Study of the strength dependence of concrete for mine construction on the content of coal mining waste in it

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Abstract. The possibility of using coal mining waste in mine concrete mixing is considered in the article. As a result of the research, scientific and practical results have been obtained that make it possible to evaluate the strength properties of mine concrete, depending on the content of coal dust particles - the waste of mining - in it. It has been experimentally proven that when a fine fraction of coal is added to mine concrete, the strength of concrete decreases at a certain ratio, but this strength is sufficient to ensure the required properties. As a result of the experiments, samples of concrete for mine construction were manufactured, into which a fine fraction of coal - coal dust - was added in various ratios. A series of mine concrete tests was carried out to determine its physical and mechanical properties; the optimal composition was determined, which provides process and strength performance of the mixture. The conclusions have been drawn about the quantitative content of a fine fraction of coal in mine concrete, which make it possible to maintain process performance of the mixture and the strength of structures.

1 Introduction

The environmental pollutions is one of the most discussed and relevant issues in modern society [1-3]. Due to the fact that the world's population is steadily growing, the need for resources, energy, etc. is also increasing. In this situation, a huge number of problems arise associated with environmental pollution due to intensive mining, the generation of a huge amount of waste as a result of human activities. Many problems require an integrated approach that can allow them to be solved without the use of additional resources by improving existing processes. One of the main examples of solutions to the problem is the use of waste as a secondary resource for industry [4-7].

The main source of waste and environmental problems in the Kemerovo region - Kuzbass is the coal industry [8-9], since there are large deposits of coal. Annual coal production in Kuzbass is more than 200 million tons. With such production rate and with an increase in mining volumes, it is necessary to mine new deposits by means of underground

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or open-cut method, which also requires additional resources, building materials, the production of which also has a negative impact on the environment. Under these conditions, the governor of the Kemerovo Region - Kuzbass has approved the new eco standard - "Clean Coal - Green Kuzbass", and scientists conduct a lot of researches in this field aimed at reducing the negative impact of coal mining on the environment [10-12].

In mine construction, as well as in underground mining, a large amount of concrete is required [13-14], which is mixed directly in the mine or above-ground and conveyed down. Certain labor costs are required to supply materials to the mine, which are comparable to those of coal and waste rock raising. In addition to commercial fractions of coal, a fine fraction - dust - is formed during underground mining. It is not used in industry and has no value for consumers. Its raising from the mine is not advisable, but at the same time it interferes with further mining operation when stored inside the mine. In mine construction, the use of coal mining waste (coal dust) for concrete mixing allows to reduce the consumption of concrete and raw materials supplied into the mine, and also to reduce the amount of coal dust to be raised from the mine.

Due to the fact that mine concrete should provide certain process and strength performance, it is necessary to study this issue in more detail conducting experiments and determining its optimal compositions.

The purpose of this work is to design the composition of the mixture for concrete lining with the use of coal as a filler, to study process and strength performance of this building material.

2 Research methods

When coal dust interacts with concrete mixing water, chemical reactions occur to form various acids (for example, carbonic acid). Carbonic acid actively interacts with calcium hydroxide formed during cement hydration. As a result of this chemical reaction, various salts - carbonates - are formed, slowing down the concrete mixture hardening process. For mixing concrete using coal dust, it is required to use special types of hydraulic binders with enhanced properties, for example, resistance to carbonate corrosion.

At the first stage of the experiments, the concrete composition was designed and its setting time was studied. The influence of liquid glass admixture on the strength properties of concrete and the setting time of the mixture were determined. The results obtained at the first stage of the experiment are described in detail in [15]. In this work, we study the strength properties of mine concrete with the addition of a fine fraction of coal as a filler, with UGM-70 and UGM-U mixtures as a binder.

To determine the compression and bending strength, samples with dimensions of 4×4×16 cm were made from UGM-70 binder mixture (Fig. 1). Ratios of binder (Bin1) to coal (C) in percent Bin1/C were as follows: 100/0, 90/10, 85/15, 80/20, 70/30, 60/40, 50/50, 40 / 60; 30/70, 20/80.

