Journal of International Scientific Publications:
Materials, Methods & Technologies, Volume 7, Part 2
ISSN 1313-2539, Published at: http://www.scientific-publications.net

APPLICATION OF THE HIGHLY DISPERSED MATERIALS IN THE FINE GRAINED CONCRETE

Ludmila A. Veshnyakova, Tatiana A. Makhova, Arcady M. Ayzenstadt, Ekaterina A. Grunova
Northern (Arctic) Federal University named after M.V. Lomonosov
17, Severnaya Dvina Emb. Arkhangelsk, Russia

Abstract

Samples of sand in a highly dispersed state were obtained. Mathematical models depending on the bulk density of the dry construction mixes with the sand in a highly dispersed state are proposed. The optimal composition and the efficient fine grained concrete with sand in a highly dispersed state was developed.

Key words: *dry mix, the optimal composition, fine grained concrete, mathematical modeling*

1. INTRODUCTION

Currently, the development of scientifically engineered solutions for obtaining high-strength concrete, modified nanoparticles is relevant and very important task. [Gopalakrishnan at all, 2011] Research shows that the most promising solution to produce high quality composite building materials, suitable for long term operation in extreme conditions is to use the micro-and nanosystems and nanotechnology approach in their creation. [Ryzhonkov, 2008].

This applies also to the process of obtaining a concrete composite. So, besides the binders, which are the main structure- shaping components, important components of the concrete are small -sized fillers and large-sized fillers of the mixtures. Small -sized fillers are mainly involved to the formation of the binder microstructure, large-sized fillers are form conglomerate macrostructure.

Large-sized fillers in concrete are occupy about 80% of the volume and have a significant impact on the physical and mechanical properties of concrete, as well as on its cost. Rigid skeleton of high-strength large-sized filler increases the strength and deformation modulus of the concrete, reduces the structural distortion under the load and creep of the concrete [Andrievsky, 2005].

High strength concrete is achieved by adjusting its properties by optimizing the particle size distribution of the large-sized fillers and reducing its void index; the using of special cements, including modified by milling; using of plasticizers, additives and highly dispersed chemicals (small-sized fillers) [Gusev, 2005]. Therefore, proportioning of the concrete in the fine grained concrete technology becomes very important because of their ensuring the amount of cementitious material, distributing in the effective volume of the composite, optimizing the particle size distribution of the large-sized fillers, small-sized filler and cement particles for the achievement the possibility of the mineral grains close packing. Under these conditions, fine grained concrete have a high packing density and, consequently, high initial and final strength.

Usually water-cement paste fills the voids between the grains of the large-sized filler, and only slightly pushing them (by the amount of two or three medium diameter cement grains). With this connivently arrangement grain of the large-sized filler, properties of the highly dispersed filler lead to the marked effect on the concrete strength.

Based on the above stated, adding various dispersed fillers in high-and ultradispersed state is the way to improve the properties of fine grained concrete. This way is consist with regulating the structure and consequently reaching reduction of material consumption of a concrete structure [Bazhenov, 2006]. A nanodisperse material is a system, which having an excessive surface energy and high reactivity, requires thorough studies of control mechanisms for the change of composite properties. It also requires to work out methods for production nanomodified surfaces of disperse materials. [Gusev, 2005, Smirnov, 2011, Frolova at all, 2011]. At the same time, we believe that a complex approach to the formation of nanocomposites with optimum or desired composition of nanosized constituents presupposes working out of an algorithm to calculate energy parameters of disperse material surface. This algorithm is based on thermodynamic evaluation of energy properties of nano-fillers surface [Veshnyakova at all, 2012, Tutygin at all, 2012]. In the research [Veshnyakova at all, 2012] the applicability of the thermodynamic approach to the optimization of a two-component mixture of river sand and highly- dispersed sand was shown.

So, the following research goals were defined: to experimentally obtain highly-dispersed systems from fine river sand - based raw materials of Arkhangelsk region; to research the influence of the highly-dispersed systems on the bulk density value of the dry mix for the fine grained concrete.

