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Silica fumes of different types for high-performance fine-grained concrete

Микрокремнеземы различных типов для высокопрочных мелкозернистых бетонов

A.S. Rassokhin,
A.N. Ponomarev,
Peter the Great St. Petersburg Polytechnic University, St. Petersburg, Russia
O.L. Figovsky,
International Nanotechnology Research Center Polymate, Migdal Haemek, Israel

Аспирант А.С. Рассохин,
канд. техн. наук, профессор А.Н. Пономарев,
Санкт-Петербургский политехнический университет Петра Великого, г. Санкт-Петербург, Россия
д-р техн. наук, директор О.Л. Фиговский,
International Nanotechnology Research Center Polymate, г. Мигдаль ха-Эмек, Израиль

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Ключевые слова: микрокремнезем; мелкозернистый бетон; модифицированный бетон; наноуглерод; сравнение свойств

Abstract. One of the most often and successfully applied admix as a part of the modified concrete is active amorphous silica fume. The increased practical interest in this admix has led to emergence in the market of various producers and also to emergence of different types (brands) of the silica fume produced from various raw materials with use of various technologies. At the same time their makeup, dispersion and content of silicone dioxide drastically ranges. It takes toll on results of use of such admixes in relation to the same recipes of concrete mixtures. The research is focused on the experimental study of the most useful types of active silica fume and the comparison of results of their using in fine-grained concrete. Results of these researches have shown a dependence of properties of the modified concrete on the content of active silica fume and from degree of its dispersion. The best results had silica fumes produced as the accompanying product by silicon production and including some additional quantity of particles of nanodimensional carbon.

Аннотация. Одна из наиболее часто и успешно применяемых добавок в составе модифицированных бетонов – активный аморфный микрокремезем. Однако повышенный практический интерес к этой добавке привел к появлению на рынке различных производителей и, что более существенно, к появлению различных видов (марок) микрокремнеземов, получаемых из различного сырья с использованием различных технологий. При этом заметно варьируется их состав, дисперсность и содержание собственно диоксида кремния. Это не может не сказываться на результатах использования таких добавок применительно к одним и тем же рецептурам бетонных смесей. Настоящая работа посвящена экспериментальному исследованию нескольких, наиболее распространенных в настоящее время видов активного микрокремнезема и сопоставлению результатов их применения в мелкозернистых бетонах. Результаты этих исследований показали зависимость характеристик модифицируемых бетонов от содержания активного микрокремнезема и, особенно, от степени его дисперсности. Наилучшие результаты были получены для микрокремнеземов, получаемых, как сопутствующий продукт при производстве кремния и содержащего некоторое дополнительное количество частиц наноразмерного углерода.

1. Introduction

Active silica fume is an important part of many high-strength and special concrete now that has led to emergence in the market of various producers and also to emergence of different types of active silica fumes. It affects properties of the product. From the analysis of literature, it is visible that active silica fume was initially used only as means for increase in strength characteristics of the modified concrete

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and cement economy [1–5]. A little later, it has become clear, that the use of this admix allows to improve also rheological and technological properties of concrete [6, 7] and, along with a plasticizing agent, to provide effective water reduction and increase in durability (frost resistance) of the created concrete. The first detailed contributions about results of comparative researches of properties of fine-grained concrete with the silica fumes containing various amount of silicon belong to the beginning of the 90th years [8–14]. Industrial production of silica fume for use in construction has reached mass proportions so far. The statutory enactments use of active silica fume and other mineral and organo-mineral microadmixes to concrete have been developed [15–20]. And new combinations of silica fumes not only with plasticizing agents, but also with some new types of nanocarbon have been developed [21–25]. All this does relevant this research to find out the best materials in the market. The main research task is the detailed comparative study of the quality of silica fume of various producers and effects of their application in recipes, first of all, of fine-grained concrete because use of the modified fine-grained concrete all-time increases [26–32].

