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Fiber-Reinforced Concrete With Mineral and Slag Wastes Fibers and Nanosilica

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Abstract: In study, the results of the use of mineral fiber as a reinforcing component for concrete are presented. The rheological characteristics of the cement pastes with the introduction of mineral fiber and nanosilica are identified. Introduction of the nanosilica to fiber cement compositions improves the corrosion resistance of the mineral fiber, due to the fact that nanosilica binds $Ca(OH)_2$ during Portland cement hydration. Physical and mechanical properties of fiber-cement compositions are defined. Introduction to the mineral fibers and nanosilica increases the physico-mechanical characteristics of fiber cement compositions. A noticeable improvement of flexural strength is associated with reinforcing action of the mineral fibers and the introduction of nanodispersed silica.

Key words: Fiber-reinforced concrete, mineral fiber, nanosilica, slag wastes, rheological characteristics

INTRODUCTION

Development of construction technologies entails the improvement of materials and structures. Advanced materials, studies and constructions should have a complex of improved characteristics. It is known that the concrete constructions are not sufficiently high flexural strength. This problem can be solved by dispersed reinforcement of concrete with different fibers . Dispersed reinforcement by metal and non-metallic fibers allows to qualitatively improving the performance of composites. It is necessary to consider the possible negative influence of the hardening cement by using non-metallic mineral fibers.

The most effective of non-metallic mineral fibers for concrete dispersed reinforcement is the basalt roving and finely staple fiber. However, the technology of production of these types of mineral fibers are characterized by high energy costs. In the Republic of Buryatia a mini-factory was starting for the production of heat-insulating mineral fiber obtained by Centrifugal Blow Method with melting the raw materials in the electromagnetic technological reactor (Buyantuev and Kondratenko, 2013). Using this, melting reactor mineral fibers were obtained from basalt and waste of ash and slag. The preparation of such fibers based on technogenic wastes into efficient construction materials is an important scientific and technical challenge. Use of these mineral fibers with less stable and homogeneous properties compared to the roving and staple fibers for dispersed reinforcement of cement composites is a promising direction in the technology of their production.

Non-metallic fibers are chemically similar to minerals of Ordinary Portland Cement (OPC), so they are susceptible to negative effects from the hydration products. Various methods are used to reduce the negative impact of the alkaline medium of OPC to nonmetallic fibers: heat treating the fibers to improve alkali resistance, coating the fibers with the protective layer, the introduction of siliceous additives which binds portlandite (Stepanova and Buchkin, 2011; Babaev *et al*., 2013).

Various micro and nanomaterials, in particular silica fume are used to improve the corrosion resistance. The potential use of Nanosilica (NS) obtained by evaporation of the material by a relativistic electron beam in order to increase the corrosion resistance of the fiber is an interesting and relevant. Earlier, by Urkhanova *et al*. (2011, 210), high-strength concrete using NS have been

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obtained. Introduction NS leads to a change in the microstructure of the hardening stone accelerates pozzolanic reaction and forms an additional quantity of CSH (I).

MATERIALS AND METHODS

In current research to obtain fiber-reinforced concrete the following raw materials were used: OPC CEM I 32,5, a mineral fibers based on basalt and slag waste of the Buryat Republic, nanodispersed silica Tarkosil® T50.The average diameter of basalt fiber is 10 μm, tensile strength 1350 Mpa. The average diameter of slag waste fiber is 8 μm and it has tensile strength of 1390 MPa. Nanopowder additive Tarkosil® T50 was obtained by the apparatus, developed at the Khristianovich Institute of Theoretical and Applied Mechanics, Budker Institute of Nuclear Physics SB RAS and Bardakhanov LLC (Novosibirsk, Russia). Tarkosil® T50 has a specific surface $S_{sp} = 50.6\ m^2/g$, so its primary particles have an average size of about 53 nm.

In order to determine rheological properties of cement pastes containing nanopowder Tarkosil® T50 was used rotational viscometer Fungilab (the Khristianovich Institute of Theoretical and Applied Mechanics SB RAS). Compositions of cement pastes used for determining the viscosity are shown in Table 1. Sonication was used for the distribution of NS in water for 10 min. Compositions of cement pastes were mixed with water and water and nanosilica suspension for 5 min. Before the test, all compositions of cement pastes were kept in 5 min and then a dynamic viscosity was determined in a rotary viscometer.

Samples of the fiber cement compositions were prepared with dimensions 20×20×20 mm. Samples were stored in forms at 20-22°C, 95-100% of humidity then on water over for 28 days.