2. EXPERIMENTAL

2.1. Materials

As inert large-sized filler, river sand from the field "Kenitsy" Arkhangelsk region was used. As a binder, Portland cement CEM I 42,5B by OJSC "Mordovcement" was used. Fine river sand was used as the basis for the highly-dispersed filler making. Fine river sand was pre-washed from clay particles, dried and made to constant weight at 105°C. The total weight of the sand was separated as follows: fraction larger 5 mm was removed; the rest of the sand was used for the grinding.

2.2. Methods

Chemical composition of the obtained sand in highly-dispersed state was described by X-ray fluorescent spectroscopy with Shimadzu EDX-800 HS spectrometer

The process of dispersion was carried out on the vibration mill MB 20-1,5, using dry method.

Particle size distribution of the sand in highly-dispersed state (small-sized filler) was determined with Delsa Nano Series Zeta Potential and Submicron Particle Size Analyzers and Mettler Toledo probes with Focused Beam Reflectance Measurement system, i.e. Lasentec S400E with laser videomicroscopy system PVM V819.

Determination of the specific surface area of the sand in highly-dispersed state was performed with volumetric adsorption method. The method deals with the analysis of gas trapping by solid at constant cryogenic temperature and gradual increase in pressure.

The density for the tested samples was determined by weighing waxed samples and with the help of pycnometer test according to GOST (all-Union state standard) 5180-84 «Soils. Methods of determining physical characteristics in laboratory conditions».

3. RESULTS AND DISCUSSION

Content of the main components (calculated as oxides) in the tested sand in the highly- dispersed state as follows: SiO_2 (58%), MgO (8%), Fe_2O_3 (5%), CaO (14%), Al_2O_3 (9%), the total content of other components is 19%.

Selected river sand as large-sized filler, satisfies the requirements for the materials used for making the control and the main compositions of the fine grained concrete (Table 1).

Table 1. Results of tested samples of the river sand

True Specific Gravity, ρ_{tr}^{sp}, g/sm^3	Bulk Density, $\rho_{н}^{ср}$, g/sm^3	Voidage, V_{void}, %	Fineness Modulus of Sand, M_F	Group of Sand	Class of Sand
2,640	1,667	36,9	2,23	medium size	I

The results about the size characteristic of the highly-dispersed sand, implemented on the Delsa Nano analyzer, were shown in Table 2. The treated results of the determination of the size in fractures and quantity of the particles in the different ranges of the highly-dispersed sand, implemented on the Lasentec S400E analyzer with the focused beam reflectance measurement system (FBRM), were shown in Table 3.

In Fig. 1 shows the photos of the shape and size of the sand particles before and after grinding, obtained with the using laser videomicroscopy PVM V819.