2. Methods

As the studied types of silica fume in this research have been studied:

- amorphous silica fume MKU-85 (compacted) productions of JSC Kuznetskiye ferrosplavy containing 82-87% of SiO_2;
- amorphous silica fume MKU-95 (compacted) productions of JSC Kuznetskiye ferrosplavy
- amorphous silica fume MKU-95 productions of PJSC Rusal;
- amorphous silica fume MD1 productions of pilot production of INRTU [33];
- amorphous silica fume with nanocarbon MD2 productions of pilot production of INRTU [33];
- amorphous silica fume with mark MK 17-42 productions of PJSC Rusal.

For research of extent of influence of dispersion of silica fume on properties of the modified concrete have been used methods of mechanical (spherical and planetary mills) and ultrasonic dispergating (the density of the power of ultrasonic machining is from 3 to 5 VA/cm³). The size distribution of silica fume before additional dispergating and after additional dispergating was controlled on a laser granulometr "Mastersizer" productions of Malvern Instruments Ltd.

The test recipe of fine-grained concrete is:

- Portland Cement CEM I 42.5 N, production of JSC Mordovtsement (content of free alkalis (in terms of Na_2O) doesn't exceed 0.85% of masses)……………………………18.82 % of masses;
- Washed-out river sand with the fineness modulus 0.5………………………..66.42 % of masses;
- Silica fume of different studied types ………………………………………..….3.32 % of masses;
- Water of mixing as per GOST Standard 23732-2011 [21]………………...….11.44 % of masses;

The prepared concrete mixes were filled in standard forms with the sizes of 100x100x100 mm (time of vibration is 30 seconds) in number of 6 pieces for each type of the test mix and for every curing period. Form stripping was carried out on the second day. The tests of control samples for compressive breaking strength as per Russian State Standard GOST 10180-90 [22] on a hydraulic press PSU – 50A (the certificate on checking No. 0028982 of March 09, 2017) were carried out for 2, 3, 7, 14, 17, 21 and 28 days.

3. Results and Discussion

Characteristic results of additional dispergating of silica fume MKU-85 by mechanical methods (in spherical and planetary mills) are presented on Figure 1.

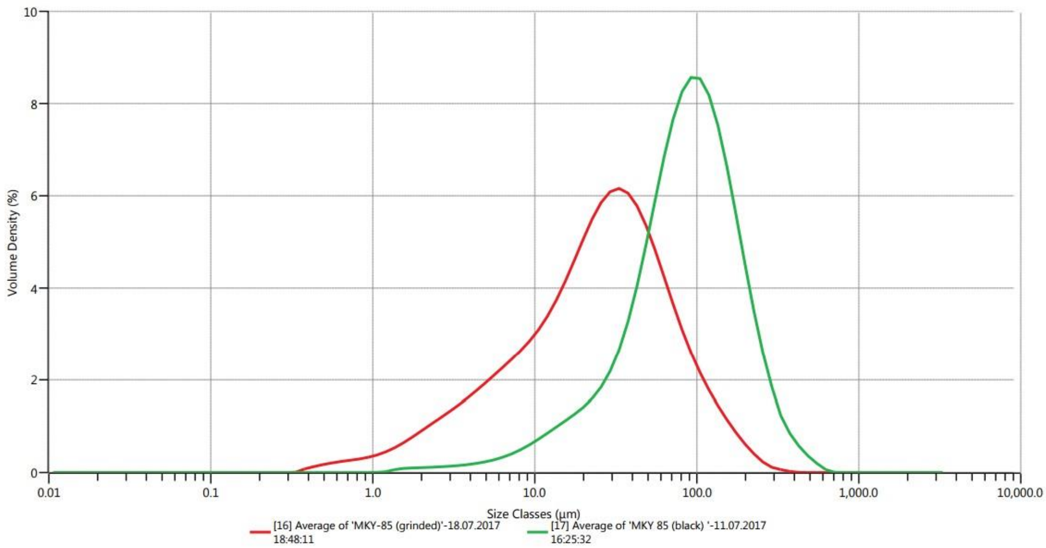

Figure 1. Size distribution of particles of initial MKU-85 and MKU-85 after additional mechanical dispergating

