Introducing pozzolanic admixture to improve frost resistance of pavement concrete

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Abstract. Concretes with the w/c ratio less than 0.35 that consist of multicomponent mixtures are highly resistant to frost aggression, which increases structure durability. It is generally accepted that cyclic freezing of structures in a saturated state causes concrete disintegration due to ice formation in macro and microcapillaries. The samples of high-performance concrete, experimentally frozen at minus 50 °C and thawed at 20 °C in a 5 % solution of NaCl, dried by themselves, which made ice formation unlikely. The mass of the frozen samples changed approximately the same way as the mass of the control samples, and only after a certain number of cycles the main samples started to sharply gain in mass and lose strength. Moreover, the tested samples showed only slight penetration of moisture deep into the concrete, while its core remained dry. This allows us to assume that when testing the frost resistance of highly functional concrete samples, their disintegration was caused by thermal deformations with practically no ice formation. The use of plasticizers slightly changes the concrete strength to frost resistance, and only a complex admixture, containing superplasticizer and silica fume, allows this factor to be increased 2-3 times. Most effective is a complex of pozzolana and a polycarboxylate superplasticizer.

1. Introduction

As a rule, an increase in frost resistance of concrete is achieved by reducing its water/cement (w/c) ratio, increasing cement consumption, its grade of compressive strength, and air entrainment [1-5]. This approach originated in the research work of T.K. Powers, who put forward a hypothesis about the hydrostatic pressure of water produced by its freezing in macrocapillary pores with an increase in the volume of the solid phase [6,7]. Presently, a number of authors have studied pore space and developed knowledge about air entrainment to improve frost resistance of concrete [8-11]. However, there is evidence to the possibility to obtain high-frost-resistant concrete without air entrainment [12-14]. In this case, some authors consider efficient to use silica fume and other highly active pozzolanic admixtures that change the phase composition of cement stone [15-18]. To effectively use silica fume, it is necessary to introduce also an effective polycarboxylate superplasticizer [19,20]. The effect of phase composition of cement stone in concrete on its frost resistance has not been studied sufficiently.

This research aims to study the effect of complex admixtures on the frost resistance of high-performance concrete, including road surfaces.

2. Materials and methods

To determine the effect of cyclic freezing and thawing, concrete samples were prepared and hardened for 28 days at 20 °C under air-wet conditions and a relative humidity of at least 98 %. Samples were made from ordinary materials of constant quality and Duquerhoff Korkino cement CEM 1 42.5 N. Some of the samples were prepared without admixtures, and some of them – with water-reducing admixtures of polycarboxylate MasterGlenium ACE 430 (ACE) and naphthalene formaldehyde SP-1 in the proportion of 1 % of the cement mass. In addition, a series of samples were prepared with complex admixtures, containing 1 % of superplasticizer ACE or SP-1 and 10 % of silica fume (SF).

3. Results

Experimental samples of concrete cubes with an edge of 10 cm were made from an equally flowable concrete mixtures with the same w/c = 0.31. Figure 1 shows the results of testing concrete samples for compressive strength.

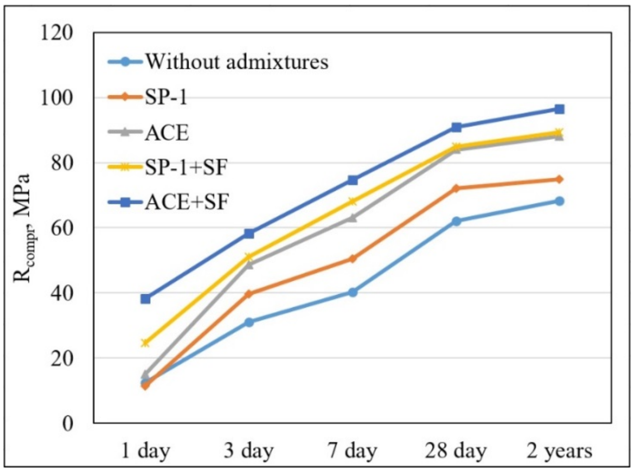

Figure 1. Compressive strength of concrete samples**.**

Plasticizers aged for 24 hours, especially SP-1, slow down the formation of concrete strength, whereas its complex introduction with silica fume increases the daily strength up to 24 MPa with SP-1+SF and up to 38 MPa with ACE+SF. The strength of control samples of the grade age without admixtures is 60 MPa, with SP-1 – 72 MPa, and with ACE – 84 MPa. At all times of hardening, the greatest strength was achieved with the joint action of water reduction and introduction of pozolana, the maximum strength of concrete with ACE+SF reaches 91 MPa. Thus, due to introduction of pozzolana, an increase in component in the cement stone with complex admixtures contributes to the increase in concrete strength at all times of hardening.