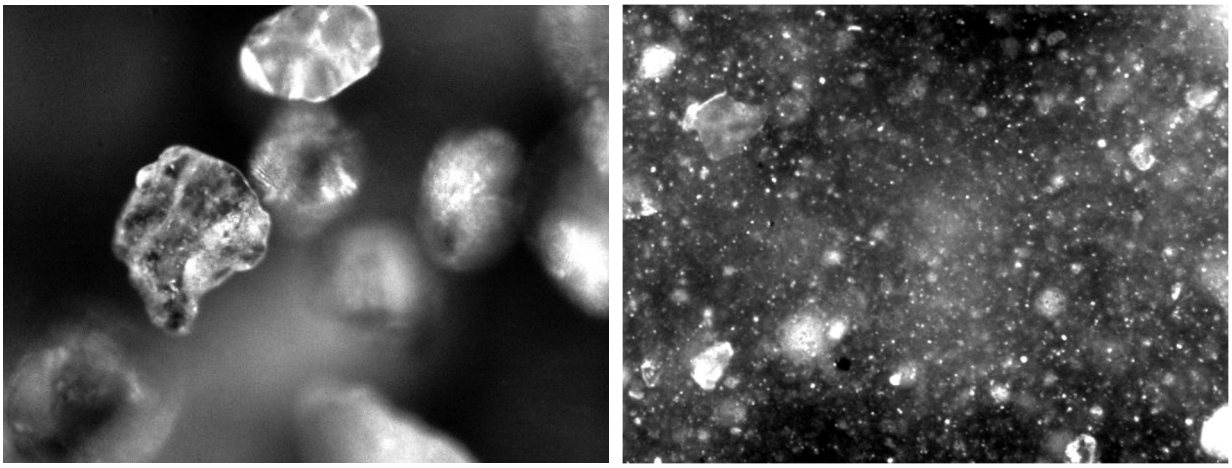
Data indicates that for the system in the nano-and colloid-dispersed state with range of the particle size 1 ÷ 500 nm, which was stable for sedimentation and aggregation, the analyzer DelsaNano was accepted for receiving correct and reproducible results. Using the Lasentec S400E system was preferred for the micro-and coarsely dispersed systems (500 nm and above). Combination of two these methods was realized for the full analysis in determination of the particle-size distribution for the polydisperse system [Veshnyakova at all, 2012].

Table 2. Characteristic of fractions of the highly-dispersed sand, implemented on the Delsa Nano analyzer

Grinding time t, min	Size in fractures, nm / Composition,%							Average size, nm
	№ 1	№ 2	№ 3	№ 4	№ 5	№ 6	№ 7	
480	450,1/21	750,2/11	462,1/12	474,3/12	486,9/11	499,8/10	513,0/8	483,0±39,4

Table 3. Quantitative characteristic of fractions of the highly-dispersed sand, implemented on the Lasentec S400E analyzer

Grinding time t, min	Quantity of the particles in the range, μm., pcs./ Composition,%					
	300-500	150-300	50-150	10-50	5-10	1-5
480	0,11 /0,01	0,05 /0,00	3,21 /0,36	227,64 /25,21	220,63 /24,43	451,25 /49,98



a b

Figure 1 - Photos of the different samples of the sand, implemented on the PVM V819 System (Particle Vision and Measurement for Process R&D), Mettler Toledo: a – sample of sand before grinding, b – sample of the highly-dispersed sand (after grinding)

Specific surface area of the sand in highly-dispersed state was 8580 ± 43 м^2/кг. This value of the specific surface area is comparable to the published data for fine small-sized fillers.

As mentioned earlier, the achievement of the highest packing density (ie, optimizing particle size distribution of the dry mix) can be achieved by mixing the real raw components with their grain composition in the optimal ratio. To determine the ratio content of the dry mix, i.e. sand in a highly dispersed state, portland cement and river sand, providing the most particles dense packing (maximum bulk density of the dry mix), a full factorial planning experiments with the using central composite orthogonal design with the simultaneous variation of components was made: the mass fraction of binder (C = 400-600 kg.), river sand (S = 1400-1600 kg), highly dispersed sand (NS = 2-6%) with other invariable parameters. Mathematical model was adopted as a function that relates the parameter optimization - bulk density of dry mix for fine grained concrete, with variable factors: cement content (X_1), river sand content (X_2) and small-sized filler content in a highly dispersed state (X_3).

The value of the bulk density of dry construction mix for the fine grained concrete is influenced by the content of cement, river sand and small-sized filler in a highly dispersed state with all other invariable parameters. The value of main level of each independent variable was set (Table 4). When the degree of the polynomial chosen for describing the process, equal $k \leq 4$, only full factorial experiment plan (FFE) was accepted as the core of an orthogonal central composite plan. Power order of the plan was defined $k=2$ for describing the experiment process. The total number of tests in the matrix of the composite plan of three-factor experiment was 15. Planning matrix and the values of the response function are shown in Table 5.