With an increase in the amount of coal, the mixture workability increased; therefore, the W/S (W - water, S - solid mixture of binder and coal) ratio was being decreased, starting from a ratio of 70/30. At a ratio of 20/80, the mixture workability significantly reduced.

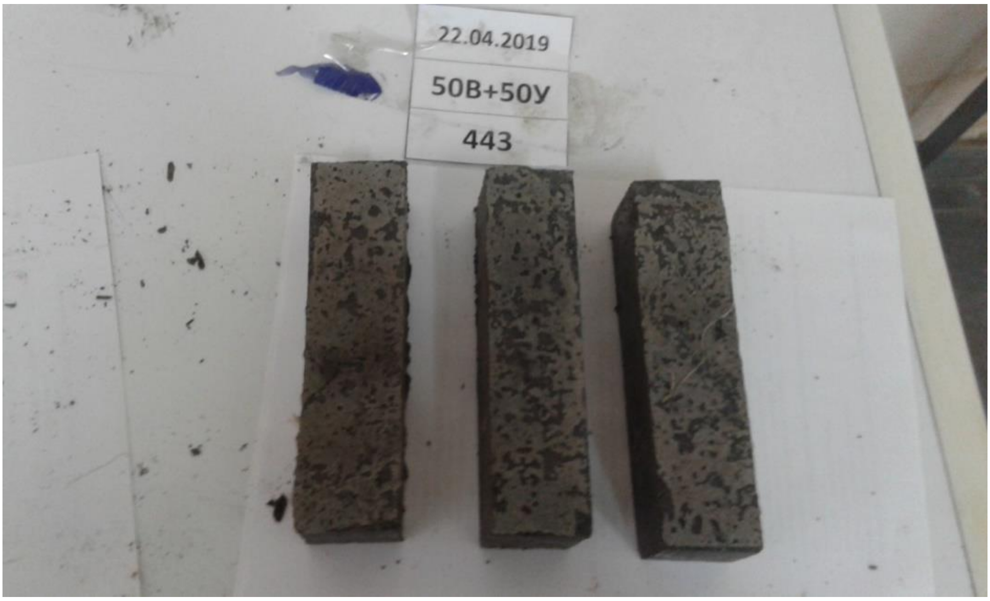

Fig. 1. The samples made from UGM-70 binder mixture and a fine fraction of coal in a 50/50 ratio

The mixture components were dosed by weight and the dry components were mixed for five minutes. Then the mixing water was added in full and the mixture was mixed for another five minutes. Then the mixture was placed in a mold and compacted on a vibrating platform. After compaction, the samples were stored under normal conditions for 3 or 7 days.

The bending and compression strength was determined by destructive methods on an MII-100 testing machine and a PSU-10 hydraulic press. The strength of concrete mixtures was determined in accordance with the State Standard GOST 310.4-81. "Cements. Methods of bending and compression strength determination" on samples with dimensions of 4×4×16 cm.

3 Results and discussion

To study the structure of the mine concrete made from UGM-70 mixture and a fine fraction of coal, a test cube with dimensions of 100x100x100 mm was made, which was subsequently sawn into 2 halves and polished (Fig. 2), so that you can visually see the structure of concrete, the arrangement of the aggregate's particles and space between coal particles filled with UGM-70 binder.

The results obtained in the course of experiments to determine the strength of the samples with different ratios of components are presented in Table 1 and Table 2.

