The Research in the Use of Monolithic Concrete for the Mine Construction

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Abstract. The aim of the work is to study the use of slag aggregate concrete for the construction of monolithic concrete lining of mine workings. In the coal industry the average of 10-15 m of development workings are constructed to extract 1,000 tons of coal. The monolithic concrete is 97-98% of the total material consumption for the construction of vertical shafts in Kuzbass; lining costs being 50% of the total cost of shaft construction, which are directly dependent on the material consumption and cost. Considering the amount of annually produced coal in Kuzbass mines, it becomes obvious that the cement consumption in the industry amounts to several million tons, the consumption of the aggregates is about ten million cubic meters. It was found that 25-30% of concrete-lined mine workings are re-lined annually. This is due to the concrete destruction under the influence of unfavorable operating conditions, especially the destructive action of mine water. Therefore, the problem of production of concrete capable of withstanding these phenomena seems quite relevant.

***Keywords* — concrete; mine construction; strength; slag aggregates; floured admixtures.**

I. INTRODUCTION

Currently, the heavy fine and coarse aggregate concrete is mainly used in the mine construction. The relevance of this work also lies in the fact that the Kuzbass region suffers a shortage of high quality natural materials for the production of heavy concrete, and therefore, there is a trend of its regular price increase. At the same time, a large number of annually replenishable production waste - fuel and metallurgical slag, which can be used as the concrete aggregate - is accumulated on the dumps of Kuzbass metallurgical and energy operations. Metallurgical dumping fuel and granulated slag are local Kuzbass materials; each of them having a number of advantages and, therefore, being of great interest for the production of the efficient concrete meeting the mine construction requirements. The idea of this work is to use the active properties of slag having the latent hydraulic activity which can be used to produce the cement concrete able to withstand the harsh environments of mine structures [1, 2, 3, 4].

The aim of the work is to study the use of slag aggregate concrete for the mine construction, providing the cost reduction and the structural durability increase.

The scientific novelty of the work lies in the justification of the possibility of joint use of blast furnace and fuel slag for the mine construction concrete and in determining the impact of slag concrete structure on the change of the physical and mechanical characteristics.

The practical significance of the work lies in the fact that its results allow the concrete to be produced using relatively cheap wastes of metal and fuel industries characterized by high durability, water resistance, and aggression resistance, which will increase the durability and reduce the cost of mining structures.

II. MATERIALS AND METHODS

The problems in determining the physical and mechanical properties of slag aggregates and the dependence of the slag concrete strength on the main technological factors were solved in the research work.

Ash and slag mixtures from Kuzbass thermal power plants have a relatively uniform chemical composition, the module size of 2 to 3.5, they are resistant to the ferrous and silicate decay and contain up to 1% of unburnt particles, up to 6% of CaO, and are not restricted by the radiation factor.

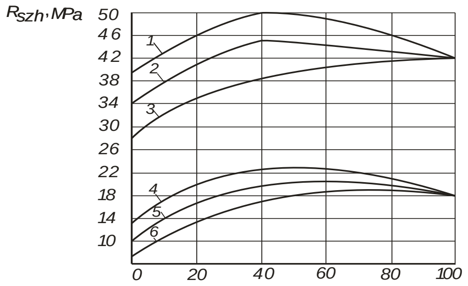
The dump blast furnace slag is supplied in the form of 0-150 mm size gravel of 1400-1550 kg / m^3 bulk density. This slag gravel does not comply with the standard requirements for the grain structure and therefore should be crushed and sorted.

The crushed dump slag screenings cover up to 30% of the demand for the fine aggregate. To piece out a shortage and optimize the grain composition, the ash and slag mixtures were used; the river sand being used for a comparison. The research results showed that the maximum strength of the dump blast-furnace slag concrete is achieved when the content of ash and slag mixtures in the fine aggregate is 50-70% (Fig. 1).

In accordance with the building codes it is recommended to use in the concrete [5] only the acidic wastes, the basicity factor of which is less than one. Kuzbass slags contain in their composition from 37 to 39% of CaO, their basicity factor is 0.89, that is, they are acidic and can be used as the aggregates for the concrete, the hydraulic activity module of which ranges from 0.34 to 0.4. According to its ability to react with water like the cement in the finely crushed, the metallurgical slag is low-level active and its hardening is ensured only in the presence of the cement clinker. This slag is close to Portland cement according to its chemical composition, but it contains a high amount of silica, alumina, and less calcium oxide. Slag

The conference was funded by RFBR according
to the research project №16-05-20506

aggregates are not inert, they react with the related cements in the contact area - this leads to the uniformity increase and the concrete structure improvement.



