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## The effect of particulate reinforcement on strength and deformation characteristics of fine-grained concrete

## Влияние дисперсного армирования на прочностные и деформативные характеристики мелкозернистого бетона

**S.V. Klyuev,**

**A.V. Klyuev,**

*Belgorod State Technological University named after V.G. Shukhov, Belgorod, Russia*

**A.D. Abakarov,**

*Daghestan State Technical University, Makhachkala, The Republic of Daghestan, Russia*

**E.S. Shorstova,**

**N.G. Gafarova,**

*Belgorod State Technological University named after V.G. Shukhov, Belgorod, Russia*

**Канд. техн. наук, доцент С.В. Ключев, канд. техн. наук, старший преподаватель**

**А.В. Ключев,**

*Белгородский государственный технологический университет*

*им. В.Г. Шухова, г. Белгород, Россия*

**д-р техн. наук, заведующий кафедрой**

**А.Д. Абакаров,**

*Дагестанский государственный технический университет, г. Махачкала, Республика Дагестан, Россия*

**аспирант Е.С. Шорстова,**

**аспирант Н.Е. Гафарова,**

*Белгородский государственный технологический университет*

*им. В.Г. Шухова, г. Белгород, Россия*

**Key words:** fiber concrete, disperse reinforcement; fiber; strength and deformation properties of concrete; disperse-reinforced fine-grained concrete; the density at normal humidity conditions; the limit of tensile strength in bending; tensile strength under compress

**Ключевые слова:** фибробетон; дисперсное армирование; волокна; прочностные и деформационные свойства бетона; дисперсно-армированный мелкозернистый бетон; плотность в нормальных влажностных условиях; предел прочности на растяжение при изгибе; предел прочности при сжатии

**Abstract.** One of the options to improve the reliability and increase the service life of concrete structures can be a reinforcement of the total volume of fine-grained concrete with different fiber types. The article presents the results of complex researches on studying of influence of parameters of the dispersed reinforcement (fiber, length and type of fiber, dosage by volume) and the material of the fibers of strength of disperse-reinforced fine-grained concrete on a stretching at a bend, the estimation of efficiency and accountability in the calculation of building structures. The article considers the possibility of using industrial materials. It is proven that rougher texture leads to a larger force of adhesion between the particles of filler and the cement matrix. In addition, the large surface area of angular aggregate facilitates the development of greater traction. The article considers the issues of application of steel fibers to disperse reinforcement of fine-grained concrete. As a binder we used fine ground cement and the binder with low water demand. Their physic-mechanical characteristics of binders were studied. From the results of experiments it was found that grinding cement with plasticizing additive "Polyplast SP-1" in the amount of 0.6 % by weight of cement is more intense. This shows that in addition to the plasticizing action, it has an intensifying effect at grinding; this is due to the wedging action of most additives. It is also seen that the kinetics of grinding TMC and VNV on attrition crushing granite similar and previously studied industrial raw materials. As reinforcing material steel wave fiber were used. For increasing the strength and deformation characteristics were developed by the compositions of fine-grained fiber-reinforced concrete on technogenic raw materials (screening instruments) and composite binders with the use of nanodispersed powders (NDP). The use of composite binder and high-density packing of grains of filler significantly increases the strength characteristics. Optimal selection of filler allowed to receive on technogenic Sands of Kursk magnetic anomaly of the fiber-reinforced concrete with strength limit under compression – 160.2 MPa, at a bend of 31.2 MPa.

