Comparison of physical and mechanical properties of mining waste with a grain size up to 2 mm reinforced with cement CEM I and CEM III

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Abstract. The article presents the results of tests for mining waste mixtures - cement. The addition of cement was aimed at limiting the leaching of fine particles and improving physical and mechanical parameters. The studies used cement CEM I 42.5 R and CEM III/ A 42.5N - LH / HSR / NA and plasticizing sealant. The paper presents the results of freeze resistance, swelling tests, pH of water leachate and oedometer soil testing.

Keywords: mining waste, mining waste mixtures - cement

1 Introduction

The rationale for the article is the need for management mining waste from hard coal mines. Mining wastes arise as a west in the exploration and extraction of hard coal. The stored mining waste creates anthropogenic forms of land surface formation. For 40 years, mining waste from various types of mines has been used to build earthworks for flood and road embankments [1-3,7-8]. One of the characteristic features of this waste is its low resistance to physical weathering.

The results of the research presented in the article were a continuation of the study and complementing the work [4-5]. The tests were aimed at checking and optimal indication of the best mixture of mining waste - cement.

In order to improve the physical and mechanical properties, it was proposed to stabilize the material with cement. Cement stabilization is also aimed at limiting the leaching of fine particles from the material when using material for the construction of flood embankments. The mining waste was stabilized with Portland cement CEM I 42.5 R and cement CEM III / A 42.5N - LH / HSR / NA and plasticizing sealant. Portland cement CEM I 42.5 R contains from 95 - 100% Portland clinker and up to 5% calcium sulphate binding time regulator. The main component of cement CEM III / A 42.5N - LH / HSR / NA is ground Portland clinker (35 ÷ 64%), granulated blast furnace slag (36 ÷ 65%) and calcium sulphate binding time regulator (up to 5%). It is characterized by low hydration heat (LH), high resistance to alkaline corrosion (NA) and high resistance to corrosive agents (HSR). For research purposes, also plasticizer sealing concrete and mortar were used to seal and waterproof Soudaproof IW. The Soudaproof IW sealing plasticizer is used for structural concrete which must withstand the external pressure of water, and for retaining walls, underground storeys, basements, foundations, patios, etc.

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2 The procedure of sample preparation and description of the tests carried out

The research results presented in the article were made for mining waste with a grain size up to 2.0 mm. The material consists of kernels of claystones, rock crumbs and 10% carbon and up to 5% sulphur. According to ISO-4 [9] the material consists of 18-23% of the silt and clay fraction and 77-82% of the sand fraction. The mining waste is equidistant (U=4,75). The material is suitable for stabilization with cementitious binder [11-12].
Samples were prepared for the tests:

- without added cements (ZG S1),
- with the addition of 8% Portland cement CEM I 42.5 R, with a diameter of 70.0 mm and a height of 35.0 mm (ZG S1 + 8% CEM l),
- with the addition of 8% Portland cement CEM I 42.5 R, dimensions 100.0 x 100.0 x 50.0 mm (ZG S1b + 8% CEM l),
- with the addition of 5% Portland cement CEM I 42.5 R and plasticizer Soudaproof IW in a proportion of 1.3 L / 100.0 kg of cement, 70.0 mm in diameter and 35.0 mm in height (ZG S1 + 5% CEM l + P),
- with the addition of 5% Portland cement CEM I 42.5 R and the Soudaproof IW plasticizer in a proportion of 1.3 L / 100.0 kg of cement, size 100.0 x 100.0 x 50.0 mm (ZG S1b + 5% CEM l + P),
- with the addition of 5% CEM III / A 42,5N - LH / HSR / NA metallurgical cement, 70.0 mm diameter and 35.0 mm height (ZG S1 + 5% CEM III),
- with the addition of 5% CEM III / A 42.5N - LH / HSR / NA, size 100.0 x 100.0 x 50.0 mm (ZG S1b + 5% CEM III)
- with the addition of 10% CEM III / A 42,5N - LH / HSR / NA metallurgical cement, 70.0 mm diameter and 35.0 mm height (ZG S1 + 10% CEM III),
- with the addition of 10% CEM III / A 42.5N - LH / HSR / NA, size 100.0 x 100.0 x 50.0 mm (ZG S1b + 10% CEM III)

In order to perform the test samples for each mix mining waste - cement, underwent determination of the optimum moisture content and maximum dry density of solid particles. The optimum moisture content for mining waste (ZG S1) was determined according [10] by method I, and it is 13.3% and $\rho_{dmax} = 1.87$ g/cm^3, for mining waste with cement CEM I 12.3% and $\rho_{dmax} = 1.88$ g/cm^3, cement CEM III – 12.1%, $\rho_{dmax} = 1.89$ g/cm^3.

