Development of sulfate-resistant concrete based on slag portland cement

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Abstract. Today concrete is one of the main building materials, used in the process of construction. Concrete mixtures must have high workability, retarding setting, quick hardening, long time transportation with further easy casting into molds, versatility of application and obtaining the constructions, not requiring significant expenses, connected with waterproofing works. At this it should not be forgotten that the main task is the provision of the required strength and durability of concrete construction that is the possibility of long time resistance to mechanical loads, chemical and physical environmental influences. Special interest is drawn to concrete protection from the influence of aggressive environments or in other words, to the increase of concrete sulfate resistance as it is exactly the sulfate water environment of different aggression levels is mostly often found in the ground waters. The influence of sea waters and sewage drains on the concrete constructions is similar to the influence of the sulfate water medium of different aggression levels. Water impact is one of the main factors influencing the durability of concrete constructions.

1. Introduction
Concrete sulfate resistance is an ability of concrete to keep its standards-compliant properties without any signs of failure during the whole operational lifetime in the aggressive sulfate medium. Sulfate resistance is required for the constructions having contact with an aggressive environment (ground waters, closely located chemical and other harmful enterprises having an impact on environmental precipitations and so on).

2. Relevance of research
In practice the constructions suffering from sulfate ions influence eventually lose their properties (strength, water resistance, sulfate resistance) what sooner or later leads to construction failure and impossibility of its further usage [1].

What is the danger of sulfate water environment?
First of all, it is exactly the sulfate water environment of different aggression level is mostly often present in the ground waters. Besides, influence of sea waters and sewage drains on the concrete constructions is similar to the influence of sulfate water medium of middle and high levels of aggression that is why the resistance to these types of aggressive influence on concrete is similar.

On the second hand, sulfate water environment is considered to be the most destructive for ordinary concrete. The matter is that in the result of contact of sulfate ions with such components of cement rock as tricalcium aluminate (3CaO*Al₂O₃) and calcium hydroxide Ca(OH)₂ (free lime) there are
formed very dangerous crystal new formations named ettringite \((3\text{CaO}\cdot\text{Al}_2\text{O}_3\cdot6\text{H}_2\text{O}\cdot3\text{CaSO}_4\cdot3\text{2H}_2\text{O})\) \[2-11\].

The formation of ettringite is accompanied by gradual increase of crystals volume and this produces the increasing pressure on surrounding them cement rock causing its internal stress. As much as the crystals grow the stresses increase and routinely this leads to the formation of multiple micro cracks in a cement rock, its strength significant decrease and subsequently complete destruction of the cement rock and therefore concrete.

This process starts from the surface of concrete where it contacts with the sulfate medium and then gradually penetrates inside achieving reinforcement and expands further. When the protective layer of reinforcement is destroyed its aggressive medium contacts with reinforcement and accelerated corrosion of reinforcement takes place. Products of reinforcement corrosion are also extending in volume and increase the pressure on surrounding concrete speeding up the process of its destruction. As a result a construction is fairly quickly becomes unfit for the use long before the expected useful life ends \[12-14\].

Speed of concrete destruction in the sulfate medium depends first of all on the aggression of this medium, operational conditions and environmental temperature.

In the conditions of sulfate aggression it is reasonable to apply concrete on the basis of slag Portland cement in concrete and reinforced concrete structures of underwater and underground parts of structures which are in constant contact with natural or industrial waters, in constructions which do not pass through the alternate freezing and melting and do not possess evaporating surface \[15-22\].

3. Aim
The aim of the work consisted in developing a composition of sulfate resistant concrete of the class not lower than B30 on the basis of slag Portland cement for products and structures which are used in aggressive environments.

4. Tasks which were to be solved
1. Determine optimum ratios of cement, slag and a chemical additive for creating sulfate resistant concrete;
2. Determine the properties of concretes obtained on the basis of these materials ratios;
3. Choose the most effective composition out of the obtained compositions and study the structure of sulfate resistant concrete on the basis of optimum ratio.

5. Theoretical part
As a binding material there was used CEM I 42,5H cement and the basic component for increasing sulfate resistance of the concrete to be obtained was granulated blast-furnace slag. For increase of concrete mixture plasticity and acceleration of concrete hardening Relamix T-2 complex additive was used.

For development of composition of heavy sulfate resistant concrete two-factor experiment was planned and carried out \[23\]. The factors of the experiment were:
- Factor X: ratio of cement and granulated blast-furnace slag;
- Factor Y: content of Relamix T-2 complex additive.