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**Аннотация.** Одним из вариантов повышения надежности и увеличения сроков эксплуатации железобетонных конструкций может быть армирование всего объема мелкозернистого бетона с помощью различных видов фибры. В статье представлены результаты комплексных исследований по изучению влияния параметров дисперсного армирования (длина волокон и вид фибры, дозировка по объему) и материала волокон на прочность дисперсно-армированного мелкозернистого бетона на растяжение при изгибе, дана оценка эффективности такого метода и возможность учета при расчете строительных конструкций. В статье рассмотрена возможность применения техногенного сырья. Доказано, что более грубая текстура приводит к большей силе сцепления между частицами заполнителя и цементной матрицей. Кроме того, большая площадь поверхности углового заполнителя дает возможность развития большей силы сцепления. В статье рассмотрены вопросы применения стальной фибры для дисперсного армирования мелкозернистых бетонов. В качестве вяжущего использовался тонкомолотый цемент и вяжущее низкой водопотребности. Были изучены их физико-механические характеристики вяжущих. Из результатов экспериментов установлено, что помол цемента с пластифицирующей добавкой «Полипласт СП-1» в количестве 0,6% от массы цемента проходит интенсивнее. Это свидетельствует, что помимо пластифицирующего действия, она обладает и интенсифицирующим действием при помоле, это объясняется расклинивающим действием самой добавки. Также видно, что кинетика размалываемости ТМЦ и ВНВ на отсеве дробления гранита аналогична, как и на ранее изученном техногенном сырье. В качестве армирующего материала использовалась стальная волновая фибра. Для увеличения прочностных и деформативных характеристик были разработаны составы мелкозернистого фибробетона на техногенном сырье (отсев КВП) и композиционных вяжущих с применением нанодисперсного порошка (НДП). Установлено, что применение композиционных вяжущих и высокоплотной упаковки зерен заполнителя значительно повышают прочностные показатели. Оптимальный подбор заполнителя позволил получить на техногенных песках КМА фибробетон с пределом прочности при сжатии – 160,2 МПа, при изгибе 31,2 МПа. Ключевые слова: фибробетон, дисперсное армирование, волокна, прочностные и деформационные свойства бетона, дисперсно-армированный мелкозернистый бетон, плотность в нормальных влажностных условиях, предел прочности на растяжение при изгибе, предел прочности при сжатии.

## Introduction

In recent years, many developed countries increases production of high quality concretes for various purposes, i.e. concrete, performance characteristics which meet or exceed the highest quality criteria, regulated by standards of different countries [1].

The main building material that provides high load capacity and long life span is concrete. The development of modern concrete Sciences is aimed, on the one hand, at improving physical and mechanical characteristics of concrete, and on the other hand, the reduction of costs in production and operation of concrete and reinforced concrete structures. For the implementation of these tasks requires the use of innovative technologies in concrete production.

The use of traditional methods of reinforcement of concrete steel flat or three-dimensional frames leads to heterogeneity of structure, the formation of voids in the concrete, deterioration of the deformation characteristics of structures [2–4], one of the effective ways of the directed formation cementogenesis systems (mortars and concretes) is volumetric dispersed reinforcement. The use of finely dispersed fibre reinforcement, regardless of material (steel, glass, basalt, etc.), aims to promote the formation of more ordered and homogeneous structures, characterized by high resistance to development of cracks [3, 5].

The wide application of fiber-reinforced concrete is found in many areas of construction and successfully used in countries such as South Africa, Germany, Japan, USA, etc. [6–13].

Currently in concrete science is widely used by different types of particulate fillers: crushed waste of metallurgical and energy industries, quartz sand, limestone, and carbonate, the Dolomites, there is a considerable resource base in many regions of the country.

Currently, more and more active in the construction industry implemented multi-component fine-grained concrete, the use of which previously was constrained by several factors: used as filler sand only led to a significant increase in the specific surface of the filler and its emptiness; for obtaining concrete mixtures required elevated (15–25 %) water consumption and cement compared with concrete large aggregate, which ultimately led to increase in shrinkage of concrete, etc [14, 15].

Fine structure of cement composites has several advantages, among which: the possibility of creating high-quality fine uniform structure without inclusions of grains of large aggregate having a different structure in relation to the cement-sand matrix; high thixotropy and the ability to transform the concrete mix; the possibility of forming structures and products by casting, extrusion, pressing, stamping, spraying, etc. [1]. In addition, the size of the aggregate in concrete allows you to utilize the effect of particulate reinforcement in the manufacture of fiber-reinforced concrete.