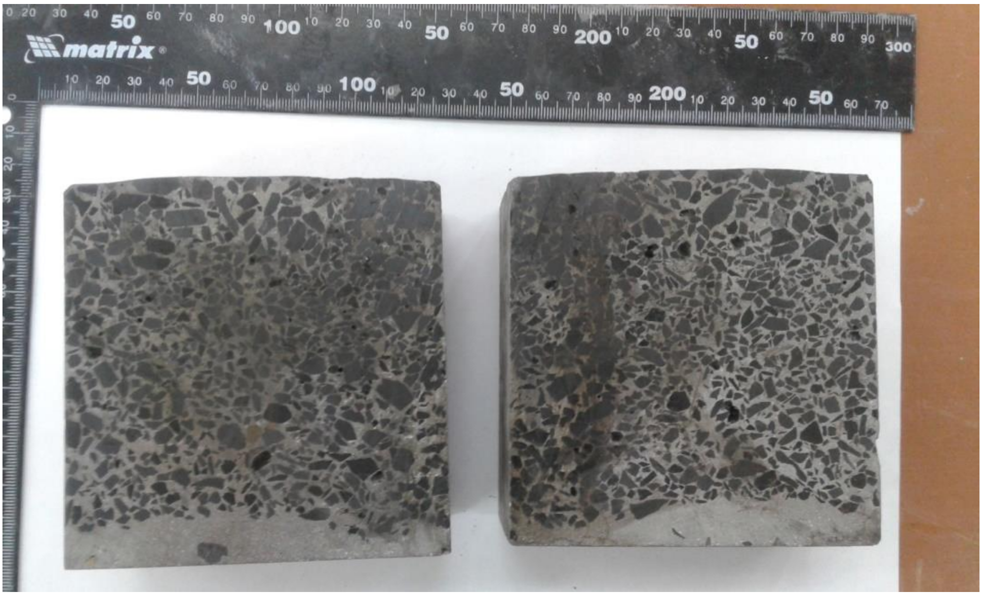

Fig. 2. The test sample sawn in half

Table 1. Bending and compression strength of the samples made from UGM-70 binder mixture at 3 days (W/S = 0.24)

The sample grade	Ultimate bending strength				Breaking load, kg		Ultimate compression strength			
	Reference samples		90+10 samples		Reference samples	90+10 samples	Reference samples		90+10 samples	
	kg/cm²	MPa	kg/cm²	MPa			kg/cm²	MPa	kg/cm²	MPa
1	56.5	5.5	44.3	4.3	4280	4640	171.2	16.8	185.6	18.2
1′					4460	4080	178.4	17.5	163.2	16.0
2	60.5	5.9	56.5	5.5	4560	4840	182.4	17.9	193.6	19.0
2′					4540	4680	181.6	17.8	187.2	18.4
3	53.4	5.2	53.5	5.2	5240	4640	209.6	20.5	185.6	18.2
3′					4800	4220	192	18.8	168.8	16.5
Average value	56.8	5.6	51.4	5.0			185.9	18.2	180.7	17.7

Table 2. Bending and compression strength of the samples made from UGM-70 binder mixture with the addition of coal at 3 days

Admixture amount	Water-solid ratio	Grade	Ultimate bending strength, MPa	Average value, MPa	Breaking load, kg	Ultimate compression strength, MPa	Average value, MPa