On the graphics (Figure 1) it is distinctly noticeable that particles that size less than 1 micron are practically absent in initial MKU-85 and that the quantity of particles that size less than 10 microns don´t exceed 4.5 % of masses. After an additional mechanical dispergating the quantity of particles with sizes less than 10 microns already exceeds 26 % of masses. Also, the fraction begins to be shown by sizes less than 1 micron.

The results of the additional dispergating of silica fume MD2 with admixes of carbon nanoparticles (up to 0.5 %) are presented in Figure 2.

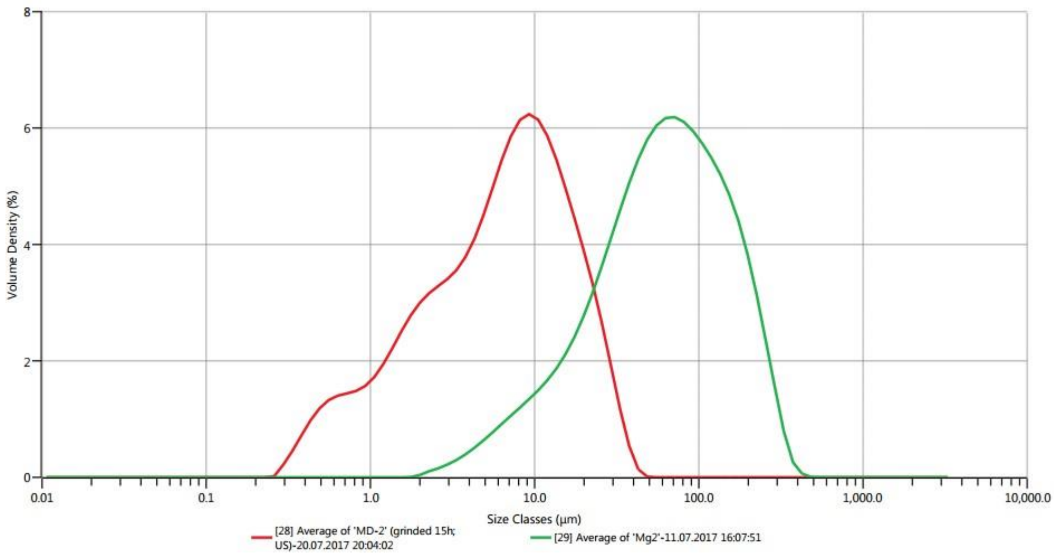

Figure 2. Particle size distribution of initial MD2 and MD2 after additional mechanical dispergating

Here it is impressive to see that particles that size less than 1 micron are completely absent as a part of MD2 before additional dispergating and a quantity of particles with a size of less than 10 microns is available no more than 6.8% of masses. The results are obtained by the weight of the spectra recorded on a dense cardboard. After dispergating the situation changes the quantity of particles with a size of less than 10 microns is available already more than 65 % of masses. Also, there are particles with a size of less than 1 micron in the quantity of about 10.5 % of masses.

The results of additional ultrasonic dispergating of the particles of silica fume MKU-85 which have undergone intensive mechanical dispergating show some displacement of this distribution towards increase in quantity of particles of the smaller sizes (Figure 3).

