Experimental investigations of concrete on slag Portland cement as a coating material for agricultural aerodromes

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Abstract. The results of concrete testing on sulphate-resistant slag Portland cement for rigid coating of agricultural roads and aerodromes are presented in the paper. The results of experimental investigations of samples in the form of cubes on compressive strength and samples in the form of prisms on bending strength under different hardening conditions and at different water-cement ratios are presented. Selection of hardening conditions of concrete on sulphate-resistant slag Portland cement was made based on achievement of quality indicators no worse than in concrete on Portland cement. The expediency of introducing into the concrete organic surface-active additives - lignosulfonates in order to achieve the required strength is grounded. It is proved experimentally that the proposed concrete has sufficient frost resistance.

Introduction

The effectiveness of the use of rigid coatings made from prefabricated concrete products on agricultural aerodromes is not fully investigated. The experience of their practical using at aerodromes deserves further study. In addition, existing prefabricated structures used for the construction of aerodrome and road surface coatings are ineffective from the economic point of view for agricultural aviation aerodromes in most cases. Therefore, the using of new building materials and the development of lightweight economic coatings made of prefabricated concrete elements for using at agricultural aerodromes require serious consideration.

Formulation of the Problem

A promising direction in the construction of agricultural aerodromes coatings is the using of concrete on slag Portland cement binder [1], which favorably differs from Portland cement with greater environmental friendliness, affordability, reduced energy consumption and cost.

Sufficient number of works has been devoted to solving the problem of improving the performance of concrete [2-14]. The using of Portland cement, modified by complex additives of plasticizing and air-pulling action, contributed to the creation of polyfunctional concrete [3,4]. The introduction to Portland cement of pozzolana, carbonate additives and blast furnace slag contributes to increasing its activity by optimizing the particle size distribution [5-7]. Studies [8] have shown that when composite binder is used, it is possible to obtain high strength concrete at early hardening times. At the same time, the use of slag opens the possibility to obtain concrete, which is not inferior to concrete on conventional Portland cement [9].

Therefore, the determination of frost resistance and strength characteristics of concrete on slag Portland cement binder during compression and bending, and justification of the possibility, effectiveness and expediency of its use for rigid agricultural roads and aerodromes, is actual task.

The aim of the work is to determine the strength characteristics of concrete based on sulphate-resistant slag Portland cement during compression and bending under different conditions of hardening; substantiation of expediency of introduction into the concrete of organic surfactants -

lignosulfonates in order to achieve the required strength; experimental investigations of concrete samples on frost resistance.

Materials and Methods

For the experiments, concrete samples were made under different hardening conditions [15]. Sulphate-resistant slag Portland cement of brand 400 was used as a binder for these samples. It has the following physical and mechanical characteristics:

- Water-cement ratio 0.38;
- Flow of the cone 115 mm;
- Fineness of grinding: 91.8% of cement by weight passed through sieve 008;
- Normal density of cement dough 26.50%;
- Timing of setting: the beginning of setting comes in 4 hours 10 minutes after mixing the cement dough, and the end of setting – in 5 hours 30 minutes;
- Compressive strength after steaming 271 kgf / cm^2 = 26,6 MPa;
- Bending strength after steaming 50.7 kgf / cm^2 = 4.97 MPa;
- Content of granular metric blast furnace slag in cement is 48% by weight.

Concrete samples after molding were in the following different hardening conditions:

H -normal hardening at relative humidity of air 90-95% in a special chamber;

C - dry hardening at a relative humidity of air 40-70% in room conditions;

M - normal hardening after thermic humidity treatment in the regime 2 hours + 3 hours + 6 hours at the temperature T = 70 ° C, where

2 hours - holding the samples before steaming,

3 hours - raising the temperature in the steaming chamber (where the samples are placed) to a given value T,

6 hours - holding the samples in the steaming chamber at a given temperature T;

MC - dry hardening after thermic humidity treatment under the same regime during 2 hours + 3 hours + 6 hours at the temperature T = 70 ° C;

M1 - normal hardening after thermic humidity treatment under the same regime 2 hours + 3 hours + 6 hours at the temperature T = 90 ° C;

MIC - dry hardening on regime 2 hours + 3 hours + 6 hours at T = 90 ° C;

W1 - normal hardening after thermic humidity treatment on regime 1 hour + 2 hours 20 minutes + 3 hours 30 minutes at the temperature T = 90 ° C, where

1 hour - holding the samples before the steaming,

2 hours 20 minutes - raising the temperature in the steaming chamber (where the samples are placed) to a given value T,

3 hours 30 minutes - holding the samples in the steaming chamber at a predetermined temperature T;

W1C - dry hardening after thermic humidity treatment on regime 1 hour + 2 hours 20 minutes + 3 hours 30 minutes at the temperature T = 90 ° C.