0	0.240	100/0 (1)	6.90	6.23	7440	6760	29.18	26.51	28.04
		100/0 (2)	5.91		7020	6860	27.53	26.90	
		100/0 (3)	5.86		7140	7680	28.00	30.12	
10	0.240	90/10 (1)	5.21	5.51	7060	6780	27.69	26.59	27.34
		90/10 (2)	1.25		6700	6680	26.27	26.20	
		90/10 (3)	5.82		7150	7460	28.04	29.25	
15	0.240	85/15 (1)	5.52	5.89	6440	5800	25.25	22.75	24.58
		85/15 (2)	1.08		6280	7180	24.63	28.16	
		85/15 (3)	6.26		6160	5740	24.16	22.51	
20	0.240	80/20 (1)	5.47	5.25	4320	4580	16.94	17.96	20.07
		80/20 (2)	5.48		5880	5560	23.06	21.80	
		80/20 (3)	4.79		5000	5360	19.61	21.02	
30	0.229	70/30 (1)	4.16	3.90	4060	4220	15.92	16.55	17.14
		70/30 (2)	3.25		!2600	4640	10.20	1820	
		70/30 (3)	4.29		4540	4390	17.80	17.22	
40	0.225	60/40 (1)	3.18	3.29	2760	3100	10.82	12.16	13.61
		60/40 (2)	3.32		3880	3600	15.22	14.12	
		60/40 (3)	3.38		4050	3440	15.88	13.49	
50	0.222	50/50 (1)	2.92	2.91	2780	2180	10.90	8.55	11.33
		50/50 (2)	2.88		3180	3400	12.47	13.33	
		50/50 (3)	2.94		2930	2860	11.49	11.22	
60	0.218	40/60 (1)	2.14	2.20	2170	1850	8.51	7.25	8.93
		40/60 (2)	2.28		2370	2420	9.29	9.49	
		40/60 (3)	218		2490	2370	9.76	9.29	
70	0.214	30/70 (1)	1.65	1.46	1450	1280	5.69	5.02	5.48
		30/70 (2)	1.25		1410	1290	5.53	5.06	
		30/70 (3)	1.50		1480	1480	5.80	5.80	
80	0.210	20/80 (1)	0.76	0.78	690	700	2.71	2.75	2.72
		20/80 (2)	0.81		665	680	2.61	2.67	
		20/80 (3)	0.77		695	725	2.73	2.84	

The results obtained showed that the admixture of coal in any amount reduces the compressive and bending strengths. Samples without the admixture of coal had the maximum strength. Their ultimate bending strength was 6.23 MPa, and the ultimate compression strength - 28.04 MPa. The ultimate bending strength decreases uniformly and linearly with an uniform increase in the amount of coal, and with the addition of coal in the amount of 80%, it decreases to 0.78 MPa. The behavior of the ultimate compression strength is more complicated. The table shows unevenness when adding coal in the amount of 10 and 20%. This is due to the fact that during sample mixing, two factors were changed - the ratio between the binder mixture and coal, as well as the water-solid ratio, which has a major effect on the compression strength of concrete. Further change in strength proceeds evenly, and decreases to 2.72 MPa with the addition of coal in the amount of 80%.

Based on the studies carried out, it can be concluded that the optimal ratio between UGM-70 binder mixture and coal is 40/60, respectively.

Further studies were carried out with UGM-U mixture. When making samples from UGM-U binder mixture, the ratio between the parts of binder (Bin2) and coal (C) in percent Bin2/C was as follows: 60/40, 50/50, 40/60, 30/70, 20/80. The concrete mixture was mixed similarly to the mixture using UGM-70 binder. Vibration compaction was not used when molding the samples. When testing the samples, some concrete segregation was observed at Bin2/C ratios of 60/40, 50/50, 40/60 (Fig. 3). This is due to the high workability of the mixture. With a decrease in the amount of mixing water, the segregation degree will decrease, and the concrete strength will increase. The results of determining the bending and compression strength are given in Table 3.

Fig. 3. Sample segregation under compressive strength testing

Analysis of the results obtained showed that the effect of adding coal to concrete when using UGM-U mixture also reduces the compression and bending strength. Without the use of coal, the samples had a bending strength of 9.98 MPa and a compression strength of 32.61 MPa. The behavior of bending strength is linear. The compression strength behavior is non-linear with 70% coal admixture. With an increase in the coal admixture to 80%, the ultimate bending strength decreased to 0.84 MPa, and the ultimate compression - strength decreased to 1.57 MPa.