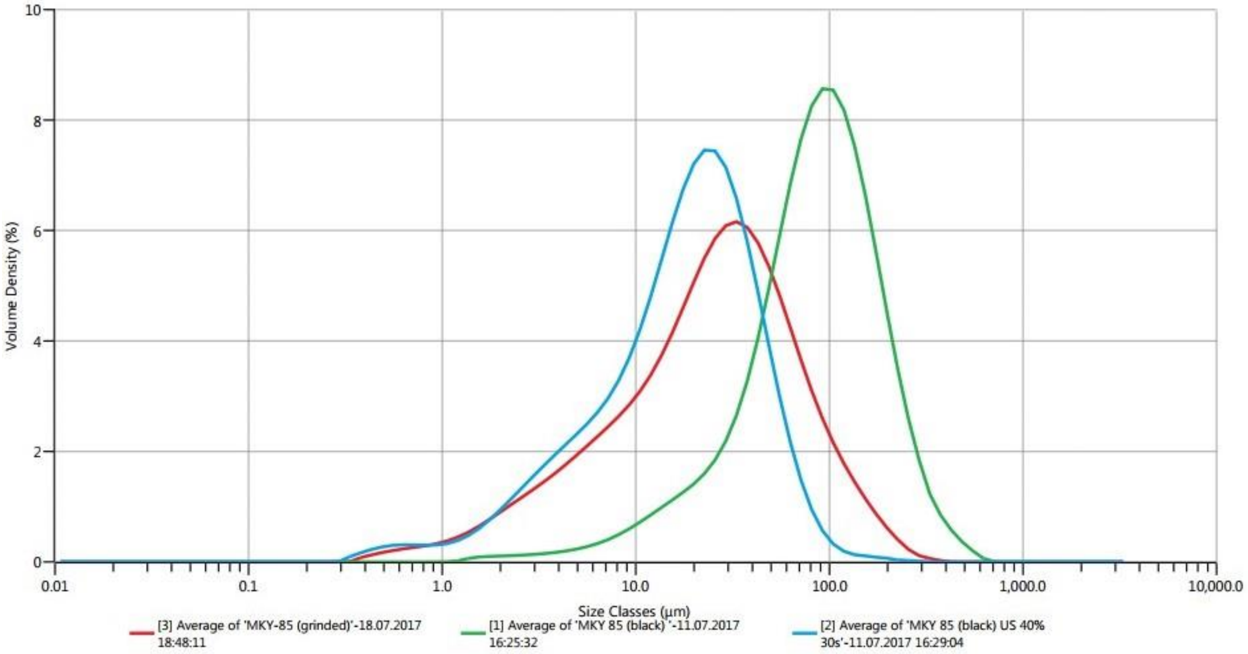

Figure 3. Particle size distribution of silica fume MKU-85 pre- and post of ultrasonic and mechanical dispergating