Finely fibrous fillers in cement compositions to have a positive influence on the processes of structure formation, the strength of the filled concrete and other physical-mechanical and operational properties of materials. Use of dispersed reinforcement in the hardened cement mortars and concretes allows to:

- increase the tensile strength of shear and tensile bending, impact and fatigue strength;
- reduce shrinkage strain; to increase the fracture toughness by changing the nature of cracking at all levels of the structure;
- increase elasticity, resistance to impact and abrasion;
- increase the frost resistance, water resistance, heat resistance and fire resistance [16–21].

In cement composites, cracks are present from the sub micro - to the macro-scale level. The process of destruction of the concrete structure under the action of force factors at the micro level emerges as a local act of promoting primary cracks to the point of bifurcation, which is a defect structure in the form of grain filler or pores, while at the mouth of the crack resets the critical energy density. The process of destruction of the sample consists of discrete acts of destruction at the micro scale level.

Thus, the destruction of the concrete under action of static loads has a discrete character, and the feasibility of applying particulate reinforcement is dictated by the fractal hierarchy of process fracturing is offered.

A positive effect of the disperse reinforcement of concrete is beginning to tell after reaching the volumetric concentration of fibers contributing to the initial spatial coherence of fire tracker [22, 23]. It is possible to allocate two stages of the mechanism of influence on the structure of concrete and its physical-mechanical characteristics:

- at the stage of fiber structure formation during plastic shrinkage contributes to the redistribution of stresses from the shrinkage of the busiest areas on the entire volume of concrete;
- when loading in the process of operation of structures fiber of the fiber slow the growth of cracks, evenly distribute concentrations and reduce pressure in areas of macro defects, the surface area of the different components of concrete and the points of application.
- The theory of change of creep strain and shrinkage to date, the following [24]:
- reduction of shrinkage deformations is achieved through distributed interaction between fiber fibers with cement stone;
- in composite material with a perfect uniform arrangement of fibers, creep of the concrete matrix is limited to a tangential surface tension between the matrix and fiber reinforcement due to the forces of adhesion of materials.

At the present time a large number of experimental studies for specific production conditions and types of concrete (wire mesh, heavy-duty transport construction, etc.) are held. There is no scientific theoretical basis explaining the relationship of the properties of fine-grained concrete, the dosage and type of fiber of the fiber. To predict the possible positive effects it is necessary to study the interaction of fibers dispersed reinforcement with the mortar matrix, the relationship of the characteristics of various types of concrete for the purpose of modifying / adjusting the strength and performance characteristics to the structural analysis. To expand the scope of fiber in the manufacture of reinforced concrete structures it is necessary to systemize the production and the scientific and experimental experience that allows you to justify its use and define the deformation properties of the structures of fine-grained concrete. To expand the areas of calculation and application of dispersion-reinforced structures necessary theoretical generalization and systematization of the dependencies between process parameters (properties of the starting materials, composition and manufacturing process products), formation of structure and deformation-strength characteristics of fine-grained concrete.

The properties of the material of the fibers depend on the scope of fine-grained concrete and its characteristics. Fiber fibers can be nylon, acrylic, glass, steel, polyester, basalt, polypropylene, cotton and other materials (table 1). At present three main types of dispersion microanatomy are used abroad: fiber (fibre) in the form of short pieces of thin steel wire, glass and polypropylene fibers. In the Russian

Federation more widely used is the fiberglass on the basis of basalt [25]. The difference of material properties fiber reinforcement necessitates a differentiated approach to their use as reinforcement.