The most important characteristic of concrete pavement is its flexural strength. Figure 2. shows the results of 10x10x40 cm beam tests.

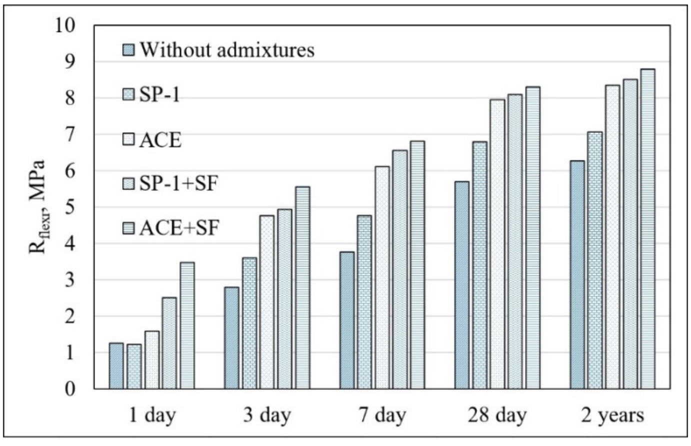

Figure 2. Flexural strength of concrete**.**

Introduction of ACE contributes to the formation of a gel-like structure of cement stone, enhances its adhesion properties and, accordingly, the flexural strength of concrete. Flexural strength of grade age concrete without admixtures is 5.7 MPa, and with admixtures - more than 8 MPa.

Figure 3. shows the data on water absorption of concrete samples with various admixtures.

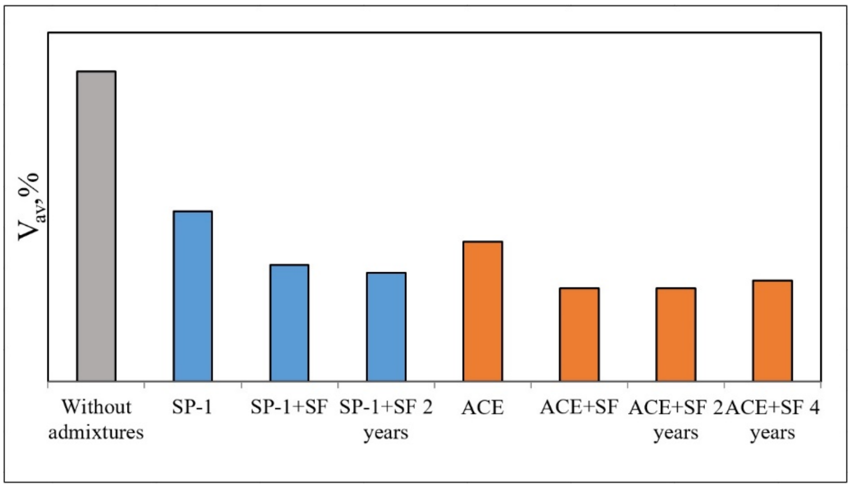

Figure 3. Water absorption of concrete samples according to the mass**.**

The open porosity of concrete, which determines its durability, especially decreases with complex modification, this kind of porosity persists over time, that is, the hydration products form stable structural elements.

Frost resistance is one of the most important indicators of concrete pavement durability, when it is used in the climatic conditions of the Russian Federation. Frost resistance of concrete was determined by the 3rd accelerated method according to GOST 10060-2012. The main samples were tested in series after a number of cycles corresponding to $F_2$100-$F_2$500. Figure 4. shows the results of sample tests.