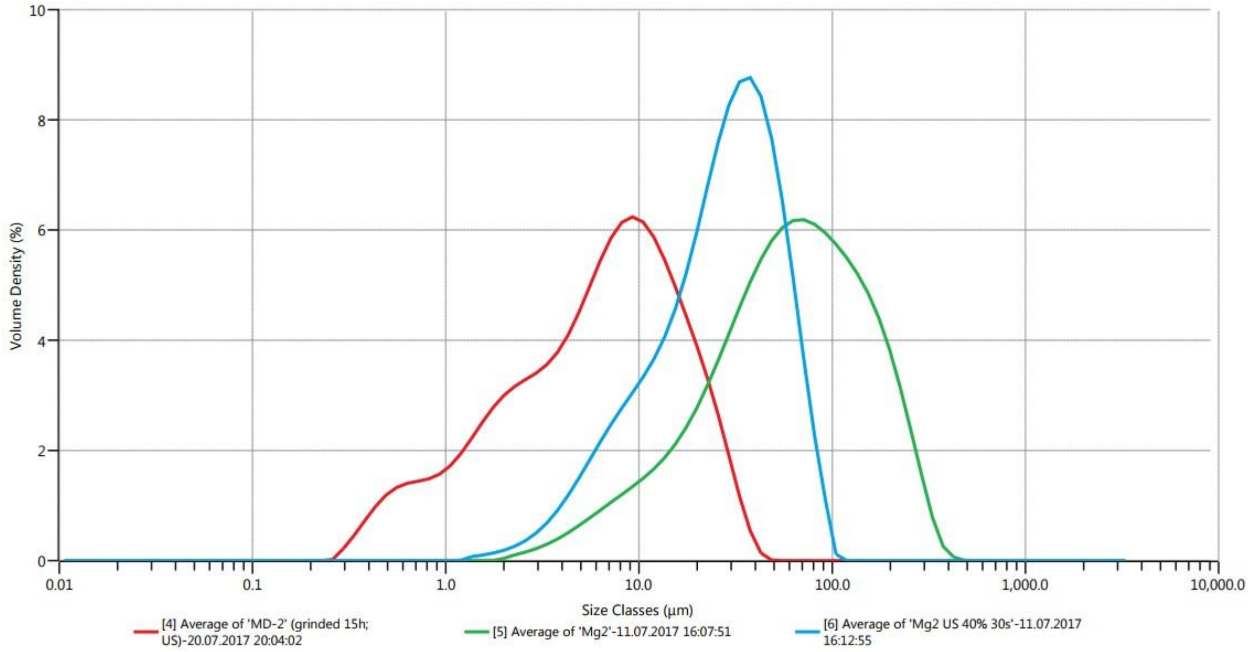

Figure 4. Particle size distribution of silica fume MD-2 pre- and post of ultrasonic and mechanical dispergating

The results of the ultrasonic dispergating for the MD-2 are in an interval between size distribution of initial silica fume and size distribution of the silica fume particles which have been mechanically dispersed (Figures 3 and 4).

It is possible to interpret such differences proceeding from the fact that as a part of the MD-2 there are carbon nanoparticles which promote aggregation of silica fume particles at enough high concentration of silica fume in dispersion.

Nevertheless, the main interest is represented by the obtained results at determining of compressive breaking strength of samples of the fine-grained concrete modified by different types of the silica fumes which are different not at least because of the structure dispersion. The obtained results on various curing periods of concrete samples are given in the Tables 1–7.

Table 1. Comparative properties of the test samples of fine-grained concrete modified by different types of silica fumes (curing period is 2 days)

Type of silica fume \ Properties of concrete	Compressive breaking strength, MPa, 2 days	Density, g/cm^3	Strength-to-density ratio
Check sample, without silica fume	8.1	2.26	3.58
Sample with MKU-85	11.15	2.19	5.09
Sample with MKU-85 with additional dispergating	8.1	2.24	3.61
Sample with MKU-95	11.1	2.24	4.95
Sample with MKU-95 with additional dispergating	7.85	2.17	3.62
Sample with MKU-95* productions of PJSC Rusal	13.65	2.26	6.04
Sample with MD-2	10.1	2.27	4.45
Sample with MD-2 with additional dispergating	7.35	2.21	3.33
Sample with mark 17-42 of PJSC Rusal	13.55	2.26	6.0

Table 2. Comparative properties of the test samples of fine-grained concrete modified by different types of silica fumes (curing period is 3 days)

Type of silica fume \ Properties of concrete	Compressive breaking strength, MPa, 3 days	Density, g/cm^3	Strength-to-density ratio
Check sample, without silica fume	12.15	2.245	5.41
Sample with MKU-85	15.15	2.21	6.85
Sample with MKU-85 with additional dispergating	11.1	2.21	5.02
Sample with MKU-95	15.45	2.26	6.84
Sample with MKU-95 with additional dispergating	10.9	2.2	4.95
Sample with MKU-95* productions of PJSC Rusal	17.3	2.25	7.69
Sample with MD-2	14.15	2.25	6.29
Sample with MD-2 with additional dispergating	10.1	2.22	4.55
Sample with mark 17-42 of PJSC Rusal	14.7	2.14	6.87

Table 3. Comparative properties of the test samples of fine-grained concrete modified by different types of silica fumes (curing period is 7 days)