**Table 1. Technical characteristics of the different fibers of a fiber**

Figure	Basalt fiber	Polypropylene fiber	Fiber glass	Steel (metal) fiber
Material	Basalt fiber	Polypropylene	Fiber glass	Carbon steel Wire
Fiber Diameter	13-17 $\mu\text{m}$	10-25 $\mu\text{m}$	13-15 $\mu\text{m}$	0.5-1.2 $\mu\text{m}$
Fiber length	3.2-15.7 $\mu\text{m}$	6-18 $\mu\text{m}$	4.5-18 $\mu\text{m}$	30-50 $\mu\text{m}$
Melting point. °C	1 450	160	860	1 550
Resistance to alkali and corrosion	High	Low	Low, alkali – middle	Middle

Works of some researchers [16–21, 26, 27] established that to obtain high-strength compositions must satisfy the following conditions:

- a significant part of the strength of the fibers must be maintained in the process;
- you need a high fiber grip with the mortar matrix and the most dense of their contact without any entrapped air in the contact zone;
- optimal most uniform distribution of fibers throughout the volume of the matrix at simultaneous exclusion of direct contact with each other;
- materials of the fibers should have chemical inertness relative to the cement matrix;
- higher elastic modulus compared to the matrix.

### Methods

However, the calculation of bearing capacity of structure, it is necessary to know the dependence of bending strength on the parameters of reinforcement. Comprehensive research work on the creation of multi-factor mathematical models of fiber-reinforced concrete is conducted in the following areas:

- the study of the macrostructure of the disperse-reinforced concrete: the location, the uniformity of distribution, effect of fiber on a surrounding structure of concrete;
- the interaction between fibers and concrete, manifested in the strength characteristics of the resulting composition;
- integration of dispersed reinforcement in the design strength and deformation characteristics of structures and prediction of internal stresses arising under the action of operational loads.

By results of the given experiments conclusions are drawn on that the substantial increase in the length of fiber fibers filler a larger particle size results in a deterioration of the concrete structure and decrease of the strength indicators. The required fiber length of the fiber for maximum strength in bending shall be determined by the maximum aggregate size of concrete, for example, for fine-grained concrete is 2–6 mm, for coarse – 12–20 mm.

### Results and Discussion

Currently, experiments carried out at various constant parameters to cover all possible combinations of baselines. In the next stage of research it will be determined by other deformation and strength parameters of disperse-reinforced concretes that are required to calculate the model design. After the arrangement of empirical data they will be calculated based on the strength properties of dispersion-reinforced concrete from the entire range of initial parameters for use in mathematical models to calculate the strength characteristics of this type of concrete.

With the aim of recycling of technogenic raw materials are in the dumps of mining – waste wet magnetic separation of ferruginous quartzite and eliminations of crushing is proposed their use as filler for composite binders and aggregate of fine-grained fiber-reinforced concrete.

The influence of the shape and texture of aggregate on concrete strength is not sufficiently researched, but possibly a rougher texture results in greater force of adhesion between the particles and the cement matrix. In addition, the large surface area of angular aggregate means that you can develop greater traction. Conducted research using scanning electron microscopy (SEM) showed that the screenings from the crushing of granite and quartzitic sandstone (COI) have a rough surface and angular shape, in contrast to the natural sand with a smooth surface and rounded form of grains (Fig. 1).