The steaming chamber was switched off after holding the samples. The samples were gradually cooled from temperature T to room temperature.

Research Results

Samples for the experimental determination of the strength limit of concrete were produced of cubic-shaped with size 10 x 10 x 10 cm. They were tested at the age of 1 day, 3 days, 7 days, 28 days, and 180 days. Samples were mounted on the press and loaded gradually by the force P (Fig.1) [16].

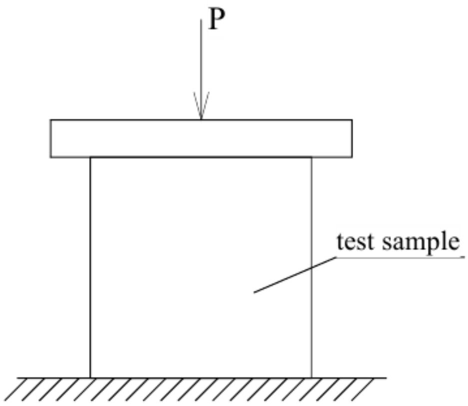

Fig. 1. Testing of concrete on compressive strength

The fracture load for sample corresponds to the limit compressive strength of concrete.

Samples for the experimental determination of the tensile strength of concrete at bending were made in the form of a prism with size 10 x 10 x 40 cm. They were tested at the age of 1 day, 7 days, and 28 days. The test scheme can be represented as follows: (Fig. 2) [16]

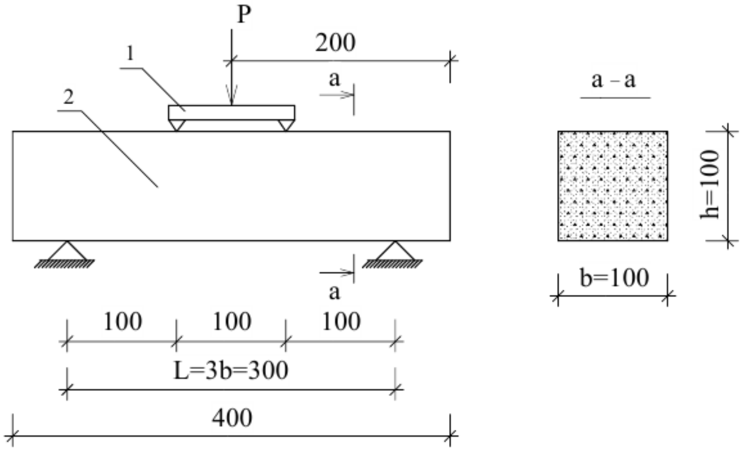

Fig. 2. Testing of concrete on strength at bending:
1 - beam for transferring of a load to the sample; 2 - sample

The samples were loaded gradually by a load P. The fracture load for the prism $P = P_{fr}$, corresponds to the limit strength of concrete at bending f_{ctd}. The dependence of f_{ctd} on P_{fr} can be represented as follows:

$$f_{ctd} = \delta \frac{P_{fr} \cdot L}{b \cdot h^2}, \tag{1}$$

where L, b, h – the dimensions of the sample shown in Fig. 2, δ – the calculated coefficient.

The samples were tested by groups, and CK brand were assigned to them which the test number was added to. The results of testing of concrete for strength are presented in table.1, 2.

Analyzing the test results of samples of 1-3 groups (Table 1), we can conclude that their bending strength on the 28th day was insufficient. This caused the need for testing with low water-cement ratio (4-6 sample groups). The possibility of reducing the water-cement ratio was ensured by the introduction into the concrete mixture of organic surface-active additives. Lignosulfonates (LSTs) were selected from them, as the most common and available industry wastes [17, 18]. It was found that the lowering of water-cement ratio had a positive effect not only on the compression strength of concrete, but, very importantly, on the bending strength of concrete (Table 2). Besides, the ratio of compressive strength to bending strength in the samples made with the addition of lignosulfonate is less than in samples made without the additive, which is also a positive factor.