Table 4. Varying levels of the experiment factors

Factors		Varying range,	Varying levels				
in natural form	in coded form	Δx_i	-α	-1	0	+1	+α
Cement content, g	X_1	100	378,5	400	500	600	621,5
River sand content, g	X_2	200	1357	1400	1600	1800	1843
Highly dispersed sand content,%	X_3	2	1,57	2	4	6	6,43

Table 5. Planning matrix of dry construction mix testing

№	Factor Values					
	In dimensionless coordinate system			In the natural scale		
	X_1	X_2	X_3	Cement, g	River sand, g	Highly dispersed sand,%
1	-1	-1	-1	400	1400	2
2	+1	-1	-1	600	1400	2
3	-1	+1	-1	400	1800	2
4	+1	+1	-1	600	1800	2
5	-1	-1	+1	400	1400	6
6	+1	-1	+1	600	1400	6
7	-1	+1	+1	400	1800	6
8	+1	+1	+1	600	1800	6
9	-α	0	0	400	1600	4
10	+α	0	0	600	1600	4
11	0	-α	0	500	1400	4
12	0	+α	0	500	1800	4
13	0	0	-α	500	1600	2
14	0	0	+α	500	1600	6
15	0	0	0	500	1600	4

Given the calculation of the required ratios, regression equation largest bulk density, depending on the amount of cement, sand and small-sized filler as follows:

- in coded form:

$$y = 1904{,}63 - 20{,}8 \cdot x_1 + 19{,}71 \cdot x_2 - 17{,}33 \cdot x_3 - 4{,}24 \cdot x_1^2 - 10{,}07 \cdot x_2^2 + 9{,}72 \cdot x_3^2 + 8{,}05 \cdot x_1 \cdot x_2 - \\ - 6{,}17 \cdot x_1 \cdot x_3 + 7{,}29 \cdot x_2 \cdot x_3; \quad (1)$$

- in the decoded form:

$$y = 1904{,}63 - 20{,}8 \cdot C + 19{,}71 \cdot S - 17{,}33 \cdot NS - 4{,}24 \cdot C^2 - 10{,}07 \cdot S^2 + 9{,}72 \cdot NS^2 + 8{,}05 \cdot C \cdot S - \\ - 6{,}17 \cdot C \cdot NS + 7{,}29 \cdot S \cdot NS; \quad (2)$$

Based on the calculation data and with using the regression equation, the nomograms reflecting the dependence of the bulk density of cement and small-sized filler in a highly dispersed state were built. Construction of surfaces of the response function was carried out in the program «Sigma plot» (www.sigmaplot.com). The obtained nomograms (Fig. 2 and 3) are allowing to identify the mixture with an optimum particle size: composition №1 – cement content 500 g, highly dispersed sand content – 6% of the river sand mass; composition №2 – river sand content 1525 г., highly dispersed sand content – 6% of the river sand mass.

The response function view from the bulk density of dry mix from varied factors was confirmed the high role of small-sized filler - sand in a highly dispersed state to increase the compactness of particle packing components. The optimum quantity of sand in a highly dispersed state will also be determined by its effect on the hydration process of cement, the contact zone formation between the small-sized filler particles and the cement.

To evaluate the structure-properties of investigated small-sized filler in highly dispersed state, it is necessary to produce samples with the control composition (concrete mix without small-sized filler in a highly dispersed state) and with the main composition (concrete mixture with small-sized filler in highly dispersed state sand).

Fabrication and testing of concrete mixture samples were carried out at an air temperature $(20\pm3)^0$C. Mixing of concrete mixture produced by hand. The result of slump testing of concrete mixture with highly dispersed sand was 15 cm. Compression strength of concrete samples was determined at the age of 1, 2, 3, 7 and 28 days. Results of testing samples of the main and control compositions are shown in Table. 6. Graphs comparing strength of concrete samples of the main and control composition are shown in Fig. 4.