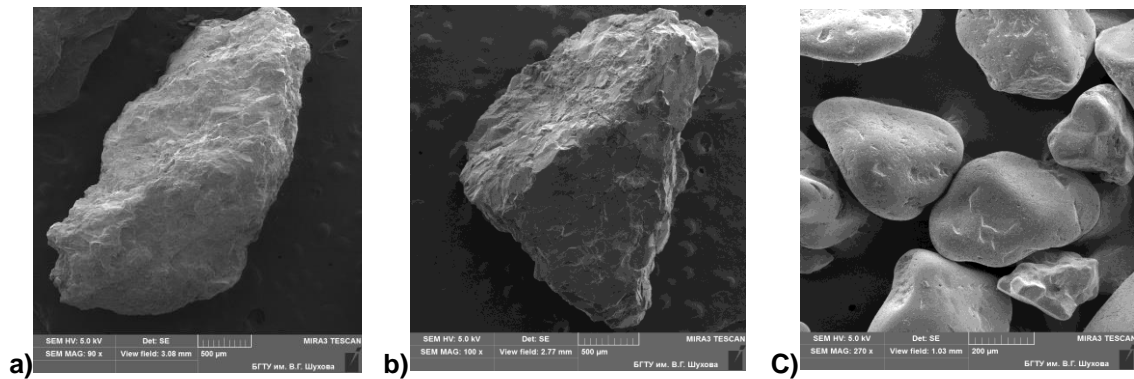


Figure 1. The grain: a – dropping out of quartzitic sandstone; b – dropout granite; c – natural sand  
Main physico-mechanical properties of fillers are presented in Table 2.

**Table 2. Physico-mechanical properties of filler**

Indicator	COI Screening crushing	Screening granite	Tavolzhanskiy sand
Module size	3.50	2.89	1.38
Bulk density. kg/m <sup>3</sup>	1490	1536	1448
True density. kg/m <sup>3</sup>	2710	2640	2630
Voidness %	47.8	51.2	44.9
Water requirement. %	5.5	7.8	7

For obtaining of fine-grained fiber concrete with high performance characteristics, reduction of the clinker component and optimization of the processes of structure formation, appropriate use of highly active composite binders (KV) such as fine crushed cement (TMC) and cementing agent of low water requirement (VNV).

From the results of experiments found that grinding cement with plasticizing additive "Polyplast SP-1" in the amount of 0.6% by weight of cement is more intense. This shows that in addition to the plasticizing action, it has an intensifying effect at grinding; this is due to the wedging action of most additives. It is also seen that the kinetics of development TMC and VNV on attrition crushing granite similar and previously studied industrial raw materials.

The study of the properties of composite binders showed that VNV-100, the activity of more than 70 % higher compared to the baseline cement, decreases water-cement ratio and the normal density in comparison with cement (table 3).