Table 3. Bending and compression strength of the samples made from UGM-U binder mixture with the addition of coal at 7 days

Admixture amount	Water-solid ratio	Grade	Ultimate bending strength, MPa	Average value, MPa	Breaking load, kg	Ultimate compression strength, MPa	Average value, MPa

40	0.225	60+40 (1)	4.79	4.70	4400	4870	17.25	19.10	16.58
		60+40 (2)	4.68		5020	3680	19.69	14.43	
		60+40 (3)	4.62		3220	4180	12.63	16.39	
50	0.222	50+50 (1)	3.49	3.61	2740	3580	10.75	14.04	13.12
		50+50 (2)	3.53		3340	4110	13.10	16.12	
		50+50 (3)	3.81		3050	3260	11.96	12.78	
60	0.218	40+60 (1)	2.95	2.84	2810	2110	11.02	8.27	9.29
		40+60 (2)	2.73		2230	2440	8.75	9.57	
		40+60 (3)	2.83		2420	2210	9.49	8.67	
70	0.214	30+70 (1)	1.72	1.76	1300	1160	5.10	4.55	3.58
		30+70 (2)	1.93		890	890	3.49	3.49	
		30+70 (3)	1.64		106	1130	0.42	4.43	
80	0.210	20+80 (1)	0.85	0.84	400	450	1.57	1.76	1.57
		20+80 (2)	0.89		410	440	1.61	1.73	
		20+80 (3)	0.77		340	360	1.33	1.41	

Comparison of the strength of UGM-70 and UGM-U concrete mixtures is shown in Fig. 4.

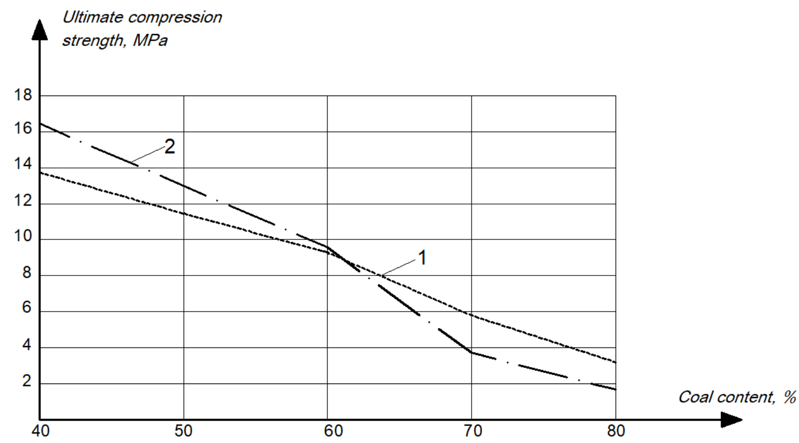

Fig. 4. The compression strength of concrete samples versus the coal content when using UGM-70 (1) and UGM-U (2) mixtures

The analysis of the compression strength of samples based on UGM-70 and UGM-U binder mixtures showed that their change in the ultimate compression strength have a similar behavior with the same change in the water-solid ratio. With the addition of coal in an amount of 40%, the ultimate strength of the UGM-U mixture samples is 23% higher than that of the UGM-70 mixture samples.

With a further increase in the coal admixture, the difference in the ultimate strength decreases, and with the addition of coal in an amount of 60%, it is 4%. With a further increase in the amount of coal admixture, the ultimate strength of UGM-70 mixture samples is greater than that of the UGM-U mixture samples.

Subsequent research can be aimed at optimizing the concrete composition and performance. It should be noted that the use of coal as an aggregate can lead to internal corrosion of concrete; therefore, further research on the durability and corrosion resistance of concrete is an important issue.

4 Conclusions

According to the results of the study, it was found that it is possible to admix coal mining waste to the composition of UGM70 and UGM-U mixtures without reducing their properties and performance.

The admixture of coal to UGM-70 and UGM-U mixtures reduces the bending and compression strength for all the tested ratios of coal to binder mixtures. With a ratio of binder mixture to coal of 40/60, the ultimate compression strength (at 7 days) for UGM-70 mixture was 8.9 MPa, for UGM-U mixture - 9.29 MPa. This ratio can be considered optimal. A further increase in the amount of coal leads to a sharp increase in the water requirement of the mixture and a decrease in the strength. UGM-U concrete mix has high workability and segregates during molding. A decrease in the amount of mixing water should lead to a decrease in the mixture segregation and an increase in its strength.

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