Screening content, %

Fig. 1. The dependence of slag cement strength on the fine aggregate composition

1, 2, 3 – at the cement consumption of 495 kg/m^3, introduction of screenings and, consequently, ash and slag mixture, granulated slag, sand; 4, 5, 6 – the same at the cement consumption of 270 kg/m^3

It is known that most of the monolithic concrete used in mine construction is placed and hardens at low temperatures. The normal conditions of concrete hardening: temperature of + 15 + 20°C at a relative humidity of 90-100%. With the decrease of cure temperature, the strength of concrete increases slower. It is therefore of interest to study the comparative slag gravel concrete strength changes at different curing temperatures, in particular at + 5°C, usual for the mine construction. For this purpose, the experiments were conducted in which the cube samples made from the slag aggregate concrete of various composition with the modified engineering lignosulfonates and the modified engineering lignosulfonates+CaCl2 additives and the reference conventional heavy concrete samples were partially placed into a refrigerating chamber and cured therein at + 5°C, and partially hardened under the normal conditions at + 18°C and also under the hydrothermal treatment.

It was found that the strength of the metallurgical and fuel slag mixture concrete after steaming can be taken with a sufficient degree of accuracy of 80% from the project one. The grade strength is established at 28 days post-steaming or 45 days of normal hardening.

The process of the slag aggregate concrete strength development under normal conditions occurs in the first 5-7 days most actively. In these time limits the slag concrete tensile strength is 5-10% higher than the usual heavy concrete. Further the strength growth slows and after 28 days is 92.5% of the steamed concrete strength.

The introduction of 2% of CaCl2 into the concrete composition, according to the regulatory literature, provides the concrete strength increase at low temperatures up to 75% of the design concrete strength, hardening under the normal conditions. The actual increase in strength was, according to the experimental data, 75-87% for the heavy concrete, and 92-133% for the slag aggregate concrete. From the foregoing, it can be seen that it is more efficient to use the slag concrete at the lower temperatures than known types of concrete on the bases of the natural materials.

The researches in the physical and mechanical characteristics of the slag aggregate concrete were also carried out. The dependence of the slag concrete compression resistance on the cement consumption and the fine aggregate composition was determined using the concrete mixture of 2-4 cm concrete cone slump and 5-9 cm workability [6]. The results are shown in Fig. 2.

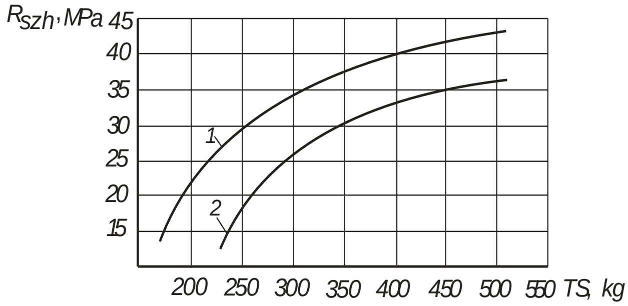


Fig. 2. The dependence of the slag concrete compression resistance on the cement consumption

1 – for the concrete mixture of 2-4 cm workability; 2 – for the concrete mixture of 5-9 cm workability

The strength of the test concrete, depending on the cement consumption and the water-cement factor at the optimal grain composition of the aggregate is from 10 to 45 MPa, which allows its use in the mine construction.

Experiments proved that the bending tensile strength of the slag concrete is 0,06-0,108 and the tensile strength is 0,045-0,063 of compression strength that allows making of the structural analysis according to the known methods. Also in the course of the research it was found that the slag concrete resistance coefficient under the action of sulfate media was 0,92-1,4, and under the action of slightly acidic it was 1,2-1,26, under the rated - 0.8. Consequently, the proposed concrete can be used under the mild acidic and sulphate aggression [7-14].

The question about the possibility of the hardening time reduction also came up during the experiments carried out to determine the slag concrete strength. One of the possible solutions to this issue is the activation of concrete aggregates.

At the moment, there are many methods of activation of the fine mineral aggregates accelerating hardening: mechanical (increase of the specific surface of cement, etc.), chemical (introduction of additives accelerating hardening), and physical and mechanical. We have tested a method for optimizing a monolithic concrete structure by introducing the milled admixtures.