Matrix of experiment and properties of the obtained compositions are presented in Tables 1-2.

According to the results of the experiment presented in the tables it is obvious that the increase of ground granulated blast-furnace slag in the composition of concrete decreases the strength but increases the sulfate resistance of concrete. While Relamix T-2 chemical additive contributes to the quick strengthening on the early stages of hardening, it does not increase it on the late stages and does not make concrete more sulfate-resistant. Responses from Table 2 allow making a conclusion that the composition of 64% of cement, 36% of slag and 2,2% of chemical additives showed the best strength values, while compositions with slag domination showed the best sulfate resistance values.
Table 1. Results of Tests of the 10 cm Edge Cubes Samples.

| X1     | X2     | 1st day | 3rd day | 7th day | 28th day | R, MPa, Curing in Steam, t=95°C, w=100% |
|--------|--------|---------|---------|---------|----------|------------------------------------------|
| 0 (50/50)* | 0 (1,7)* | 36.1    | 39.6    | 44.7    | 47.0     | 36.8                                      |
| 1 (64/36)* | 1 (2,2)* | 37.5    | 40.5    | 48.8    | 47.6     | 39.0                                      |
| -1 (36/64)* | -1 (1,2)* | 32.0    | 34.0    | 45.5    | 45.6     | 34.1                                      |
| 0 (50/50)* | 1 (2,2)* | 38.1    | 42.4    | 49.6    | 47.6     | 39.6                                      |
| 0 (50/50)* | -1 (1,2)* | 38.0    | 41.5    | 49.1    | 45.2     | 38.7                                      |
| 0 (50/50)* | 0 (1,7)* | 33.1    | 35.3    | 46.0    | 45.3     | 38.8                                      |
| -1 (36/64)* | 1 (2,2)* | 34.0    | 36.3    | 46.1    | 46.2     | 38.6                                      |

a Ratio of cement and slag in %;
b Amount of an additive of the binder mass in %.

dependency diagrams of concrete strength on its composition are presented in Figures 1-4.
Figure 1. Dependency of strength of the bars made of slag-cement and sand slurry on the ratio of cement and slag and a chemical additive content on the 28\textsuperscript{th} day of normal hardening (2, 22 $F$-test), MPa.

Figure 2. Dependency of strength of the bars made of slag-cement and sand slurry on the ratio of cement and slag and a chemical additive content on the 393\textsuperscript{rd} day of being placed in the 5\% sodium sulfate solution (1,27 $F$-test), MPa.

Figure 3. Dependency of strength of the bars made of slag-cement and sand slurry on the ratio of cement and slag and a chemical additive content on the 393\textsuperscript{rd} day of water curing (1,07 $F$-test), MPa.

Figure 4. Dependency diagram of strength loss coefficient value on the content of cement, slag and a chemical additive in the cement-sand solution (0, 01 $F$-test), %.

6. The practical importance
Character of the contour lines location on Figure 1 says that the main factor influencing strength value on compression is the increased part of cement. Analyzing Figure 2 it can be said that the composition with an equal content of cement and slag and average amount of chemical additives used demonstrated the highest strength. Character of the contour lines location on Figure 3 says that the main factor influencing strength value on compression is the increased part of cement and the role of chemical additives is insufficient. According to Figure 4 it can be seen that the compositions with the maximum content of cement have the highest strength losses and compositions with the dominant slag do not lose their strength values.

7. Conclusions
- It is determined that the developed compositions of concrete possess good sulfate resistance;
- It is experimentally determined that the compositions with the maximum content of cement and an additive have the highest strength and compositions with the dominant slag demonstrated strength retention after the influence of sodium sulfate;
- Increase of slag part in the composition of concrete without curing in steam leads to the significant strength loss on the 28th day of normal hardening but further keeping the samples in the normal conditions the decrease of strength does not take place;
- Increase of slag part in the composition of concrete after curing in steam leads to insignificant loss of strength and almost do not decrease on the 28th day of normal hardening;
- Relamix T-2 chemical additive increases the strength of concrete at compression on the early stage of hardening and does not lead to the growth of strength on the late stages of hardening as well as does not increase the sulfate resistance of concrete;
- Depending on the required class of concrete by strength and aggressive influence of sulfate corrosion all the investigated compositions of concrete can be recommended.

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