

Studies of the Possibility of Using Coal Mining Waste in Concrete for Mine Construction

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Abstract. The article discusses the possibility of using coal waste for the preparation of mine concrete. As a result of the research, scientific and practical results were obtained. It has been experimentally proved that when a small fraction of coal, which is a waste of coal mining, is added to mine concrete, the strength of concrete decreases, but with a certain ratio of this strength it is sufficient to ensure the required properties. A series of experiments was carried out with the addition of liquid glass to the concrete to control the setting time of the mixture. The properties of coal wastes were determined and the possibility of their use in mine concrete was investigated. It has been established that the introduction of a fine fraction of coal in the optimum quantity into the composition of mine concrete is possible without reducing technological parameters.

1 Introduction

Currently, environmental issues are becoming increasingly relevant in connection with the growth of minerals mining, the growth of the population generating waste all the time. Currently, many projects are being developed aimed at preserving the environment and nature [1-3]. An environmental issue requires the elimination of coal industry waste.

The Kemerovo region is one of the most developed industrial regions of the Russian Federation. A significant role in this region is played by the coal mining and processing industry. More than 250 million tons of coal are mined annually in Kuzbass and, as a result, the environmental load is increasing [4-6]. High emissions of harmful substances, pollution of air, water and soil (soil). In these conditions, the Governor of Kuzbass introduced the regional environmental standard "Clean Coal - Green Kuzbass". In the process of coal mining and preparation, large dumps of carbon-containing waste (coal fine) are formed [7-9], such waste are usually not used in the future. Their removal requires a very high expenditure of energy, and their storage occupies large areas of land used for dumps. A significant part of coal mining takes place in underground mines. In mine construction, for construction of shafts, drifts and headings, a large amount of special concrete is used [10-12] for the preparation of which large volumes of dry mix are lowered into the mine. The mixture has rather high strength characteristics and durability, but these requirements are justified only by the fact that technologically this mixture must gain strength very quickly to reduce the construction time of mines, but in the future high strength and long service life are not required, since the development of seams is carried out in a short time.

An urgent problem is the reduction in the use of dry mix for concrete preparation, which will reduce the cost of transportation, purchase, etc. The use of carbon-containing waste (a fine fraction of coal) in mine concrete will lead to a reduction in the amount of waste, energy used to lift dust from the mine, reduction of the cost of dry mix purchase and delivery to the mine for the preparation of mine concrete. The problem of using coal fines in concrete preparation has not been studied at the present level and requires detailed study, since when using coal fines in concrete, it is necessary to maintain the characteristics of the resulting mixture in order to maintain the safety of the structure. KuzSTU scientists conducted a large amount of laboratory research on the use of ash and other wastes in mine concrete [13-15], and also gained extensive experience in performing such experiments.

The aim of this work is to study the possibilities of using coal fines for the preparation of backfill mixtures in mine construction. The main task is to determine the optimal consumption of additives made of coal wastes, as well as liquid glass, to assess their effect on the strength characteristics and setting time of mine concrete.

2 Methods of research

During the interaction of coal with water, various acids (for example, carbonic) are formed, which interact with calcium hydroxide formed during the hydration of cement. In this case, various carbonates are formed causing the hardening process to slow down. For the manufacture of concrete using coal, it is necessary to use special types of binders that have increased resistance to carbonate corrosion.

This work presents the design of the concrete composition and the study of its properties with coal as a filler and mixtures of UGM-70 and UGM-U as a binder. In addition, studies of the designed concrete strength properties were carried out using liquid glass as an additive.

For the study, binders "UGM-70" and "UGM-U" were used. Both mixtures are poly-dispersed powders of iron-gray color, similar to cement, but looser. Coal for the manufacture of concrete is a loose granular bulk material with a bulk density of 950-1000 kg/m³, which is close to sand in particle size distribution. Sodium liquid glass that meets the requirements of GOST 13078-81 was used as an additive. The grain composition of coal was determined in accordance with GOST 8735-88 "Sand for construction work. Test Methods". A coal sample was sieved through a standard set of sieves with cells 5; 2.5; 1.25; 0.63; 0.315, and 0.16 mm.

The setting time of cementitious concrete mixes was defined as per GOST 310.3-76 "Cements. Methods for determining the normal density, setting time and uniformity of volume change" on a Vikat apparatus with a needle on the paste made of a mixture of a binder and water with $W/S = 0.24$.

The mobility of concrete mixtures was defined as per GOST 5802-86 "Building solutions. Test Methods" using the Mortar consistency measuring device (PGR) by the immersion depth of the reference cone.