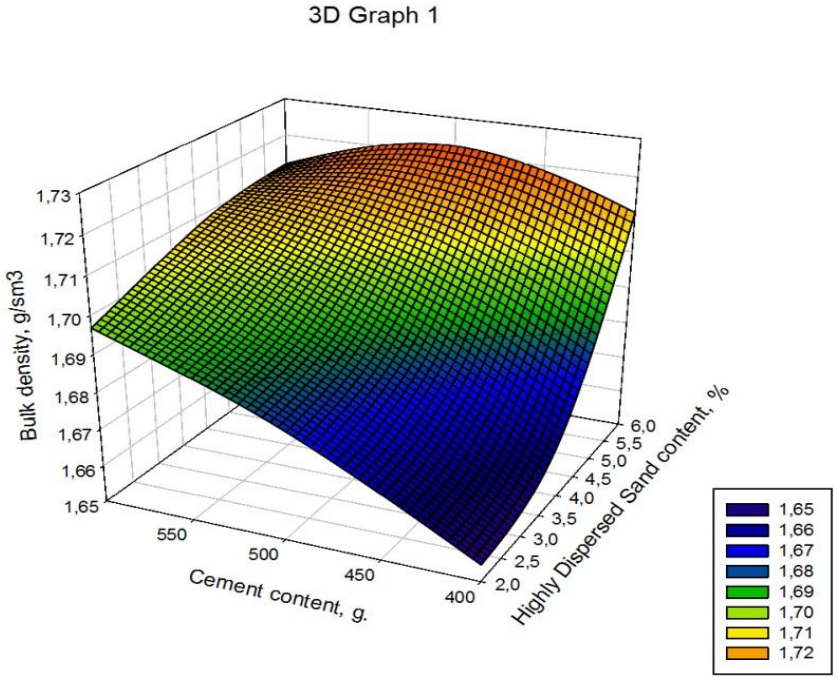


Figure 2 - The response functions of the bulk density of dry mix from the cement content (g) and highly dispersed sand content (%)

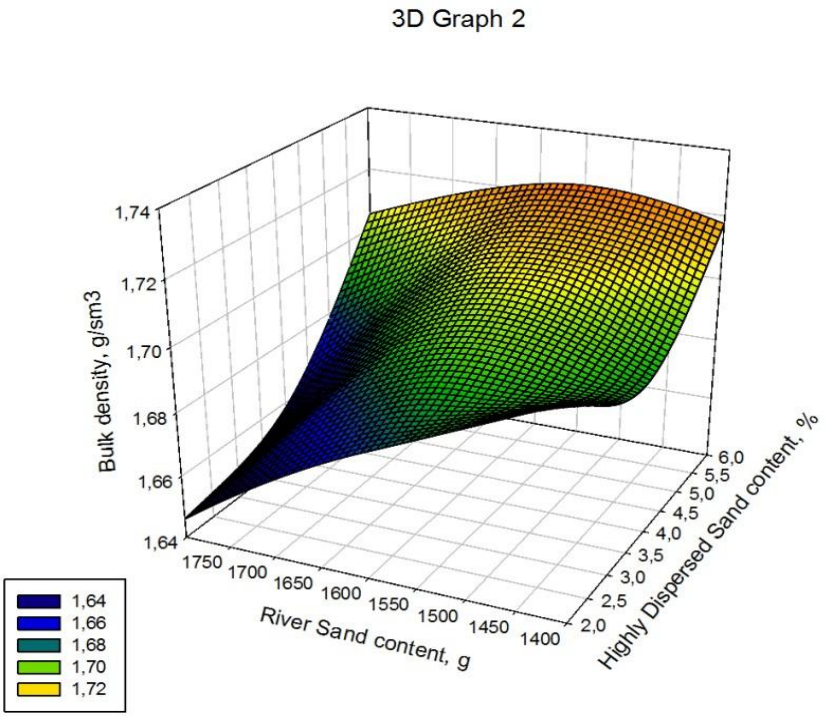


Figure 3- The response functions of the bulk density of dry mix from the river sand content (g) and highly dispersed sand content (%)