The milled admixtures are obtained by grinding the coarse aggregate (crushed stone slag), at which the exposure of new surfaces occurs, whereby there is an increase of the surface energy, and thereby improvement of the strength properties of concrete, and its remoulding effort and the workability. The effective use of the milled admixtures is possible in some cases:

- if under strength conditions, it is possible to allow the highest water-cement ratio than it is necessary according to the concrete durability requirements;

- if the concrete strength can be achieved with the lowest cement consumption than it is necessary under strength conditions.

Today, the production of the milled admixtures for the concrete became possible with the use of innovative method of grinding in a new type mill [15].

But the question is what percentage of the milled admixtures will be enough for the rapid strength development? After all, the admixture overload would lead to the reduction of the absolute strength. To answer this question, we have carried out tests to determine the optimal percentage of the milled admixtures. The comparison of strength values of the concrete with and without additives was also made.

For the test the 15×15×15 cm cubes samples were prepared, each with different milled admixture percentages (5, 10, 15, 25, 30%). The test results are shown in Fig. 3.

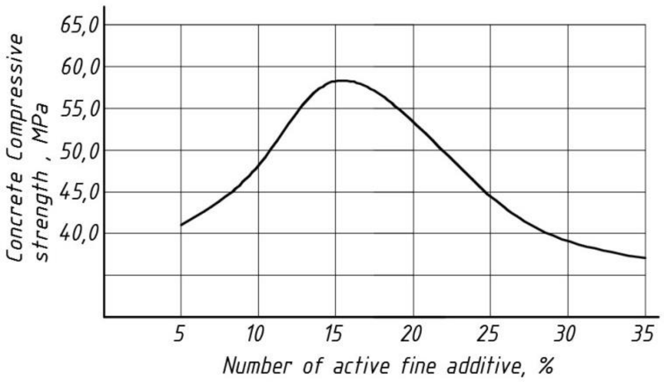


Fig. 3. The dependence of the slag concrete strength on the milled admixture amount

The figure shows that the optimum percentage of the milled admixture is about 15% at the absolute strength of 58 MPa, which is higher than that of concrete without the additive. The results comparing the strength of concrete with and without additives throughout the entire hardening period are shown in Fig. 4.

Having analyzed the results, we can conclude that concrete with the milled admixture in the early stages of hardening gains the greater strength than the concrete without such additives. In addition to the rapid curing, the use of the milled admixture reduces the consumption of cement compared with the required consumption under strength conditions.

III. RESULTS

On the basis of the obtained results, the dependences of the slag cement strength on the fine aggregate composition, the cement consumption and type, the water-cement ratio, and the presence of chemical additives were determined.

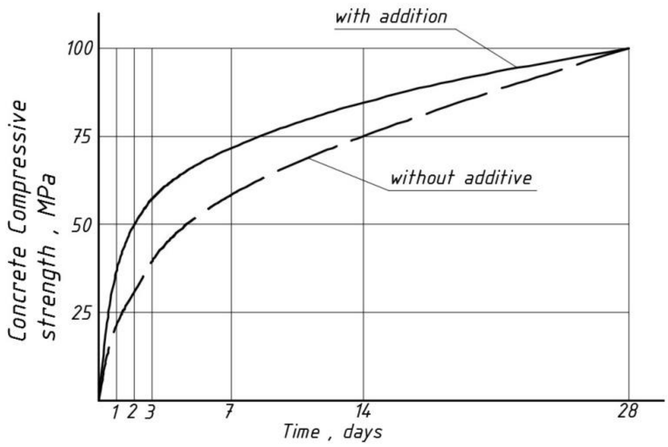


Fig. 4. Dynamics of the strength development of the concrete with the floured admixture

On the basis of which the following technological solutions have been developed:

- the optimal content of the fine aggregate should be 0,32-0,62 of the total aggregate consumption;

- the proportion of the ash and slag mixture in the fine aggregate - 50-70%;

- the use of the Portland slag is efficient for the production of the slag cement. At the same time, to produce the equally strong concrete its grade can be reduced by an order of magnitude compared with the Portland cement;

- the use of superplasticizing admixture LSTM reduces the cement consumption by 10-20% and increases the concrete mixture workability in 2-3 times without reducing the physical-mechanical characteristics of the concrete;

- the replacement of 15% of the fine aggregate with the milled admixture received from slag crushing reduces the concrete hardening time.

IV. CONCLUSION

The expected economic effect from the use of concrete on the basis of Kuzbass metallurgical and energy industry waste is the decrease of the production cost due to the use of cheaper materials; and the introduction of the research results will significantly reduce the negative anthropogenic impact on the environment due to waste disposal and land release for its more efficient use.

The results are recommended for the production of monolithic concrete that meets the mine construction requirements.

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