Durability and corrosion resistance of high-strength powder concretes

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Abstract. One of the performance indicators of building products and structures made of high-strength concretes is their durability, which determines the urgency problem of preserving high construction and technical properties over time. In this regard, an important task is to create new ways of the durability prediction and corrosion resistance of high-strength concretes in conditions of aggressive environmental exposure. This article discusses the issues of determining the durability of high-strength powder concretes under the action of one of the most common aggressive factors is sulfate solution. The results development of an accelerated method for predicting the durability of powder concretes in sulfate medium are presented.

1. Introduction

Building and construction from high-strength materials, especially for special purposes, complex construction, and unique buildings are often required to produce in difficult natural and geophysical conditions. Constructions of high-strength powder materials work in contact with groundwater containing dissolved components that can interact with structural elements of a concrete stone. This also applies to the constructions of various communication systems supplying the production process with aggressive solutions and liquids, for example in the chemical, perfume or medical industry.

The study results of high-strength compositions, structured with complex mineral modifiers, which contain reactive fine-dispersion fillers of different nature, have shown that these hardening compositions provide rapid strength gain products as a result of their interaction, both with each other and with the aggregate surface. However, the question of their durability remains open.

2. Materials and methods

To study the nature of the destructive process, we used the developed compositions of high-strength powdered concrete with technogenic materials. When creating prototypes of 40×40×160 mm, powdered mineral modifier, in addition to mineral substances: high alumina cement, microsilicasuspension (TC 14-139-121-89, $S_{sp} \approx 350 \text{ m}^2/\text{kg}$), floured calcium carbonate, etc., had polymeric components in its composition, such as Melflux 2651, Melment, as well as floured quartzitic sandstone, which mined rock of the Kursk Magnetic Anomaly (KMA). Before mixing, the waste was ground to a specific surface area $S_{sp} = 500 \text{ m}^2/\text{kg}$.

As a fine aggregate, screenings of crushing of quartzitic sandstone with a fraction of 0.315-0.63 mm were used. Quartzitic sandstone grains are characterized by a scored surface and constancy of the mineral composition, which includes $\text{SiO}_2$ (about 90%), $\text{Al}_2\text{O}_3$, $\text{Fe}_2\text{O}_3$, $\text{FeO}$, $\text{MgO}$, $\text{CaO}$, $\text{TiO}_2$.
High strength composition was obtained on the basis of ordinary Portland cement PC 42.5H with superplasticizer. The content of PMM was 35-40%. The share of the Melflux 2651 superplasticizer was 0.9% of cement consumption.

For comparison, local quartz sand with $F_m = 1.69$ was used.

Control over the samples destructive state was carried out by measuring their linear dimensions and strength properties. The rated value of elongation was considered 0.1-0.3% [6].

3. Study of the durability and corrosion resistance of high-strength concrete with the help of a new type of aggressive solution

As a result, high-strength fine-grained concrete with an optimized structure was obtained due to compaction of the concrete mix being formed due to artificial contraction, reduction of porosity, elimination of plastic deformations. At the end of the compaction period, when the concrete mix reaches its maximum density and the dynamic characteristics, an intensive process of post-compaction of the concrete grading occurs with the reaggregation of dispersed particles. With an equilibrium synergistic interaction, the concentration of the cement gel increases, which makes it possible to compact the concrete to an average density of 2100-2100 kg/m$^3$ and speed up the curing to 60-80 MPa at the age of 7 days (Table 1).

Table 1. Construction and technical properties of developmental prototypes of high-strength concrete at the age of 7 days

| No. | Material consumption per 1 m$^3$, kg | Screening of quartzite sandstone crushing (0.315-0.63) | Sand | Water | HV | Compresion strength, $R_{co}$, MPa | Flexural strength, $R_{fl}$, MPa |
|-----|-----------------------------------|---------------------------------|------|-------|----|---------------------------------|-------------------|
| 1   | Powder binder                     | C                               | 1500 | –     | 175| 0.32                           | 46.4              |
| 2   |                                   | C+W                             | 1100 | 400   | 186| 0.34                           | 45.8              |
| 3   |                                   | PPM                             | 1500 | –     | 163| 0.30                           | 51.3              |
| 4   |                                   |                                 | 1100 | 400   | 172| 0.31                           | 50.7              |
| 5   |                                   |                                 | 1350 | –     | 194| 0.28                           | 61.2              |
| 6   |                                   |                                 | 1450 | –     | 201| 0.29                           | 60.5              |

