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Abstract. Currently, modern heavy concrete including fine-aggregate ones are systems containing basic and additional components. Their production is not complete without the use of various mineral and organic additives. Such widespread additives include microsilica and various types of polymers. The effective use of additives, based on microsilica with polymers, allows creating heavy concretes with high performance properties. This topic is of a high relevance, so the research works were conducted to study the properties of fine-aggregate concrete, containing microsilica as an active mineral additive in the organic-mineral modifier composition in the Institute of new materials and technologies of Ural Federal University. This paper is devoted to the selection of composition of the organic-mineral modifier, based on the microsilica of OJSC ‘Chelyabinsk Electrometallurgical Works’.

1. Introduction

Active mineral additives (AMA) are fine-milled or fine-dispersed materials consisting mainly of amorphous substance and having pozzolanic or weak hydraulic activity [1]. AMA is introduced into cement compositions to increase the hydration degree and for the directed formation of the cement stone structure of more stable hydrated phases of reduced basicity. Speaking about the origin, the additives of this type have both natural and technogenic origin. Natural additives include volcanic glass, flasks, diatomite. They are used in concrete technology as a local raw material in the presence of the region's relevant rock deposits.

The use of technogenic additives allows solving not only technological problems but also environmental problems associated with the utilization of by-products of the different industries. The high activity additives include fast-cooled metallurgical slags (have mainly hydraulic activity) and ultrafine waste of ferroalloys production – microsilica (with pozzolanic activity) [2].

Microsilica is a byproduct of ferroalloy production and is formed during the smelting of ferrosilicon or its alloys. During the processes mentioned above industrial gases which are formed in furnaces, then taken off and fed into the bag filters where they are cleaned. Purified gases are released into the atmosphere and microsilica enters the collecting bins.

In Northern Europe microsilica is called Condensed Silica Fume, in the USA and Canada – silica dust [3].

Microsilica is the particles with size 100 times smaller than Portland cement grains consisting of amorphous silica. That is in fact it is a highly effective pozzolanic additive [1-2, 4-5].

Initially, microsilica was used as a substitute for cement but with the accumulation of experimental data it began to be used as an additional component that improves the characteristics of concrete both in the newly laid and hardened state [6].

To date there are more than ten standards and technological norms worldwide that allow to use the microsilica in cements and concretes, and at the end of 1996 a new European standard was approved.

The long-term wide popularity of microsilica in European countries is due to the low cost in relation to other additives and at the same time unique opportunities allowing to obtain concretes with high performance and unique structural capabilities from ordinary materials, for example, concretes known in the world as High Performance Concrete [7].

For clarity it is necessary to note a few examples of the use of high-strength concrete on the basis of microsilica in the construction of a complex of high-rise buildings in Chicago, the tunnel under the English channel, the bridge across the Northumberland Strait in Canada, a number of bridges in Japan, Norwegian offshore drilling platforms in the North sea.

Only in Moscow over the past decade with the use of microsilica various objects were built and reconstructed such as: Trade and recreational complex ‘Okhotny Ryad’ on Manezh square, the Kremlin, the Ulyanovsk overpass, the pedestal of the monument ‘Peter I’, etc. [8].

In Russia microsilica is sold in one of three forms:

- uncompacted (MS-85 and MS-65) where the numbers represent the mass content of SiO_2. This is the original form which is extracted from the gas cleaning filters, is an ultrafine gray powder;
- compacted (MSC-85 and MSC-65), it is obtained by granulation of raw materials as a result of air processing in the special equipment;
- suspension (MSS-85) which is an water mixture of microsilica, plasticizers, and if it’s necessary stabilizing components. It is a viscous gray liquid with a density of about 1315 kg/m^3 with a solid phase content of up to 50 % [9].

The microsilica usage allows to influence the properties of building materials positively, improving their quality characteristics namely strength, frost resistance, permeability, chemical resistance, sulfate resistance, wear resistance etc. [10-12]. Due to this, construction materials can resist various negative effects for a long time.