Samples of fiber-reinforced concrete with mineral fibers and nanosilica were prepared with dimensions 40×40×160 mm for testing flexural and compressive strength.

Scanning Electron Microscopy analysis (SEM) of samples of the mineral fibers was performed on a scanning electron microscope Jeol JSM 6510 LV with increasing x1000.

Table 1: Compositions of cement pastes

Portland cement (g)	Mineralfiber (g)	Tarkosil® T50 (g)	Water/Cement ratio
300	-	-	0.35
300	-	3	0.35
300	-	-	0.35
300	-	3	0.35
300	12	-	0.35
300	12	3	0.35

RESULTS AND DISCUSSION

The uniform distribution of the fibers in the volume of the mixture is necessary to improve the performance of high-quality fiber-cement compositions. There are different ways: the stepwise introduction of the fibers in the concrete mix, the separate mixing of the fiber and cement in milling and mixing machines and so on. It was tested two ways of distribution: admixing cement and fiber in a vibratory and ball mill. A method of mixing in the vibratory mill has appeared the best (Fig. 1). Physical and mechanical properties for this method of distribution are higher than in ball mill (15-20%).

The distribution of mineral fiber in intensive milling unit (vibratory mill) ispreferred due to slight activation of cement. Furthermore, the mineral fiber is subjected to partial grinding to optimum sizes in length (10-15 mm) for uniform distribution.

Ensuring uniform and homogeneous distribution mixing components to produce stable characteristics the hardened composite can be investigated by determining the rheological properties of the OPC. The rheological properties of cement pastes are changed with the introduction of nanodispersed additives (Senff *et al*., 2010, 2009; Quercia *et al*., 2012). Researchers previously have been identified optimal fiber distribution method which consists in joint mixing-grinding of Portland cement and mineral fiber in energy-intensive aggregate (Urkhanova *et al*., 2014). Joint introduction of mineral fiber and NS should affect the change in viscosity of fiber cement compositions. A detailed study of this question will allow revealing more completely the mechanism of action of nanosilica on the cement system.

Parameters of dynamic viscosity of cement pastes were determined with the introduction of mineral fibers and nanosilica (Fig. 2). Represented viscosity curves are typical for the type of coagulation systems which include cement paste. With an increase of time from 10-20 min there is a decrease in viscosity. The introduction of nanosilica Tarkosil® T50 increased the viscosity of the cement paste. With the passage of time (20-85 min), the viscosity of the pastes became to increase. This process was resulted from the OPC hydration and its setting had