An increase in the basic physicomechanical characteristics of fine-grained concrete with the addition of the developed powder mineral modifier has been established. The increase in ultimate compression resistance and flexural strength amounted to 31.3 and 21.6%. The growth of indicators of construction and technical properties is due to the high density of the material, due to the introduction of the modifying additive into the composition, as well as the quality of the quartzitic sandstone aggregate and the degree of its adhesion to the hardening stone [1-3].

Using the developmental prototypes has been developed as an effective system for predicting the durability of products from high-strength fine-grained concrete with industrial raw materials. The basis of this system was a fundamentally new approach to the assessment of the kinetic parameters of the destructive process in concrete, caused by aggressive environmental influences. As we said earlier, the most dangerous from the point of view of concrete destruction are liquid sulfate media containing active ions capable of interacting with components of hardening concrete, especially aluminium-containing a component, which is higher in the structure of high-strength powdered concrete than conventional...
concrete. This interaction proceeds at different rates, which can be a key element in the entire system for assessing the durability and corrosion resistance of concrete. Many methods for assessing the durability and corrosion resistance of concrete products are based on controlling the speed of a destructive (corrosive) process in an aggressive environment [4,5].

The results of studying the self-healing process of concrete by “refilling” the formed microcracks with hydrated new growths, which are formed in an aggressive sulfate solution with an increase in the volume of the solid volume, suggested that the rapid formation and accumulation of ettringite-like phases in cracks and pores in an excess amount will lead to a destructive process and the destruction of concrete in a short time. This circumstance served as the basis for the development of a new accelerated method for predicting the durability of high-strength powder concrete when exposed to aggressive sulfate solutions. In this case, a solution of persulphate acid was used, in which the acceleration of the destructive process is associated with the “chain” reaction of the formation of one $S_2O_8^{2-}$ ion from two $SO_4^{2-}$ ions.

Many existing methods for predicting the durability of concrete when exposed to sulfate-containing solutions use various techniques (increasing the concentration of an aggressive solution, increasing its temperature and pressure, etc.), which distort the course of the destructive process and take long periods of time. Therefore, the development of methods for rapid analysis, which would allow in the short term to assess the durability of cement stone in sulfate-containing medium, without changing the real picture of the process [6–8].

Since the cementing matrix undergoes destruction, the kinetics of the destructive process should be studied on model systems with the participation of individual clinker minerals. In this case, it became possible to most reliably identify the main parameters of the interaction process, leading to the formation of compounds similar in morphology and properties to ettringite-like phases. The results were obtained to accelerate the process of destructive destruction of concrete when exposed to ammonium persulfate and potassium solutions. However, the participation of potassium persulfate in the process of destruction introduces an additional ion, $Na^+$, significantly distorting the picture of the corrosion process, therefore experimental studies were carried out using ammonium persulfate.

The volume of 1% aggressive solution of ammonium persulfate per sample of powdered concrete was 100, 200, 500 and 1000 ml. Before immersion in an aggressive solution, the samples were solid for 28 days in water. In the course of the experiment were studied methodological features, such as the replacement of an aggressive solution during testing. The solution was changed in the 3rd and 7th day of age since it was found that the diffusion of the persulfate ion into the cement stone occurs only in the initial stage of the destructive process. The test results are shown in Table 2.