The microsilica is a highly reactive pozzolan addition causing the strengthening effect of the hardening cement system. It binds the lime from the solution more intensively than other mineral additives, for example zeolite tuff, blast furnace and boiler slag [13-14].

However, there is a clear disadvantage of microsilica – is its high dispersion which leads to an increase in water consumption in the concrete mixtures composition [13]. It can be corrected by the introduction of various plasticizers, i.e. organic additives [15-18]. Therefore at present preference is given to the development of complex organo-mineral modifiers allowing to realize the potential of both groups of additives and to obtain a greater effect from their introduction into the mix.

Organo-mineral modifier (OMM) is a poly-component powder material obtained by combining active mineral components and organic additives and destined to improve simultaneously the technological and physical and technical properties of cement systems. Microsilica, fly ash, metakaolin and their mixes are used as the mineral part of OMM. The organic part of OMM is presented by additives of plasticizing and water-reducing action.

2. Results and discussion

The aim of this work is to choose the composition of OMM on the basis of microsilica which will meet the requirements of Russian Standard 56178-2014 [19].

The following raw materials were used in the research: normal hardening Portland cement of type I 32.5 (MPa), sand from crushing granite screening of class II in accordance with the fineness modulus of 3,17 belonging to the group of high fineness sand, microsilica of JSC ‘Chelyabinsk electrometallurgical works’, redispersible polymer powder (RPP) PAV-22 on the basis of vinyl acetate and redispersible polymer powder DPL 210 based on vinyl acetate-ethylene.

For the selection of organo-mineral modifiers based on the selected polymers it was decided to investigate the introduction of different amounts of modifier by weight of cement with different ratios of organic and mineral parts by mathematical planning. This work was carried out by using the full factorial experiment planning method of the type 3^2. A mineral part quantity in the modifier composition as X_1 factor and the organo-mineral modifier quantity (in % by cement weight) as X_2 factor have been used (table 1).

Table 1. Conditions of the experimental design.

Factor description	Symbol	Interval	Values on the level		
			+1	0	-1
Mineral part quantity, %	X_1	19.5	99.5	90	80
Organo-mineral modifier quantity, %	X_2	7.0	15	10	8

According to Russian Standard 56178-2014 the variation intervals of factors have been chosen. In accordance with the planning matrix the concrete mixes with the same workability (115-118 mm) and cement sand ratio = 1:3 have been prepared and the cube-samples with 7 cm side size have been moulded.

The matrix of experimental design and water cement ratio of concrete mix are given in the table 2. The water cement ratio of zero concrete mix was 0.55.

Table 2. The matrix of experimental design and water cement ratio of concrete mix.

Mix number	Formalized factor value		Real factor value		Water cement ratio of concrete mix	
	X_1	X_2	Modifier quantity, %	Mineral part : organic part	PAV 22	DLP 210
1(1')	-1	-1		0.8:0.2	0.64	0.61
2(2')	0	-1	8	0.9:0.1	0.61	0.57
3(3')	+1	-1		0.995:0.005	0.62	0.60
4(4')	-1	0		0.8:0.2	0.61	0.60
5(5')	0	0	10	0.9:0.1	0.62	0.59
6(6')	+1	0		0.995:0.005	0.63	0.58
7(7')	-1	+1		0.8:0.2	0.66	0.66
8(8')	0	+1	15	0.9:0.1	0.67	0.70
9(9')	+1	+1		0.995:0.005	0.68	0.72

Samples were stored under normal conditions at a temperature (20±2) °C and relative humidity (95±5) %. The compressive strengths of concrete samples were determined in 28 days age. The strength test results are presented in table 4.

Experimental data were processed and compressive strength graphic dependences upon the quantity of modifier and quantity of mineral part were plotted with the help of 'Statistica 10.0' software package (figure 1).

It is seen that the area of high performance indexes mixes with PAV22 wider than the compositions with DLP 210. In general for both polymers the zones of high strength have moved towards increasing the quantity of the organo-mineral modifier and the amount of the mineral part in it.

According to the Russian Standard 56178-2014 the efficiency of the class A modifier chosen by us (containing 100 % microsilica as a mineral component) is estimated by two indicators: a decrease in water consumption ΔW and an increase in compressive strength ΔR. These indexes are presented in the table 3.