Type of silica fume \ Properties of concrete	Compressive breaking strength, MPa, 7 days	Density, g/cm^3	Strength-to-density ratio
Check sample, without silica fume	17.25	2.25	7.67
Sample with MKU-85	29.51	2.2	13.41
Sample with MKU-85 with additional dispergating	27.15	2.2	12.34
Sample with MKU-95	23.4	2.24	10.45
Sample with MKU-95 with additional dispergating	28.2	2.22	12.7
Sample with MKU-95* productions of PJSC Rusal	31.9	2.235	14.27
Sample with MD-2	21.2	2.245	9.44
Sample with MD-2 with additional dispergating	29.75	2.215	13.43
Sample with mark 17-42 of PJSC Rusal	27.1	2.125	12.75

From the Tables 1-3 it is absolutely visible that silica fumes MKU-85, MKU-95 with additional dispergating, MKU-95*, MD-2 with additional dispergating and MK 17-42 lean toward to attainment of the early strength of the check samples. It will be possible to discuss the possible reasons of such a fact after an analysis of all data on a curing period of am attainment of maximum strength, which will be specified in the subsequent Tables 4–7.

Table 4. Comparative properties of the test samples of fine-grained concrete modified by different types of silica fumes (curing period is 14 days)

Type of silica fume / Properties of concrete	Compressive breaking strength, MPa, 14 days	Density, g/cm^3	Strength-to-density ratio
Check sample, without silica fume	23.2	2.23	10.4
Sample with MKU-85	33.41	2.2	15.18
Sample with MKU-85 with additional dispergating	35.65	2.195	16.24
Sample with MKU-95	26.1	2.225	11.73
Sample with MKU-95 with additional dispergating	33.9	2.19	15.48
Sample with MKU-95* productions of PJSC Rusal	35.31	2.23	15.83
Sample with MD-2	24.42	2.24	10.9
Sample with MD-2 with additional dispergating	37.2	2.23	16.68
Sample with mark 17-42 of PJSC Rusal	32.7	2.125	15.39

Table 5. Comparative properties of the test samples of fine-grained concrete modified by different types of silica fumes (curing period is 17 days)

Type of silica fume / Properties of concrete	Compressive breaking strength, MPa, 17 days	Density, g/cm^3	Strength-to-density ratio
Check sample, without silica fume	25.0	2.225	11.23
Sample with MKU-85	35.0	2.05	17.05
Sample with MKU-85 with additional dispergating	37.1	2.195	16.9
Sample with MKU-95	27.65	2.21	12.51
Sample with MKU-95 with additional dispergating	36.35	2.17	16.75
Sample with MKU-95* productions of PJSC Rusal	36.72	2.225	16.5
Sample with MD-2	25.05	2.235	11.2
Sample with MD-2 with additional dispergating	41.0	2.2	18.63
Sample with mark 17-42 of PJSC Rusal	33.15	2.12	15.62

Tables 4 and 5 equally fix the dominating strength enhancement on the compression for control samples with an admix of MKU-85, of MKU-85 with an additional dispergating, of MKU-95 with an additional dispergating, of MKU-95 productions of PJSC Rusal, as also of MD-2 with an additional dispergating.

On the basis of the data it is possible to mention the availability of a not really big but stable effect of an air entrainment, which is characteristic for silica fumes MKU-85, MKU-95 and MK 17-42 regardless of their dispersion degree.

Table 6. Comparative properties of the test samples of fine-grained concrete modified by different types of silica fumes (curing period is 21 days)

Type of silica fume / Properties of concrete	Compressive breaking strength, MPa, 21 days	Density, g/cm^3	Strength-to-density ratio
Check sample, without silica fume	26.1	2.225	11.73
Sample with MKU-85	36.41	2.2	16.55
Sample with MKU-85 with additional dispergating	38.82	2.19	17.72
Sample with MKU-95	28.73	2.21	13.0
Sample with MKU-95 with additional dispergating	38.15	2.17	17.58
Sample with MKU-95* productions of PJSC Rusal	39.55	2.225	17.77
Sample with MD-2	27.9	2.235	12.48
Sample with MD-2 with additional dispergating	43.15	2.2	19.61
Sample with mark 17-42 of PJSC Rusal	34.55	2.12	16.29