The samples were concentrated in thin layers to the degree of compaction Is from 0.93 to 0.97, the moisture content in the range of 0.7 - 1.15 moisture content. Attempts with cement additions were secured against moisture loss for 28 days of setting, then tested for frost resistance, swelling, oedometer test and samples of water leachate for testing pH.

2 The physical properties of a mixture of mining waste - cement

2.1 Swelling index

For mixtures of coal waste with the addition of hydraulic binder – cement the indicator of free swelling was determined Ep according to G.W Olson [6]. The free swelling index is the percentage increase in the soil sample height. Figure 1 shows the course of the swelling tests for mining waste ZG S1, ZG S1 + 8% CEM l, ZG S1+5% CEM I + P, ZG S1 +5% CEM III [5] and ZG S1 +10% CEM III.

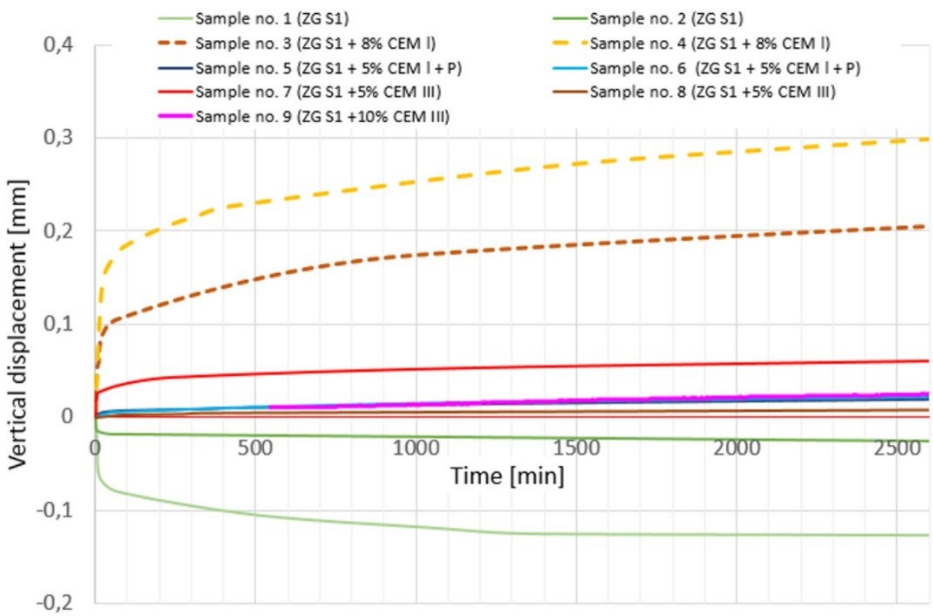

Fig. 1. The chart of swelling of mining waste and mixtures of mining waste - cement.

Table 1. Swelling ratio for mining waste with cement determined according to G.W. Olson, *[5]

Sample number	Swelling index Ep [%]		
	After 10 minutes	After 60 minutes	After 2500 minutes
Sample no. 1 (ZG S1)*	-0.04	-0.21	-0.34
Sample no. 2 (ZG S1)*	-0.02	-0.05	-0.06
Sample no. 3 (ZG S1 + 8% CEM I)*	0.20	0.28	0.54
Sample no. 4 (ZG S1 + 8% CEM I)*	0.15	0.46	0.81
Sample no. 5 (ZG S1 + 5% CEM I + P)*	0.01	0.02	0.05
Sample no. 6 (ZG S1 + 5% CEM I + P)*	0.004	0.02	0.05
Sample no. 7 (ZG S1 + 5% CEM III)*	0.05	0.09	0.16
Sample no. 8 (ZG S1 + 5% CEM III)*	0.004	0.007	0.02
Sample no. 9 (ZG S1 + 10% CEM III)	0.004	0.02	0.05

According to the classification of the free swell index Ep G.W. Olson, the swelling of the mixtures is very low. In the case of a mining waste mix + 8% CEM I, the chart could have seen faster and larger grinding. The sample with the addition of 10% CEM III cement did not show a clear difference in swelling compared to the 5% CEM III addition. In the case of mining waste without cement additives, after the sample was saturated with water, the sample height decreased.

2.2 Freeze resistance test

The freeze resistance test was carried out according to the [10] standard method - Simple method. After 28 days after the formation of mining waste with cement, the samples were immersed in water for seven days. After saturation with water, the samples were frozen in air at -18 ° C for 6 hours. The samples were thawed in water at a temperature at

18 ° C for 3 hours. The freezing - thawing process was discontinued when clear cracks and cracks appeared on the sample or the percentage loss in mass was more than 5%.