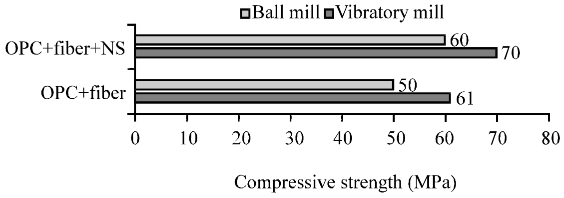

Fig. 1: Comparison of the distribution method of mineral fiber

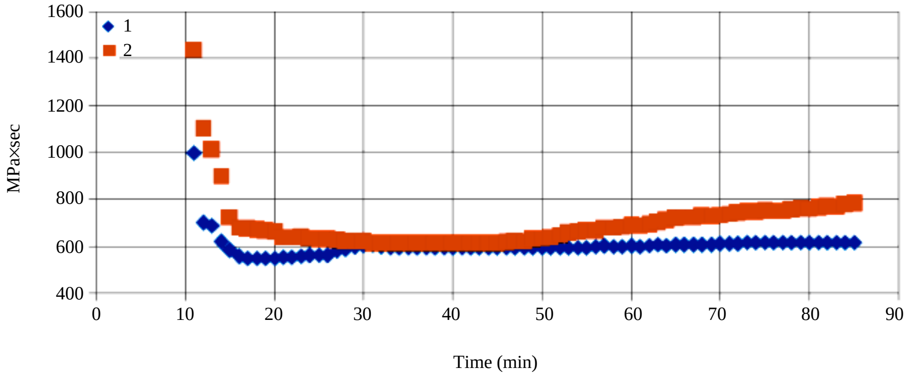

Fig. 2: Dynamic viscosity of cement pastes: 1: control, 2: with Tarkosil® T50

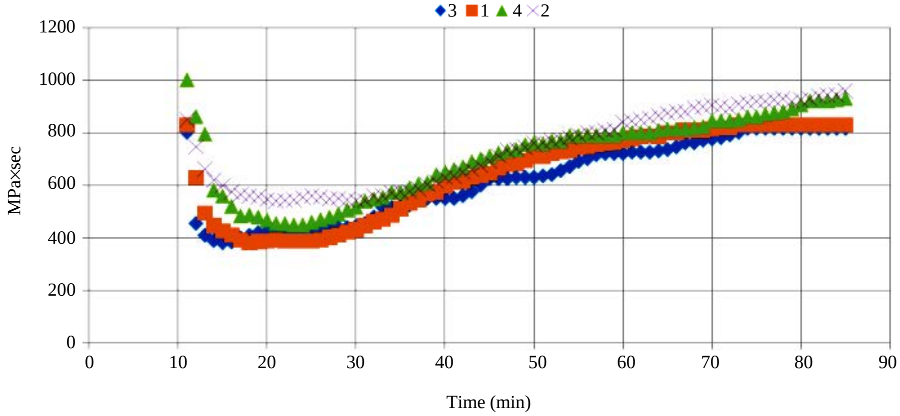

Fig. 3: Dynamic viscosity of fiber-cement pastes: 1: OPC+slag wastes fiber, 2: OPC+slag wastes fiber with Tarkosil® T50, 3: OPC+basalt fiber, 4: OPC+basalt fiber with Tarkosil® T50

begun. It's clear, the rate of the viscosity increasing with Tarkosil® T50 is higher than that of the initial cement paste.

Disperse-fibrous reinforcement of cement compositions leads to an increase of viscosity and decrease in the performance of cement paste (Fig. 3).

Introduction of mineral fiber "moves" the curve of viscosity down and slightly reduces the structural viscosity of the cement paste in the time interval of 10-20 min. It is typically that viscosity of cement paste with fibers below of the initial cement paste, however, at high shear stress. Later an increase the viscosity of cement pastes with fiber is more intense than the reference cement paste. Introduction of Tarkosil® T50 as in the case with the reference composition, leads to higher viscosity. The presence of nanosized particles reduces the amount of "free" water, thereby increasing the viscosity of cement pastes (Senff *et al*., 2010). Furthermore, the introduction of nanosilica reduces setting time of cement pastes. Nanosilica particles which have a large specific surface area actively participate in the process of hydration in the first minutes and the formation of hydration products occurs on the surface of silica particles, it promotes that the surface of the cement grains to a lesser extent remains "locked" and actively participates in the processes of hydration.

Investigation of heat cement paste showed an increase in maximum temperature with the introduction of nanosilica (Fig. 4). With the introduction of Tarkosil® T50 in quantities of 1 and 3%, there is an increase the maximum temperature for 10-12°C as compared with a control composition. At the same time the rate of temperature increasing is more intense compared to the control composition which indicates the acceleration of hydration process of cement with Tarkosil® T50.

Despite the advantage of using mineral fibers for the production of fiber reinforced concrete, particularly thin fibers it is exposed to corrosion in alkaline cement hydration. Researchers have carried out studies to assess the corrosion resistance of basalt and slag waste fibers in an alkaline medium with the introduction of nanosilica. Figure 5 shows images of samples of the mineral fiber

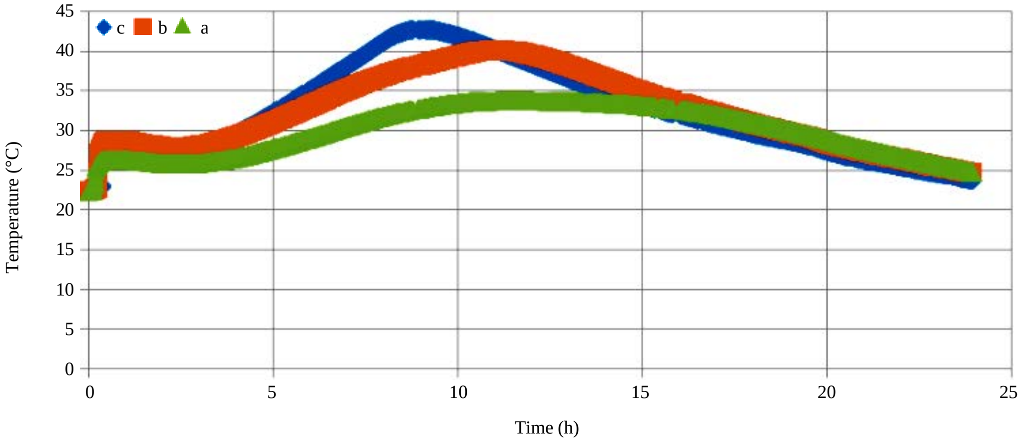

Fig. 4: Influence of nanosilica Tarkosil® T50 on the heat of cement; a: Control (no additives), b: OPC+Tarkosil® T50 (1%), c: OPC+Tarkosil® T50 (3%)