The strength of concrete mixtures was defined as per GOST 310.4-81. "Cements. Methods for determining the ultimate strength in bending and compression" on samples with dimensions of 4×4×16 cm.

3 Results and Discussion

To determine the grain size distribution of coal, a sample weighing 5000 g was taken. A coal sample was sieved through a sieve with 5 mm holes to determine the content of gravel fractions (over 5 mm). The residue on sieve #5 by weight was 298 g (5.96%). To determine the grain composition, a sample weighing 1000 g was taken from the part of the coal screened

through sieve # 5. The coal was manually sieved through a standard set of sieves with cells 2.5; 1.25; 0.63; 0.315, and 0.16mm.

The increased content of dust particles (size less than 0.16 mm) can negatively affect the strength properties of the designed concrete mix.

To determine the setting time of binding mixtures, a sample of 400 g was taken. The water-solid ratio (W / S) was taken equal to 0.24. The start and end of setting time were defined on the Vicat device with a needle. The results are shown in Table 1.

Table 1. Setting time.

Mixture	Setting time, min	
	Start	End
UGM-70	160	220
UGM-U	50	55

To determine the mobility, a solution of a binder mixture with a volume of 4 l was prepared. To prepare the solution, 10.4 kg of the mixture and 2.496 kg of water were taken. Mobility was evaluated by immersion of a standard cone.

The mobility of the UGM-70 mixture was 10.5 cm, that of UGM-U mixture was 15 cm. The UGM-U mixture had much greater mobility, it easily flowed out of insignificant gaps in the formwork, and required additional sealing of the molds.

When testing mixtures, there was a difference in the dispersion of their constituent components. The particles that make up the UGM-70 mixture feel larger than the particles that make up the UGM-U mixture.

To determine the flexural and compressive strengths, specimens of 4×4×16 cm were manufactured.

The samples were prepared from UGM-70 and UGM-U mixtures. For the manufacture of samples 2000 g of the mixture and 480 g of water were taken. Water was added to the binder mixture, and then it was mixed for five minutes. Then the UGM-70 mixture was compacted on a vibrating table. The UGM-U mixture did not require compaction, since it easily filled the mold, flowed out from insignificant gaps in the formwork, and required additional sealing of the molds. The results of strength determination are shown in Fig. 1 and Table 2.

From the obtained studies, it follows that the strength of the UGM-70 mixture in the early stages of hardening is significantly lower than the strength of the UGM-U mixture. The flexural strength of UGM-U mixture at the age of 3 days is 67% higher, and its compression strength is 71% higher. In the subsequent periods of hardening, the intensity of the set strength of the UGM-U mixture decreases. At the age of 7 days, its flexural strength is higher by 60%, and in compression by 16%.

Table 2. The strength of the mixtures UGM-70 and UGM-U.

Mixture	Age, days	Grade	Flexural Strength, MPa	Average value, MPa	Breaking load, kg		Compressive strength, kg/cm ²		Average value, kg/cm ²
UGM-70	3	UGS-70-1	5.54	5.57	4280	4460	16.78	17.49	18.22
		UGS-70-2	5.93		4560	4540	17.88	17.8	
		UGS-70-3	5.24		5240	4800	20.55	18.82	
UGM-70	7	UGS-70-1	6.90	6.23	7440	6760	29.18	26.51	28.04
		UGS-70-2	5.91		7020	6860	20.47	26.9	
		UGS-70-3	5.86		7140	7680	28.0	30.12	
UGM-U	3	UGS-M-1	10.28	9.32	7800	8100	30.59	31.76	31.23
		UGS-M-2	8.97		8420	7220	33.02	28.31	
		UGS-M-3	8.71		7440	8800	29.18	34.51	
UGM-U	7	UGS-M-1	11.16	9.98	9830	7070	38.55	27.73	32.61
		UGS-M-2	9.28		8350	8600	32.75	33.73	
		UGS-M-3	9.50		7000	9050	27.45	35.49	

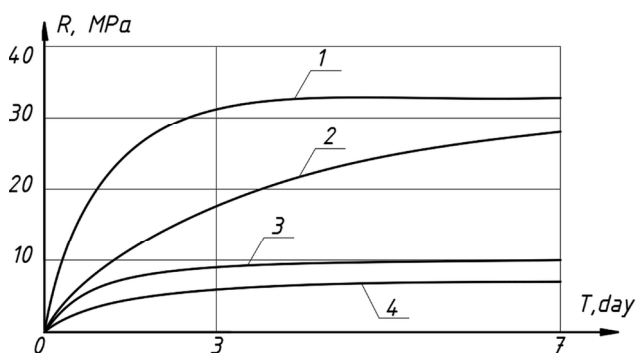


Fig. 1. Kinetics of strength development of mixtures UGM-70 and UGM-U: 1 - Compressive strength of samples with UGM-U as a binder; 2 - Compressive strength of samples with UGM-70 as a binder; 3 - Flexural strength of specimens with UGM-U as a binder; flexural strength of specimens with UGM-70 as a binder.