Table 1. The results of testing of concrete samples of 1-3 groups, made on the basis of slag Portland cement of brand 400, on compressive strength

Brand of samples	Composition of $1m^3$ concrete mixture					Hardening conditions	Limit of compressive strength, MPa, for samples aged				
	Cement (C), kg	Water (W), kg	Sand (S), kg	Crushed stone, kg	LST in % of cement		1 day	3 days	7 days	28 days	180 days
The first group of samples											
CK1	450	195	600	1050	-	H	-	9,2 9,6	17,2 17,2	25,4 27,9	32,4 32,8
CK2						C	-	9,6 10,0	16,8 17,6	22,5 22,9	-
CK5						M	25,8 26,3	-	34,4 35,2 35,6	44,6 46,3 46,3	49,6 49,6 50,4
CK6						MC	-	-	37,2 37,6	45,4 45,4 47,1	47,1 47,5 47,5
The second group of samples											
CK1a	450	190	600	1050	-	H	-	12,0 12,8	18,4 18,8	27,9 28,3	-
CK3						M1	27,1 27,1	-	30,0 33,1	38,0 38,4 39,2	40,4 40,0
CK4						M1C	-	-	34,0 34,4 34,8	40,8 41,3 41,7	46,3 46,7 46,7
The third group of samples											
CK1b	450	190	600	1050	-	H	-	10,0 10,4	19,6 20,0	30,0 32,0	-
CK9						W1	25,4 25,8 29,2	-	32,4 32,8 32,8	36,0 36,4 38,0	43,3 47,5 47,9
CK10						W1C	-	-	34,0 33,6	39,6 41,3 43,3	44,4 44,2 44,6

Influence of the hardening conditions of concrete on its strength characteristics is investigated. For this purpose, the results of testing the samples of brand CK5 without additives from the first group were compared with the results of testing the samples of brand CK3 with the addition of LST from the second group. The hardening conditions of the samples of brand CK3 (M1) with the additive were more rigid than the hardening conditions of the samples without additive CK5 (M). Comparing the experimental strength characteristics of these samples, it can be noted that the softer regime provided higher compressive strength to the 28th day, and their bending strength was almost the same. The samples of brand CK9 from the third group were in even more rigid hardening conditions (W1) in comparison with the samples of brand CK5. As expected, their compressive strength was lower than that of the CK5 samples. In this case, the bending strength of the samples of brand CK9 was increased.

Table 2. The results of testing of concrete samples, made on the basis of slag Portland cement of brand 400, on banding strength

Sample group	Brand of samples	Composition of 1m^3 concrete mixture					Hardening conditions	Water-cement ratio	Cone deposition, cm	Limit of bending strength, MPa, for samples aged		
		Cement (C), kg	Water (W), kg	Sand (S), kg	Crushed stone, kg	LST in % of cement				1 day	7 days	28 days
1	CK5	450	195	600	1050	-	M	0,43	3	2,1 2,2	-	2,9 3,1
2	CK3	450	190	600	1050	-	M1	0,42	2,5	1,9 2,1	-	3,1 2,9
3	CK9	450	190	600	1050	-	W1	0,42	3	2,1 2,1	2,8 2,8	3,3 3,9
4	CK11	450	170	600	1050	0,2	M	0,38	4,2	3,4 3,6	-	4,5 5,1
5	CK13	450	170	600	1050	0,2	M1	0,38	3,5	2,9 3,2	-	4,5 4,65
9	CK27	300	180	700	1100	-	W1	0,6	2,5	1,8 1,8	-	2,5 2,5
10	CK29	300	180	700	1100	-	M1	0,6	2,5	-	-	2,5 2,7

The check of the marked empirical dependences of strength concrete on the hardening conditions when introduced into the concrete of surface-active additives was made. For this purpose, the testing results of the brand samples CK11 from the fourth group were compared with the testing results of brand samples CK13 from the fifth group. The hardening conditions of the brand samples CK13 (Ml) were more rigid than the hardening conditions of the samples CK11 (M). Analyzing the test results, we can conclude that a softer regime provided higher compression strength to the 28th day for the samples with additives, as well as for the samples without additives. The bending strength of the CK13 samples was lower than that of the CK11 samples.

The check of the marked empirical dependences for other ratio between cement and filler was made. For this purpose, 7-10 groups of samples were made. In that the amount of cement per 1 m^3 of concrete was reduced by 1.5 times, and the amount of water, sand and crushed stone remained practically unchanged in comparison with 1-6 groups of samples. As expected, the absolute values of the compression and bending strengths in the samples of 7-10 groups were smaller than in the samples of 1-6 groups.