Table 2 presents the results of frost resistance tests. For sample ZG S1 + 8% CEM l, ZG S1+5% CEM I + P, ZG S1 +5% CEM III discussion of the results and photographs are presented in the paper [5]. In the case of mining waste with the addition of 10% CEM III cement, a decrease in the sample weight of more than 5% was noted after a sixth cycle. The tests showed no scratches or cracks, only jagged edges were observed (fig. 2). Increasing the CEM III cement content from 5% to 10% in relation to the skeleton weight resulted in twice the frost resistance.

Fig. 2. Sample of mining waste with the addition of 10% CEM lll cement before (A) and after 6 cycles of freezing – thawing (B).

Table 2. Test of freeze resistance of mining waste reinforced with cements according to PN-B-06265 "Simple method".*[5]

Sample number	Number of cycles of freezing - thawing	Average weight loss
ZG S1b +8% CEM*	I	100%
ZG S1b +5% CEM I +P*	I	80.26%
ZS S1b +5% CEM III*	III	9.43%
ZG S1b +10% CEM III	VI	14.56%

2.3 PH of the water leachate

The graph (fig. 3) presents the results of testing the pH of water flowing through a mining waste or a mixture of mining waste - cement. In the case of the test with no added cement, it was observed that the water is cloudy and contains small particles of waste. (fig 4). The water section from the mining waste samples with the addition of cement was free of fine particles and had a more alkaline pH. For the tests, a standard pH water with pH 8 was used. According to the ordinance of the Minister of the Environment [13], the value of 6.5 - 9 pH is allowed.

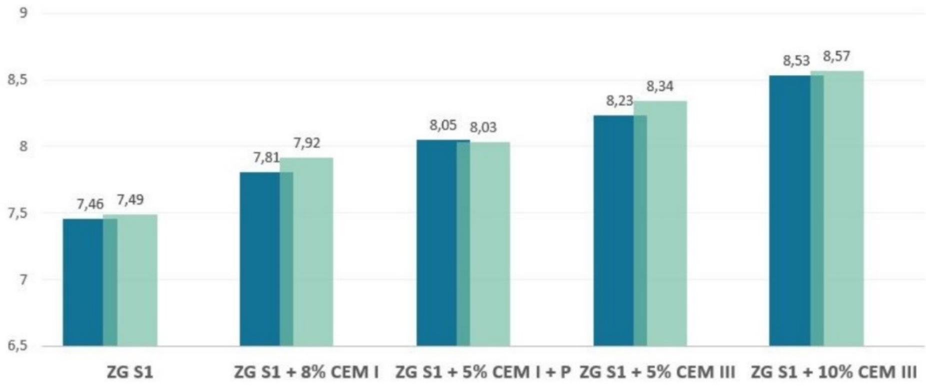

Fig. 3. Diagram of the pH of water leachates from mining waste.

Fig. 4. Water leachate from mining waste ZG S1.

3 The mechanical properties of a mixture of mining waste – cement

3.1 Oedometer examination of mining waste and mixtures of mining waste - cement

The oedometer examination was performed according to the standard [9]. Mining waste ZG S1 compacted to degree of compaction $I_s = 0.93$. The graph (fig. 5) shows the stress curve - stress relief and re-load in the range from 0 to 400 kPa. The average modulus of oedometric modulus of primary compression M_0 in the range from 0 to 100 kPa was 4.31 kPa. The average secondary oedometric modulus of compression in the range from 0 to 100 kPa was 22.92 kPa. (table 3).

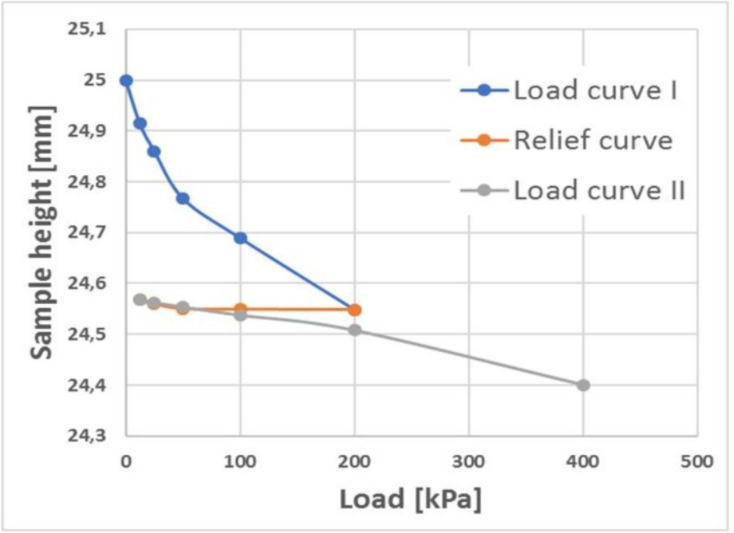

Fig. 4. Graph of change in the height of the sample from the load for the ZG S1.