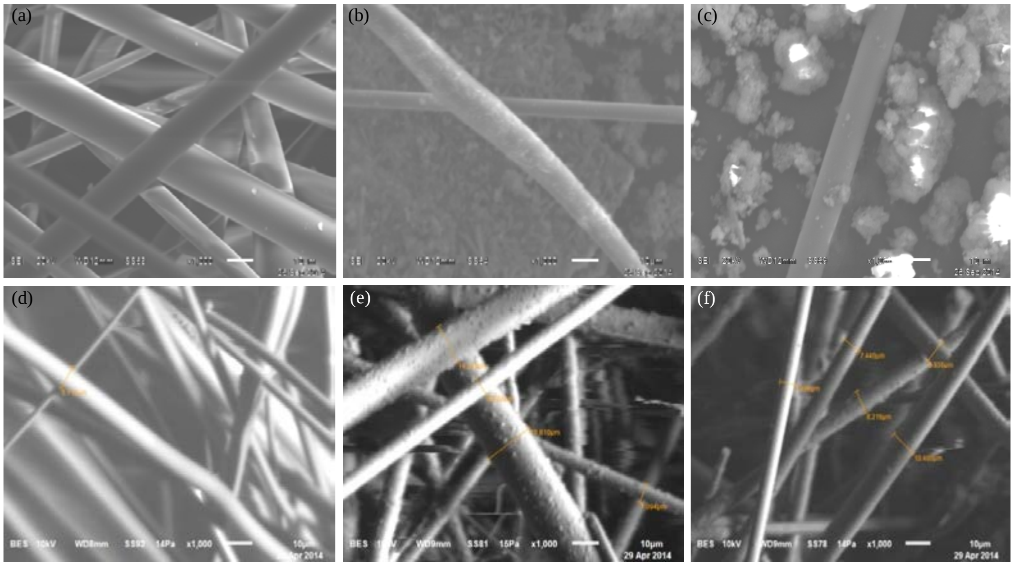

Fig. 5: SEM the surface of mineral fibers: a) original slag waste fiber, b) slag waste fiber after the boiling in lime solution, c) slag waste fiber after the boiling in lime solution with addition of nanosilica, d) original basalt fiber, e) basalt fiber after the boiling in lime solution, f) basalt fiber after the boiling in lime solution with addition of nanosilica

based on basalt and slag wastes before and after the boiling in a saturated lime solution. This method allows evaluating corrosion resistance of fibers when exposed to alkaline medium. Original fibers is characterized by a smooth flat surface before the boiling (Fig. 5a and d) after the boiling there are traces of interaction with the lime and fiber which causes the appearance of defects and new growths on the fiber surface (Fig. 5b and e). The surface of the fiber, boiled with the addition of nanosilica is remained smooth and flat with minor inclusions of new growths, products of interaction of NS with lime (Fig. 5c and f).

The study of the spectra with using a system INCA-x shows that without NS the elemental composition of the fiber surface layer differs in quantitative content of Si and Ca. On the fiber surface content of Ca is increased by 26% and the Si content is reduced by 21%, K, Na up to 0% (Table 2). This indicates a breaking of structure on the fiber surface due to interaction with hydration products of cement which leads to a decrease in the reinforcing effect.

Therefore, studies have shown that NS with high specific surface and chemical activity is reacted with portlandite during cement hydration, preventing corrosion of the mineral fiber. This leads to an increase in strength of cement and enhancing the effect of fiber reinforcement (Fig. 6).

Table 2: Spectral analysis of the fiber cement compositions

Spectrum	C	O	Na	Mg	Al	Si	S	K	Ca	Ti	Fe
OPC+mineral fiber (4%)											
1	4.52	47.99	-	-	0.96	5.57	0.83	-	38.34	-	1.79
2	4.66	46.03	-	0.40	1.51	7.65	1.23	-	37.37	-	1.15
OPC+mineral fiber (4%)+Tarkosil® T50 (0.5%)											
1	1.28	44.54	0.38	0.70	2.86	10.23	0.83	1.06	35.29	0.35	2.48
2	-	33.47	1.07	1.99	8.75	24.00	0.17	3.84	12.64	1.61	12.4

Table 3: The composition and technological parameters of fiber-reinforced concretes with basalt fiber

Material consumption per 1 m³ of concrete (kg)					
OPC	Sand	Basalt fiber	Tarkosil® T50	W/C ratio	Segregation by waterseparation(%)
550	1375	-	-	0.4	0.60
550	1375	22	-	0.4	0.45
550	1375	22	2.75	0.4	0.30