Influence of hardening conditions of concrete on its strength characteristics was also considered. For this purpose, we compared the testing results of the brand samples CK27 from the ninth group with the testing results of the brand samples of CK29 from the tenth group. The hardening conditions of the CK27 (W1) samples were more rigid than the hardening conditions of the CK29 (Ml) samples. Comparing the experimental strength characteristics of these samples, we can conclude that they are almost identical with the barely noticeable tendency that a softer hardening mode is the most acceptable.

Analyzing the testing data as a whole, it can be noted that concrete, made on the basis of slag Portland cement, when included in it surface-active additives (4-6 groups of samples) has no worse strength characteristics than concrete made on the basis of conventional Portland cement, and it can be used for the construction of prefabricated coatings for agricultural aerodromes.

The samples having the shape of a cube, with size 10 x 10 x 10 cm, for the study of concrete on slag Portland cement binder for frost resistance were made. They were subjected to thermic humidity treatment under different regimes and then they were hardened under normal conditions. After a set of strengths for 28 days, they were placed in a freezer where they were subjected to freezing and thawing cycles. One cycle corresponds to 4 hours of freezing at a temperature of T = -20-25 ° C and 4 hours of thawing, after which the samples were filled with water at room temperature. The water was drained after 4 hours and the cycle repeated again [16].

Frost resistance of concrete was visually assessed by a ten-point scale proposed by the professor S.V. Shestoperov. As is known from the large number of experiments carried out on concrete samples from different cements, concrete retains its bearing capacity (does not suffer destruction), if it has scored at least 6 points on this scale [19].

The testing results of concrete samples for frost resistance, which made on the basis of sulfate-resistant slag Portland cement, are given in table 3.

Table 3. The results of testing of concrete samples, made on the basis of slag Portland cement of brand 400, on frost resistance

Brand of concrete samples	Content in 1m^3 of concrete mixture			Water-cement ratio	Hardening conditions	Number of samples	Number of points (b) in non-fracture sample cubes (c) after finishing of the next number of freeze-thaw cycles			
	Cement (C), kg	Water (W), kg	LST in % of cement				65	220	430	630
CK3	450	190	-	0,42	M1	6	10b-6c	9-10b-6c	9b-5c 5b-1c	9b-2c 7b-1c
CK5	450	195	-	0,43	M	6	10b-6c	9-10b-6c	9b-2c 5-6b-4c	7-8b-1c
CK9	450	190	-	0,42	W1	6	10b-6c	9-10b-6c	9b-3c 8b-2c 5b-1c	8b-1c
CK13	450	170	0,2	0,38	M1	6	10b-6c	9-10b-6c	8-9b-6c	8b-1c 6b-5c
CK11	450	170	0,2	0,3U	M	6	10b-6c	9b-6c	9b-6c	9b-5c 7b-1c
CK17	450	175	0,2	0,39	W1	6	10b-6c	9-10b-6c	9-10b-6c	9b-4c 8b-2c
CK21	300	190	-	0,63	M1	6	10b-5c 7b-1c	8-9b-1c 7b-1c 6b-1c	4b-1c	-
CK23	300	195	-	0,65	W1	6	10b-6c	8-9b-3c 7b-1c	4-5b-3c	-

As one can see from table 3, concrete samples of brands CK3, CK5, CK9, CK11, CK13, CK17 have high frost resistance (from 6 to 9 points) even after 630 cycles of freezing and thawing.

The samples of grades CK21 and CK23 with a cement content of 300 kg per 1 m^3 of concrete mixture is characterized by slightly lower frost resistance. However, they can withstand at least 200 cycles of freezing and thawing. It can be concluded that the frost resistance of concrete on slag Portland cement is quite sufficient for the construction of prefabricated coatings of agricultural aerodromes.

Conclusions

Experimental studies of concrete on sulphate-resistant slag Portland cement of brand 400 have shown that the use of this material for the construction of prefabricated coatings for agricultural aerodromes allows to save Portland cement and to use of secondary raw materials.

Such concretes can provide a class of strength on compression C25 / 30 and of strength on bending C_t4.0 at the consumption of slag Portland cement 450 kg per 1 m^3 of concrete mixture.

However, reliable data on the compressive strength and the bending strength are obtained in the case of introduction into the concrete mixture of non-deficient plasticizing additives - lignosulfonates in the amount 0.2% from weight of cement. The bending strength is insufficient if plasticizing additives are absent.

The concrete on sulphate-resistant slag Portland cement has a high frost resistance. Concrete of optimal composition can withstand over 600 cycles of freezing and thawing.

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