**Table 3. Physico-mechanical characteristics of the composite binder**

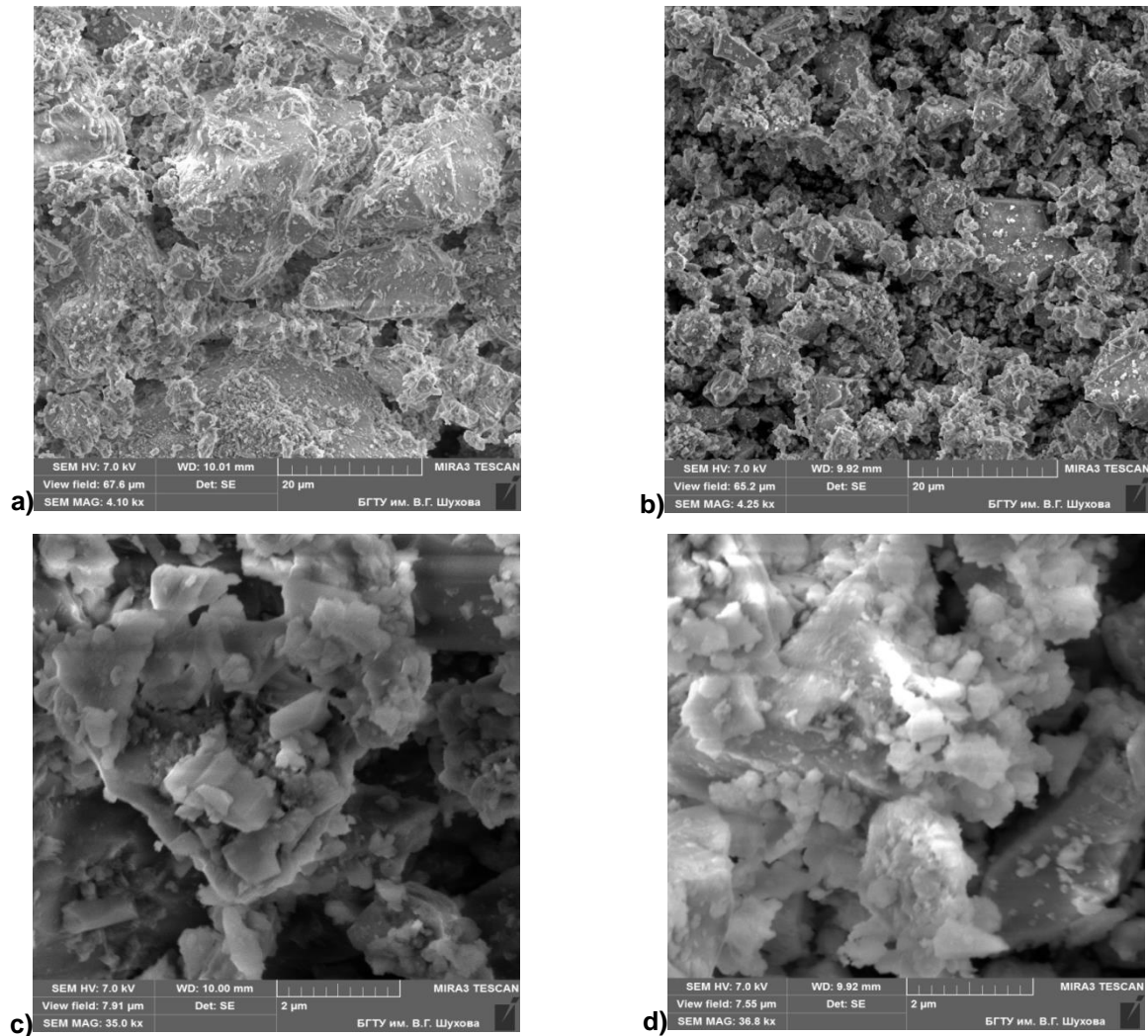
View binder	The normal density of the test, %	Setting time, hours min.		V/C	The activity of the binder (MPa)	
		beginning	ending		bending	compression
CEM I 42.5 N	26.2	2-40	4-50	0.4	7.2	48.9
TMC-50 (on granite)	26.8	2-40	4-40	0.41	5.8	41.7
TMC-50 (on KVP)	27.1	2-30	4-40	0.43	6.5	46.3
VNV-50 (on granite)	23.2	2-10	4-30	0.33	5.2	47.1
VNV-50 (on KVP)	24.3	2-10	4-10	0.35	8.8	52.2
TMC-100	25.3	2-20	4-10	0.44	10.2	71.3
VNV-100	22.8	2-10	3-30	0.28	12.4	85.2

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Thus, when introducing super plasticizer "Polyplast SP-1" in the amount of 0.6 % it is possible to obtain binding activity of 85.2 MPa.

The structure of cement stone on VNV-100 denser compared to ordinary Portland cement (Fig. 2).