Fig. 5 shows the compressibility curves for the tests ZG S1 +5% CEM I +P, ZG S1 +5% CEM III and ZG S1 +10% CEM III. Attempts to compaction from the degree of compaction $I_s = 0.93 - 0.97$. Table 3 shows the average modulus of initial compressibility M_0 and the modulus of the second compressibility M in the interval from 0 to 100 kPa.

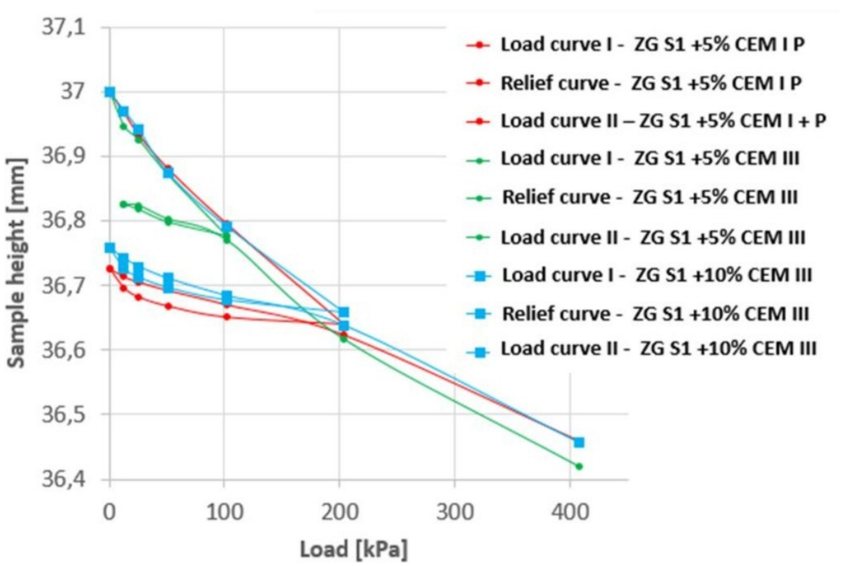

Fig. 4. Graph of the change in the sample height from the load for a sample of mining waste with cement CEM I I CEM III

Table 3. Module of primary compressibility and secondary mining waste test ZG S1 and mixtures mining waste - cement

	Average modulus of primary compressibility Mo [MPa]	Average modulus of secondary compressibility M [MPa]
Load range	σ [0 – 100 kPa]	σ [0-100 kPa]
ZG S1	4.31	22.92
ZG S1 + 8% CEM I	12.20	34.07
ZG S1 + 5% CEM I + P	18.50	66.91
ZG S1 + 5% CEM III	17.0	69.57
ZG S1 + 10% CEM III	18.15	50.67

Summary and conclusions

The presented test results showed that the use of cement improved physical and mechanical properties of mining waste with a grain size up to 2.0 mm. The main purpose of adding a cement binder was to reduce leaching of the material particles, reduce water permeability and swelling, and increase the modules of primary and secondary compressibility. Table 4 summarizes the performed tests. The "++" sign indicates the result being the best in a given category. With the "+" sign the result was the second in order.

Table 4. Comparison of performed tests for mining waste with the addition of cement CEM I and CEM III

Sample number	**Frost resistance**	**Mo [MPa]**	**M [MPa]**	**Ep [%] after a day**	**pH of the water leachate**
ZG S1					++
ZG S1 + 8% CEM I				+	+
ZG S1 + 5% CEM I + P		++	+	++	+
ZG S1 + 5% CEM III	+		++	+	+
ZG S1 + 10% CEM III	++	+		+	+

The addition of CEM I cement caused the elimination of fine particles from the material to stop. The mixture did not show frost resistance. The addition of CEM I and plasticizer cement resulted in a marked increase in the value of the first and second compressibility modulus. The addition to the plasticizer for mining waste with cement CEM I significantly reduced swelling. The addition of CEM III cement significantly improves the morosistance of the mix, stops the leaching of fine particles. The higher the CEM III cement content, the better the resistance. The results of oedometer tests showed that increasing the addition of CEM III cement from 5% to 10% did not affect the improvement of mechanical properties and limitation of swelling.

The results of the research presented in the article indicate that mixtures of mining waste with grains up to 2 mm with cement CEM III show more favorable physical and mechanical parameters.

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