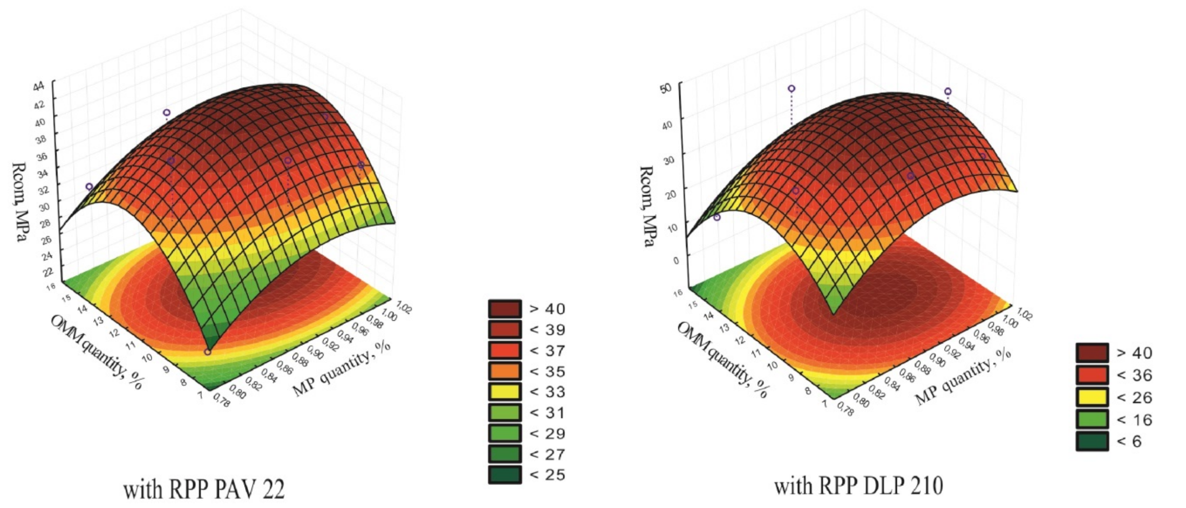

Figure 1. The curvilinear dependence of compressive strength of the fine-aggregate concretes after 28 days age with different organic part in the OMM composition.

There was no any reduction of water consumption in the mixes with PAV 22, so it can be concluded that the quantity of entered additive (RPP PAV 22) is insufficient and it is necessary to enter it in greater quantity [20]. RPP DLP 210 in the modifier composition effectively affects the reduction of water consumption. Regardless of the quantity of the entered organic-mineral modifier and the type of the organic part the concrete strength is higher at a ratio of the mineral part to the organic one 0.9:0.1.

Table 3. Organic-mineral modifiers efficiency indexes.

Mix number	Water reduction, %		Strength change, %	
	PAV 22	DLP 210	PAV 22	DLP 210
1(1’)	-1.5	0	-22.4	-24.8
2(2’)	-3.0	3.9	6.0	-1.5
3(3’)	-4.2	-0.6	-5.0	-12.0
4(4’)	0	1.8	10.0	-2.0
5(5’)	-1.8	3.0	16.8	24.5
6(6’)	-2.7	4.6	0.3	16.4
7(7’)	-3.0	-1.8	-15.0	-7.1
8(8’)	-4.2	-7.6	-2.1	6.8
9(9’)	-6.0	-11.2	-13.0	-4.7

3. Conclusion

According to the Russian Standard 56178-2014 the most effective composition was 5’ (with RPP DLP 210) containing an organo-mineral modifier in an amount of 10 % by weight of cement with a ratio of the mineral part to the organic one 0.9:0.1.

According to Russian Standard it can be classified as an organic-mineral modifier of class A, type I, group 4. As a result, the composition of the organic-mineral modifier was selected:

- organic part - polymer based vinyl acetate-ethylene;
- the percentage of microsilica and polymer is 90:10 %;
- quantity of organic-mineral modifier for fine-aggregate concrete is 10 %.

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