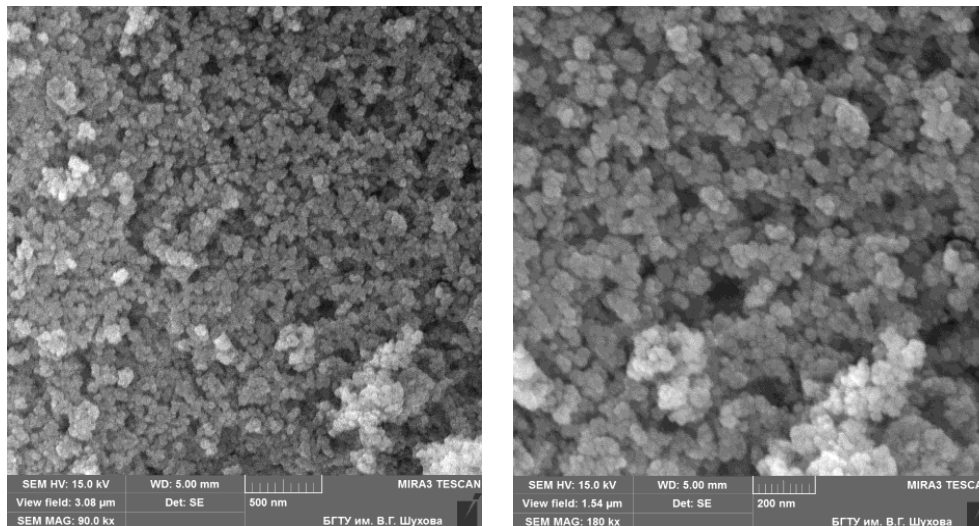


**Fig. 2. Microstructure depending on the properties of the binders:  
a, c – morphology of neoplasms of the cement stone CEM I 42,5 N;  
b, d – morphology of neoplasms of the cement stone VNV-100;  
increase a, b -x4000, c, d- x35000**

This is determined by the availability of the thinnest water films between the grains of binder and the formation in a confined volume of low-basic calcium hydrosilicates and other tumors.

To improve the operational characteristics were developed by the compositions of fine-grained fiber-reinforced concrete on technogenic raw materials (screening instruments) and composite binders with the use of nanodispersed powders (NDP). Nanodispersed powder was obtained by Professor V.V. Potapov from natural hydrothermal vents of Kamchatka Krai.

Powder, which is injected as a nano-additive in the cement samples had a specific surface area equal to 156000 m<sup>2</sup>/kg (detection was carried out by low-temperature nitrogen adsorption on the ASAP parametre-2010 N Micromeritics), the average particle diameter of 7.3 nm, a density of 35 kg/m<sup>3</sup> (Fig. 3).



**Figure 3. General view of the nanodispersed powder**

Dried up sand, elimination of crushing of a quartzitic sandstone and composite astringent material have been mixed before obtaining homogeneous structure then the steel fiber was entered batch wise to avoid formation of their uniform distribution on all volume.

Nanodispersed powder was introduced into the aqueous phase before the mixing of the mixture in the amount of 0.2 % by weight of cement. Uniform distribution of powder particles in the liquid volume was achieved with the help of ultrasonic treatment till their full dissolution, the spent time for it up to 20 minutes. Then water with the dissolved nanodisperse modifier before receiving homogeneous mass was added. After formation and consolidation samples within 24 hours were at a temperature not lower than 15 °C. Then forms have been taken off and concrete samples there were in the curing camera with a temperature of 20 °C and humidity more than 90 %. Test of samples for determination of durability on compression (cubes 100×100×100 mm) and on stretching at a bend (prisms 100×100×400 mm) were carried out by universal test machine by a standard technique.

Calculation of high density packing of mix fillers on the basis of which the percentage ratio of her components has been established has been made. Earlier [19] the efficiency of application composite astringent materials for fiber concrete has been proved since increase in strength characteristics gains to 60 % at insignificant extension in prime cost of mix due to additional power consumption by their receiving.

**Table 4. Physico-mechanical characteristics of fine-grained concrete depending on the type of binding agent**

View binder	Material consumption per 1 m <sup>3</sup> of mixture				The NDP. kg/m <sup>3</sup>	Steel fiber. kg/m <sup>3</sup>	The limit of compressive strength. (MPa)	Tensile Strength in bending. (MPa)
	Knit – ing. kg/m <sup>3</sup>	Screenin g COI. kg/m <sup>3</sup>	Sand. kg/m <sup>3</sup>	Water. l/m <sup>3</sup>				
CEM I 42.5 N	810	1100	340	204	-	-	56.3	14.3
CEM I 42.5 N+ VPU	810	1100	340	208	-	-	67.7	15.1
CEM I 42.5 N	810	1070	340	195	-	75	86.8	17.4
CEM I 42.5 N+VPU	810	1070	310	197	-	75	97.7	18.2
CEM I 42.5 N+VPU	810	1070	310	197	0.2	75	119.4	22.7