Table 7. Comparative properties of the test samples of fine-grained concrete modified by different types of silica fumes (curing period is 28 days)

Type of silica fume \ Properties of concrete	Compressive breaking strength, MPa, 18 days	Density, g/cm^3	Strength-to-density ratio
Check sample, without silica fume	27.9	2.225	11.23
Sample with MKU-85	38.27	2.195	17.43
Sample with MKU-85 with additional dispergating	40.35	2.19	18.42
Sample with MKU-95	30.2	2.21	13.66
Sample with MKU-95 with additional dispergating	39.6	2.165	18.29
Sample with MKU-95* productions of PJSC Rusal	40.42	2.225	18.17
Sample with MD-2	29.12	2.233	13.1
Sample with MD-2 with additional dispergating	44.24	2.197	20.13
Sample with mark 17-42 of PJSC Rusal	36.13	2.116	17.07

Summarizing the experimental data obtained in the research on the comparison of 8 types of active silica fume manufactured now in the Russian Federation, it is possible to draw the following main conclusions:

– the best results on late terms of concrete maturity had silica fume MD2 with additional dispergating (with additive of nanodisperse carbon of 0.5 % of masses, productions of pilot production of INRTU). The increase of strength of the fine-grained concrete by it referred of control sample modified without admixes has made 58.5 %.

The most air-entering properties has shown silica fume with mark 17–42 productions of PJSC RUSAL. Its air-entering property at concentration of admix in 3.32 % of masses referring the mass of concrete mix (17.6 % of masses referring the mass of cement) was from 3.4 % to 6.6 %.

Some of the made available samples of silica fumes (from our point of view) were retained or transported to the test location in breach of temperature-humidity conditions, in particular samples of silica fume MD-1, which have been rejected. It has led to an increase in amount of sorption humidity and to partial loss of activity. However, as it was revealed, except reduction of the sizes of particles at additional dispergating there is almost a complete recovery of admix activity.

Besides of the comparison of properties of fine-grained concrete modified by silica fumes of different types this research confirms earlier conducted researches in the field.

This research like other [1–9, 17] shows increase in durability of concrete when using silica fume.

Also, there is a confirmation of improvement of properties of silica fume at increase in its dispersion which has been made in the article [17].

This research confirms improvement of properties of silica fume at addition of microamount of nanodimensional carbon that has been investigated in the research [28].

4. Conclusions

The main result of the research can be considered the comparison of several, best known types of active silica fumes manufactured in the Russian Federation in the recent years. All tested types of active silica fumes were suitable for an improvement of strength (and also rheological) properties of fine-grained concrete. The use of the studied types of silica fumes in quantity up to 17.6 % of the mass of cement brings in an increase in strength properties of control samples of fine-grained (sand) concrete at a size from 29.5 % to 58.5 %. The shared use of these admixes with a plasticizing agent of perspective generations promises much more impressive results that forms the basis for continuation of this research. From all studied samples the best results were shown by the silica fume MD-2 productions of pilot production of INRTU activated by microamount of nanodimensional carbon.

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Aleksandr Rassokhin,
+7(911)526-68-59; rassokhinaleksandr@gmail.com

Andrey Ponomarev,
+7(911)929-35-22; 9293522@gmail.com

Oleg Figovsky,
+97(250)577-99-20; figovsky@gmail.com

Александр Сергеевич Рассохин,
+7(911)526-68-59;
эл. почта: rassokhinaleksandr@gmail.com

Андрей Николаевич Пономарев,
+7(911)929-35-22;
эл. почта: 9293522@gmail.com

Олег Львович Фиговский,
+97(250)577-99-20;
эл. почта: figovsky@gmail.com