Table 4: Mechanical and performance and technological properties of fiber-reinforced concrete

		Indicators		
Properties	Units	Reference composition of concrete	Fiber-reinforced concrete without Tarkosil® T50	Fiber-reinforced concrete with Tarkosil® T50
Theaveragedensity	kg/m³	2400.0	2460.0	2480.0
Compressive strength	MPa	44.0	50.0	62.0
Flexural strength	MPa	9.0	13.0	15.0
Waterabsorption	% by weight	4.0	3.5	2.5
Frost resistance	cycles	150.0	200.0	250.0
Shrinkage	mm/m	2.7	1.6	1.1

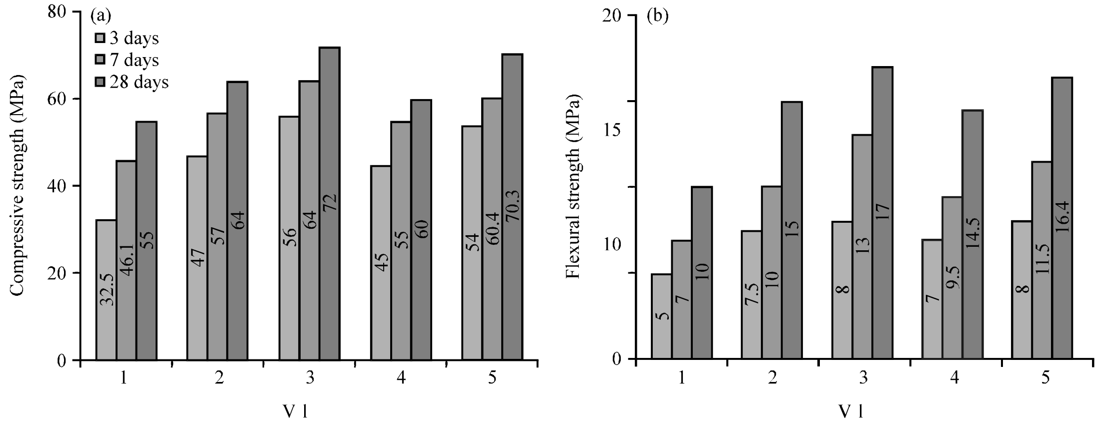

Fig. 6: a) Compressive and b) flexural strength of fiber-cement compositions: 1: control, 2: with slag waste fiber, 4% by weight; 3: with slag waste fiber and nanosilica, 4% by weight, 4: with basalt fiber, 4% by weight and 5: with basalt fiber and nanosilica, 4% by weight

The introduction of the mineral fibers increases the compressive strength after 28 days by 16%, the flexural strength by 50% compared to control composition. The additional introduction of NS improves the physical and mechanical properties: compressive strength by 30%, flexural strength by 70%. Noticeable increase of flexural strength is associated with the reinforcing action of mineral fibers and the introduction of nanosilica due to an increasing the corrosion resistance of the fiber.

The following parameters have ranged by optimization composition of fine grained fiber-reinforced concrete: the content of basalt fiber and Tarkosil® T50, the method of distribution of basalt fiber to the concrete mix. Technological properties of concrete mixtures and physico-mechanical characteristics of concrete have been defined at a variation of these parameters (Table 3 and 4). Thus, high surface area of particles Tarkosil® T50 in comparison with the cement particles contributes higher sedimentation stability and improvement in segregation of concrete mixes.

Composition of fiber-reinforced concrete with Tarkosil® T50 has shown the best results: an improvement of the compressive strength at 35%, the flexural strength at 65% in comparison with a control composition.

Concretes with Tarkosil® T50 are characterized by high performance properties. Tarkosil® T50 interacts with lime and promotes the corrosion resistance of basalt fiber that benefits the improvement of the fiber-reinforced concrete characteristics.

CONCLUSION

The presence of nanoparticles reduces the amount of "free" water. Introduction of nanosilica reduces setting time of cement pastes because nanosilica actively interacts with the cement particles and leads to accelerated hydrolysis of cement minerals. Researches of rheology of cement pastes in the initial period of hydration confirm the hypothesis about the mechanism of the nanosilica influence on a cement system, improving the basic physical and mechanical properties of cement composites.

Nanosilica with developed specific surface and high chemical activity reacts with portlandite formed during the hydration of cement and prevents corrosion of the mineral fiber. Joint introduction of mineral fiber and nanosilica leads to increased physical and mechanical properties of fiber-reinforced cement composites and concretes.

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