The hardening of the UGM-U mixture was accompanied by a large heat release. Samples from the UGM-70 mixture strongly adhered to the molds and were difficult to remove. The adhesion of samples from the UGM-U mixture was significantly weaker.

Sodium water glass as an additive in the manufacture of concrete is used to reduce the setting time and increase the water resistance of concrete. When liquid glass is added to cement concretes, it enters into a chemical interaction with calcium hydroxide to form sodium-

calcium hydrosilicates, intensifying the setting process. Improving the water resistance of concrete is achieved at high concentrations of water glass (more than 20% by weight of the binder), which leads to a significant decrease in strength.

The strength of concrete under bending and compression with the addition of liquid glass was determined on samples of $4 \times 4 \times 16$ cm in size at the age of 7 days. The samples were prepared from a binder mixture UGM-70 (Binder) and coal (C). The ratio between the components in percent B / C was taken as 40/60. Liquid glass was introduced in an amount of 3, 5 and 7% of the weight of the cementitious mixture, having previously mixed it in mixing water. The test results are presented in Fig. 2 and in Table 4.

Table 3. Strength of samples with the addition of liquid glass.

Quantity of added liquid glass, %	W / Solid ratio	Flexural strength, kg/cm ²	Mean value, kg/cm ²	Breaking load, kg		Compressive strength, kg/cm ²		Mean value, kg/cm ²
3	0.2175	2.37	2.35	2240	2320	8.78	9.10	8.94
		2.29		2390	2380	9.37	9.33	
		2.37		2120	2230	8.31	8.75	
5	0.2175	2.24	2.25	2110	2340	8.27	9.18	8.78
		2.43		2260	2350	8.86	9.22	
		2.09		2250	2120	8.82	8.31	
7	0.2175	1.98	1.89	1880	2030	7.37	7.96	6.95
		1.86		1590	1850	6.24	7.25	
		1.82		1660	1620	6.51	6.35	

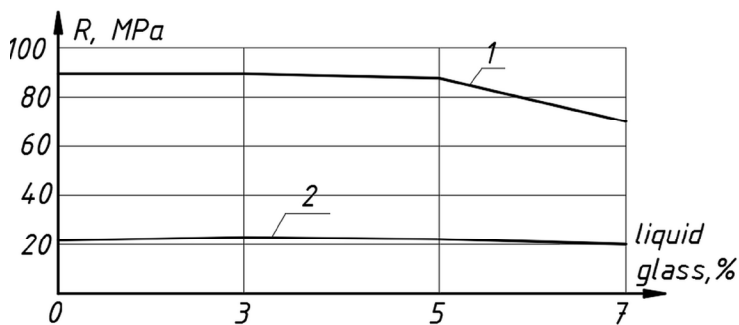


Fig. 2. The influence of liquid glass additives on the strength of concrete: 1 - in compression; 2 – in bending.

The analysis of the test results of concrete samples with the addition of liquid glass showed that liquid glass in an amount of 3-5% by weight of a binder does not affect the strength, a further increase in the amount of liquid glass leads to a decrease in the strength of concrete. With the addition of liquid glass in an amount of 7%, the compressive strength decreases by 22% compared with non-admixture concrete, the flexural strength decreases by 14%.

Table 4. Setting time for UGM with the addition of liquid glass.

Composition	The amount of liquid glass, %	Setting time, min	
		Start	Finish
UGM-70	3	160	220
	5	103	205
	7	82	121
UGM-U	3	50	55
	5	43	48
	7	15	21

The introduction of up to 5% of liquid glass into the UGM composition does not lead to a reduction in the setting time. An increase in the amount of liquid glass additive leads to a reduction in setting time and can create difficulties in concrete placing.

4 Conclusion

According to the results of the study, it has been found that there is a possibility of introducing the optimal amount of coal waste in the composition of UGM mixtures without reducing their technological parameters.

The introduction of liquid glass into mine concrete using coal wastes does not have the desired effect on strength, while with an increase in the amount of liquid glass, the strength decreases. The introduction of liquid glass affects the setting time in such a way that its use does not lead to an improvement in technological parameters and creates difficulties in placing concrete on the structures.

5 References

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