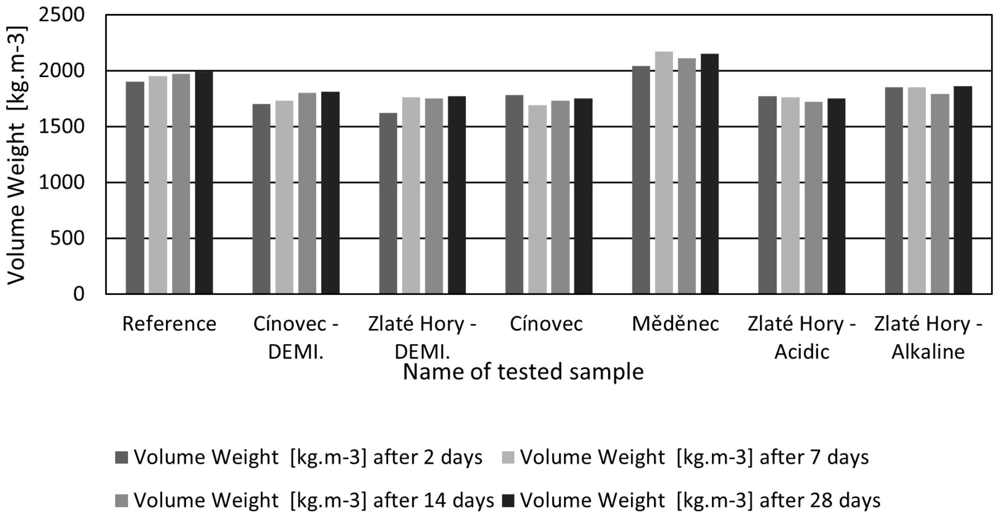

Figure 1. Graph showing the volume weights from Table 9 of the tested samples at 2, 7, 14 and 28 days.

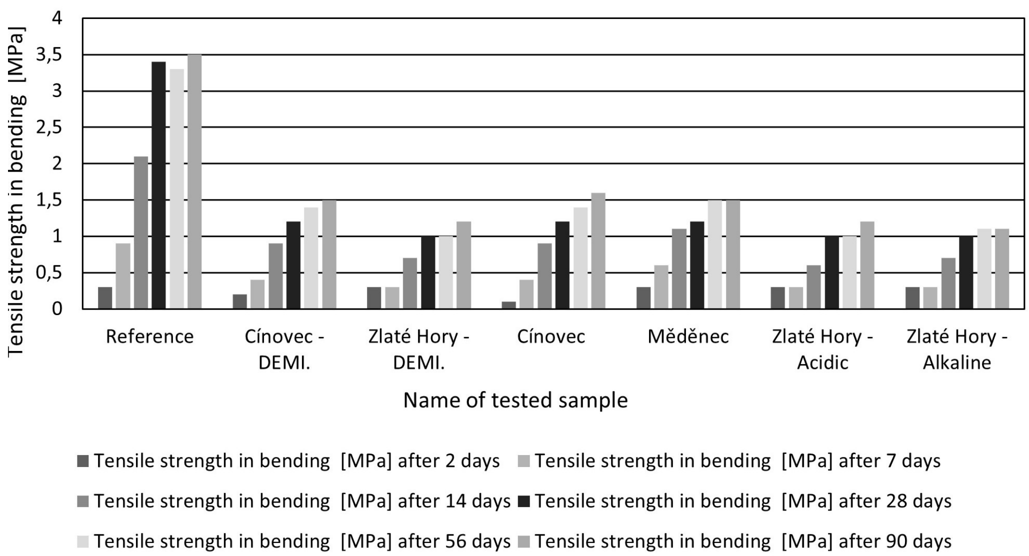

Figure 2. Graph showing the tensile strength in bending from Tables 10 and 11 of the tested samples at 2, 7, 14 and 28, 56 and 90 days.