**Table 5. Physico-mechanical characteristics of fine concrete depending on the type of binding agent**

View binder	Material consumption per 1 m <sup>3</sup> of mixture				The NDP. kg/m <sup>3</sup>	Steel fiber. kg/m <sup>3</sup>	The limit of compressive strength. (MPa)	Tensile Strength in bending. (MPa)
	Knitting. kg/m <sup>3</sup>	Screening COI. kg/m <sup>3</sup>	Sand. kg/m <sup>3</sup>	Water. l/m <sup>3</sup>				
TMC-100	810	1100	340	209	-	-	65.7	15.5
TMC-100+SPM	810	1100	340	213	-	-	77.3	16.7
TMC-100	810	1070	310	199	-	75	92.6	19.1
TMC-100+SPM	810	1070	310	201	-	75	102.4	20.5
TMC-100+SPM	810	1070	310	201	0.2	75	127.1	26.5

**Table 6. Physico-mechanical characteristics of fine concrete depending on the type of binding agent**

View binder	Material consumption per 1 m <sup>3</sup> of mixture				The NDP. kg/m <sup>3</sup>	Steel fiber. kg/m <sup>3</sup>	The limit of compressive strength. (MPa)	Tensile Strength in bending. (MPa)
	Knit – ing. kg/m <sup>3</sup>	Screening COI. kg/m <sup>3</sup>	Sand. kg/m <sup>3</sup>	Water. l/m <sup>3</sup>				
VNV-100	810	1100	340	180	-	-	97.5	17.7
VNV-100+SPM	810	1100	340	185	-	-	100.6	18.6
VNV-100	810	1070	310	172	-	75	118.1	22.2
VNV-100+SPM	810	1070	310	174	-	75	125.8	24.1
VNV-100+SPM	810	1070	310	174	0.2	75	160.2	31.2

## Conclusions

The study of physical and mechanical properties showed that the fiber-reinforced concrete on VNV-100 in all cases, exceed the characteristics of samples of similar composition made at other binders. Hence it can be concluded that the use of composite binders with the addition of superplasticizer can significantly increase the strength characteristics of concrete.

The proposed approaches improve the effectiveness of fine-grained concrete used for the production in the construction industry, namely, to optimize the structure at the nano-, micro - and macro-levels through the use of composite binders, nano-dispersed modifier, creation of high-density packing of grains of filler of technogenic raw materials and the dispersed reinforcing fibers, increasing the strength characteristics of the composite 3 times.

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Sergey Klyuev,  
+7(951)139-63-27; [Klyuyev@yandex.ru](mailto:Klyuyev@yandex.ru)

Сергей Васильевич Ключев,  
+7(951)139-63-27; эл. почта: [Klyuyev@yandex.ru](mailto:Klyuyev@yandex.ru)

Alexander Klyuev,  
+7(951)152-38-38; [Klyuyev@yandex.ru](mailto:Klyuyev@yandex.ru)

Александр Васильевич Ключев,  
+7(951)152-38-38; эл. почта: [Klyuyev@yandex.ru](mailto:Klyuyev@yandex.ru)

Abakar Abakarov,  
+7(951)139-63-27; [zhurnalnauka2015@yandex.ru](mailto:zhurnalnauka2015@yandex.ru)

Абакар Джансулаевич Абакаров,  
+7(951)139-63-27;  
эл. почта: [zhurnalnauka2015@yandex.ru](mailto:zhurnalnauka2015@yandex.ru)

Elena Shorstova,  
+7(915)525-41-33; [Kuzik\\_alena@mail.ru](mailto:Kuzik_alena@mail.ru)

Елена Степановна Шорстова,  
+7(915)525-41-33;  
эл. почта: [Kuzik\\_alena@mail.ru](mailto:Kuzik_alena@mail.ru)

Nina Gafarova,  
+7(910)361-87-44; [gafarovanina91@gmail.com](mailto:gafarovanina91@gmail.com)

Нина Евгеньевна Гафарова,  
+7(910)361-87-44;  
эл. почта: [gafarovanina91@gmail.com](mailto:gafarovanina91@gmail.com)

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