Table 6. The testing of fine-grained concrete samples

Parameter	Sign	Unit.	Age of the samples, days				
			1	*2*	*3*	*7*	*28*
The main composition							
Average Strength	R_m	MPa	3,04	6,6	13,35	19,49	29,05
Concrete Class	B	-	-	5	10	15	20
Elastic Modulus	E	MPa	735	1143	1754	3222	5702
The control composition							
Average Strength	Rm	MPa	0,75	7,58	11,12	17,12	25,58
Concrete Class	B	-	-	5	7,5	12,5	15
Elastic Modulus	E	MPa	57	1465	1929	3671	5029

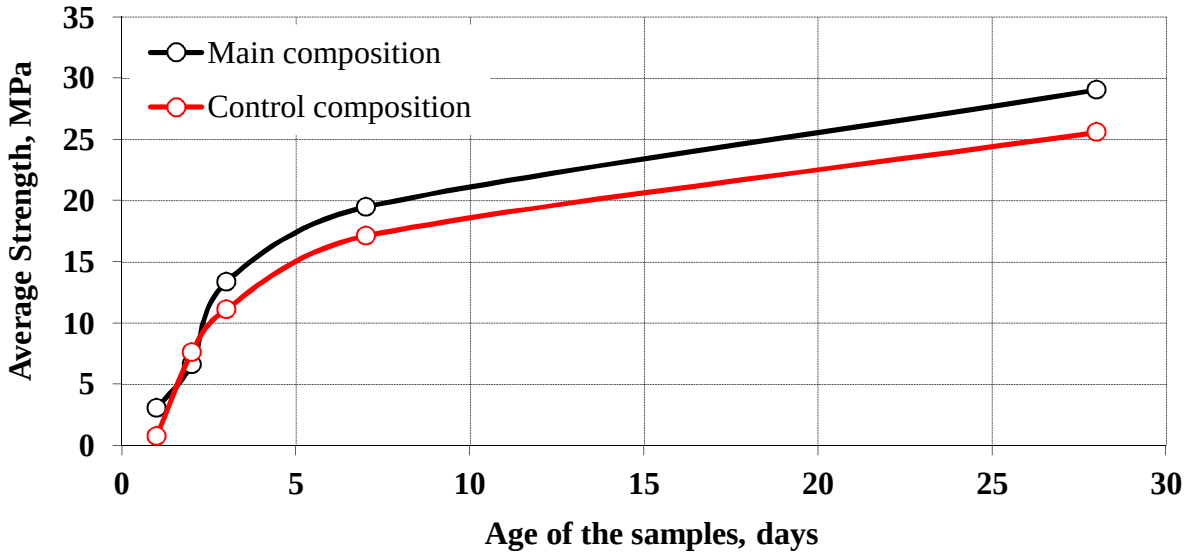


Figure 4 – The functional dependence of the average strength from the age of the fine-grained concrete samples of the main and control compositions.

4. CONCLUSION

In summary, these studies are suggesting the following conclusions:

1. Using mathematical planning method of experiment, the bulk density models of dry building mix depending on the content of cement, sand, small-sized filler - sand in a highly dispersed state, allowing to determine the optimum composition of fine-grained concrete were obtained.

2. Increasing of the strength at the main concrete sample aged at least 28 days is different from the control sample. Increase of strength slowly at first, but the achievement of 70% of the standard strength of the main sample age up to 9 days at 20^0C, as in the controls.

3. There was an increase of the initial elastic modulus of concrete samples with the main composition as compared with the control samples.

4. These results showed that the optimization of the amount injected small-sized filler of fine-grained concrete will provide obtaining the concrete with improved strength characteristics, which improves its class without increasing the consumption of cement.

ACKNOWLEDGMENT

This work was supported by the Russian Federal Target Programme "Scientific and scientific-pedagogical personnel of innovative Russia" for 2009-2013.

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