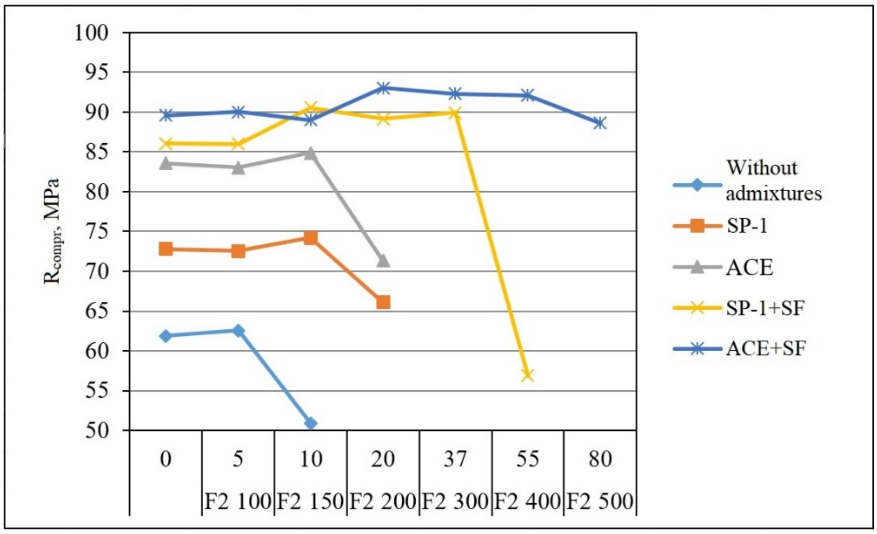

Figure 4. Frost resistance of concrete samples**.**

Introduction of superplasticizer SP-1 allowed us to increase the frost resistance of concrete to $F_2$150, as compared to that of $F_2$100 in pure concrete. It is noteworthy that the strength of the main

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concrete samples increased up to 10 cycles, which allows us to suggest that the structures of the hydrated phases of the cement stone are not stable enough. Some concrete samples with SP-1 showed surface peeling with exposed aggregate grains after 20 cycles of freezing and thawing. Despite the high efficiency of the ACE admixture, which increases the concrete strength, its frost resistance also does not exceed F_2150. Introduction of pozzolanic admixture increases the frost resistance of concrete - if combined with SP-1 to F_2300, and if combined with ACE to over F_2500, therefore introduction of pozzolanic admixture is an effective way to increase the frost resistance of concrete at constant w/c ratio due to the formation of amorphized hydrated phases of increased stability.

Thus, the results of sample tests for the frost resistance of concrete allow us to conclude that the most effective way to increase the durability of concrete is to use a complex additive ACE + SF. A probable reason for increased resistance of concrete with this complex is a decrease in the content of free portlandite in the structure of cement stone [16].

Another criterion for frost resistance is change in the sample mass, presence of external defects, spalling of edges, etc., occurring during cyclic freezing. The standard allows the loss of mass of the main samples that does not exceed 2 %. The evaluation of mass change that was made during the cyclic tests for freezing and thawing revealed a number of features of the obtained high-performance pavement concretes.

Firstly, due to the amorphization of the structure, we achieved low water absorption of control concrete samples and the main ones saturated with standard salt solution.

Secondly, samples of high-performance concrete with an amorphized structure are characterized by self-drying during cyclic freezing and thawing, that is, a relatively thin shell of a liquid-saturated concrete layer is formed on the sample surface, and below it is drier.

Thirdly, it was noted that the mass of the main samples during cyclic freezing and thawing in high-performance concretes did not reduce, but increased due to additional saturation, see Figure 5.