**Table 2** - Characteristics of samples of powder concrete after 35 days of stay in a 1% solution of ammonium persulfate of different volume.

| The volume of solution per sample, ml | The linear expansion, mm / m | Flexural strength, MPa | Coefficient strength |
|--------------------------------------|-----------------------------|-----------------------|---------------------|
| Without changing the aggressive solution | 100 | 2.62 | 6.48 | 0.51 |
| 200 | 2.60 | 6.35 | 0.50 |
| 500 | 2.97 | 5.84 | 0.46 |
| 1000 | 2.83 | 5.54 | 0.44 |
| With the change of aggressive solution | 200 | 0.72 | 6.22 | 0.49 |
| 500 | 0.74 | 6.10 | 0.48 |

According to the data obtained, the elongation of the samples is almost independent of the volume of the aggressive solution. When changing the solution, this indicator loses a natural character. Due to this circumstance, all the samples were tested at the age of 35 days, when the linear expansion of the samples in the solution without replacing it, reached the limit value. The tensile strength of the samples at this time has a low value, the same in experiments, both without changing the aggressive solution and
with changing the aggressive solution. In the case when the volume of persulfate was 100 and 200 ml per sample, the resistance coefficient was slightly higher than in 500 and 1000 ml. In solutions of 1000 ml per sample, due to the acidic environment of ammonium persulfate (pH = 2.5-3), a corrosion process of type II takes place, which leads to a distortion of the destructive picture of the process.

Thus, the research has expanded the group of dispersed fillers of the multicomponent binder of technogenic origin and proposed to use the waste of ceramic production. These wastes as a result of the preceding burning mechanism contain mullite-like calcium aluminosilicates or their mixture with dispersed quartz, which are ready-made crystallization centers during cement hardening. The high-strength composition was obtained by modifying its complex organomineral additive, consisting of a superplasticizer and floured mineral component.

4. Conclusion

Thus, as a result of the work carried out, new data on the study and development of compositions and technology for the use of high-strength compositions have been obtained. The main solved task was finding ways to reduce the cost of raw materials and technological work.

The study of the kinetics of the destructive process of high-strength powdered concrete in model systems showed that the main hydrated minerals of cement clinker interact with an aggressive solution containing persulfate ions. The products of this interaction are ettringite-like phases and gypsum, i.e. a destructive process proceeds, analogous to corrosion of concrete of the third type. Dicalcium silicate is more resistant to corrosion a solution of persulfate than tricalcium. Binder, consisting of calcium silicates and tricalcium aluminate, with an increase in the amount of the latter, is characterized by a decrease in durability and corrosion resistance.

The parameters of an aggressive solution affect the intensity of destruction of powdered concrete. Destructive processes of powdered concrete, occurring in sulfate and persulfate solutions are similar. In both cases, the corrosion products are calcium aluminate trisulfate hydrate and gypsum. The rate of increase in destructive processes of cement stone is higher in persulfate solution.

Different nature of the course of the destructive process in samples of powdered concrete with fine aggregate and without it, as well as its kinetic parameters, is established. The obtained data allowed us to determine the main methodological methods of controlling the destructive process in aggressive solutions containing sulfates.

According to the research results has been proposed as a method for accelerated comparative tests of concrete powder for durability under the action of sulfate medium.

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References

[1] Tolstoy A D, Lesovik V S, Kovaleva I A 2014 Organogenic high-strength compositions Bulletin of the Belgorod State Technological University named after V G Shukhov 5 67-69
[2] Tolstoi A D, Lesovik V S, Kovaleva I A 2014 High-Strength Decorative Complexes with Organomineral Additives Research J. of Pharmac., Biolog. and Chemic. Sci. 5(5) 1607
[3] Lesovik V S 2014 State and prospects for the use of technogenic materials Bulletin of the Central Regional Branch of the RAACS 17
[4] Dobrolyubov G V, Ratinov V B, Rosenberg T I 1983 Prediction of the durability of concrete with additives (Moscow: Stroyizdat) 212 p
[5] Deneva A, Milchevska S 1981 Accelerated method for determining the sulfate resistance of cement Construction 8(28) 31-33
[6] Moskvin V M, Ivanov F M, Alekseev S N, Guzeev E A 1980 *Corrosion of concrete and reinforced concrete, methods for their protection* (Moscow: Stroyizdat) 536 p

[7] Tolstoy A D 1987 *Sulfate resistance of concrete with pyritiferous aggregate, determined by the accelerated method*: dissertation (Belgorod) 178 p

[8] Nikitina L V 1983 Formation and transformation of ettringite in expanding systems *Works of VNITsment* 77 75-78