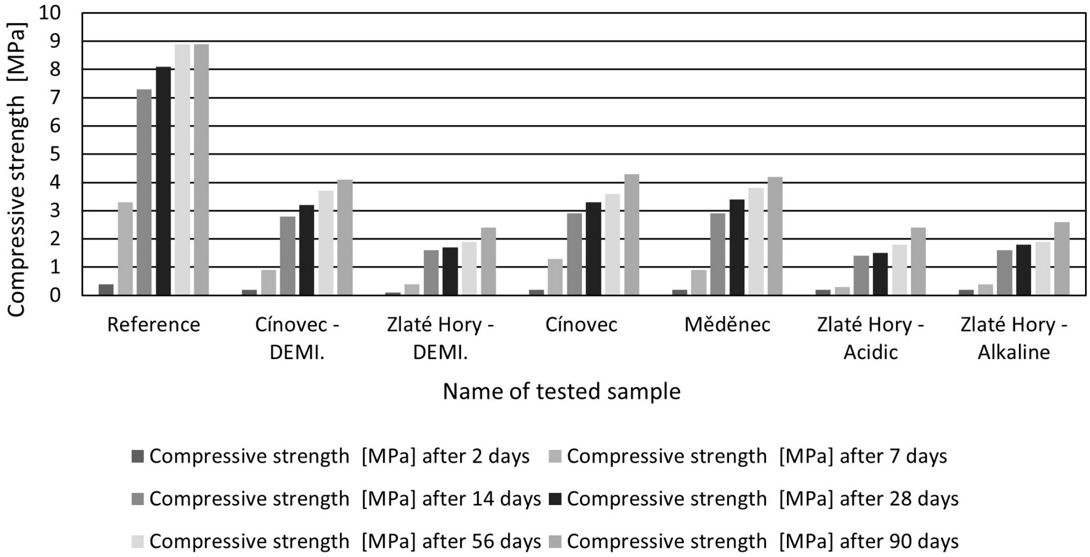

FIGURE 3. Graph showing the Compressive strength from Tables 10 and 11 of the tested samples at 2, 7, 14 and 28, 56 and 90 days.

	Properties [MPa]	**Reference**	**Cínovec + Demi.W.**	**Zlaté Hory + Demi W.**
2 days	Tensile strength in bending	0.3	0.2	0.3
	Compressive strength	0.4	0.2	0.1
7 days	Tensile strength in bending	0.9	0.4	0.3
	Compressive strength	3.3	0.9	0.4
14 days	Tensile strength in bending	2.1	0.9	0.7
	Compressive strength	7.3	2.8	1.6
28 days	Tensile strength in bending	3.4	1.2	1.0
	Compressive strength	8.1	3.2	1.7
56 days	Tensile strength in bending	3.3	1.4	1.0
	Compressive strength	8.9	3.7	1.9
90 days	Tensile strength in bending	3.5	1.5	1.2
	Compressive strength	8.9	4.1	2.4

TABLE 10. Achieved volumetric weights of given recipes.

	Properties [MPa]	**Cínovec**	**Měděnec**	**ZH + Acidic W.**	**ZH + Alkaline W.**
2 days	Tensile strength in bending	0.1	0.3	0.3	0.3
	Compressive strength	0.2	0.2	0.2	0.2
7 days	Tensile strength in bending	0.4	0.6	0.3	0.3
	Compressive strength	1.3	0.9	0.3	0.4
14 days	Tensile strength in bending	0.9	1.1	0.6	0.7
	Compressive strength	2.9	2.9	1.4	1.6
28 days	Tensile strength in bending	1.2	1.2	1.0	1.0
	Compressive strength	3.3	3.4	1.5	1.8
56 days	Tensile strength in bending	1.4	1.5	1.0	1.1
	Compressive strength	3.6	3.8	1.8	1.9
90 days	Tensile strength in bending	1.6	1.5	1.2	1.1
	Compressive strength	4.3	4.2	2.4	2.6

TABLE 11. Achieved strength properties of the formulations with mine waters.

for these backfill mixtures without a static function.

4. Conclusion

In conclusion, it can be stated that:

- According to the measured results, it can be concluded that it is possible to prepare relatively well-flowing mixtures with very high-water coefficients without the addition of plasticizers and with extremely low dosage of binder based on fly ash mixtures under placement conditions without static function.
- FBC fly ash appears to be a promising binder for the preparation of backfill mixtures.
- The presence of free lime in fly ash can compensate for the significantly lower pH of the mine water.
- The lower pH of the water used to produce the tailing mixtures did not have a negative effect neither on volume weights nor strength in bending nor Compressive strength of the tested samples in given times.
- It will thus be possible to use untreated mine water to produce mixtures.

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