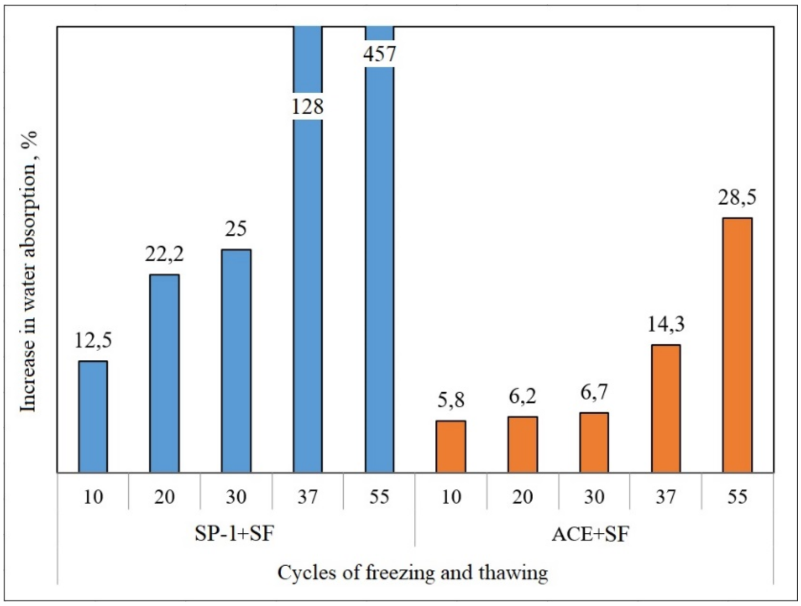

Figure 5. Water absorption of main samples with an increase in the number of freezing and thawing cycles.

The mass increase when control and main samples are saturated is initially identical and only for samples with SP-1+SF there is a sharp mass increase after 37 cycles and especially after 55 cycles due to the formation of additional pore volumes caused by disintegration, which is confirmed by changes in strength characteristics during the frost resistance test. Disintegration may be caused by uneven temperature deformations, especially at the thawing stage, as well as inconsistencies in the coefficient of thermal expansion of concrete components.

4. Conclusions

1. Under the equal technological factors of flowability and w/c ratio, superplasticizers slightly increase the frost resistance of high-performance concrete.
2. It is possible to maximize the frost resistance of concrete to F2500 by introducing polycarboxylate superplasticizer with silica fume.
3. Change in the mass of high-performance samples, which were cyclically frozen in a solution of table salt, can serve as a criterion for their resistance.

References

[1] Shtark I, Vikht B 2004 *Durability of concrete* (Kiev: Oranta) p 301
[2] Zhang J X, Kong X J 2013 *Advanced Materials Research* **857** 212–221
[3] Morozov N M, Krasinikova N M, Borovskikh I V 2015 *Engineering and construction magazine* **7** 30–38
[4] Bazhenov Yu M, Demyanova V S, Kalashnikov V I 2006 *Modified high-quality concrete* (Moscow: ASV) p 368
[5] Ekkel S V 2014 *Technology of concrete* **1 (90)** 36–41
[6] Powers T C 1945 *Proc. ACI* **41** 245–272
[7] Powers T C 1980 *JACI* **77 (4)** 264–268
[8] Hasholt M T 2014 *Mater. Struct.* **47 (5)** 911–923
[9] Micah Hale W, Freyne S F, Russell B W 2009 *Constr. Build. Mater.* **23 (2)** 878–888
[10] Bugrim S F, Slepokurov E I, Mukhametgaleev S P 1980 *The issue of water freezing in capillary-porous bodies* (Moscow: Stroiizdat) pp 89–96
[11] Sheikin A E, Chekhovsky Yu V, Brusser M I 1979 *Structure and properties of cement concretes* (Moscow: Stroyizdat) p 344
[12] Karakurt C, Bayazit Y 2015 *Adv. Mater. Sci. Eng.* **2015** 1–8
[13] Aitcin P C 2004 *High-Performance Concrete* (Quebec: E&FnSpon) p 364
[14] Pigeon M 1996 *3rd Gen. Rep. on Durability, in 4th Int. Symp. on the Utilization of High Strength/High Performance Concrete* (Paris) **1** pp 39–45
[15] Trofimov B Ya, Kramar L Ya 2009 *Popular concrete science* **3** 69–83
[16] Shuldyakov K V, Kramar L Ya, Trofimov B Ya 2016 *Adv. Mat. in Tech. and Constr.* (Tomsk: AIP Conf. Proc.) pp 070011-1-6
[17] Zengqi Z, Zhang B, Peiyu Y 2016 *Construction and Building Materials* **121** 483–490
[18] Sabet F A, Libre N A, Shekarchi M 2013 *Construction and Building Materials* **44** 175–184
[19] Vovk A I 2007 *Technologies of concrete* **2** 8–9
[20] Plank J, Sakai E, Miao C W, Ya C et al 2015 *Cement and Concrete Research* **78 part A** 81–99

Acknowledgments

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