Nanostructured Basaltfiberconcrete Exploitational Characteristics

K A Saraykina, V A Shamanov
Civil Engineering and Material Sciences Department, Perm National Research Polytechnic University, 109, Kuybisheva str., Perm 614010, The Russian Federation

E-mail: cems@pstu.ru

Abstract. The article demonstrates that the mass use of basalt fiber concrete (BFC) is constrained by insufficient study of their durability and serviceability in a variety of environments. This research is aimed at the study of the basalt fiber corrosion processes in the cement stone of BFC, the control of the new products structure formation in order to protect the reinforcing fiber from alkaline destruction and thereby improve the exploitational characteristics of the composite. The research result revealed that the modification of basalt-fiber concrete by the dispersion of MWNTs contributes to the directional formation of new products in the cement matrix. The HAM additive in basaltfiberconcrete provides for the binding of portlandite to low-basic calcium hydroaluminosilicates, thus reducing the aggressive effect of the cement environment on the reinforcing fibers properties. The complex modification of BFC with nanostructured additives provides for an increase in its durability and exploitational properties (strength, frost resistance and water resistance) due to basalt fiber protection from alkali corrosion on account of the compacting of the contact zone "basalt fiber - cement stone" and designing of the new products structure and morphology of cement matrix over the fiber surface.

1. Introduction
Modern building is inextricably linked with tasks of construction production efficiency improvement, the cost and complexity of technological processes decrease, the economical use of material and energy resources, the use of new progressive materials, including those made with the use of nanotechnologies [1].

Today the most part of construction works is conducted with use of concrete. Despite a number of undeniable advantages and widespread application, unreinforced concrete is characterized by relatively low crack resistance. Traditionally this problem is solved by reinforcing concrete with steel individual rods, grids and frames. However, exploitational and economic conditions often dictate the need to replace steel reinforcement with nonmetallic ones, which significantly reduces the construction weight and improves other characteristics (resistance to acid and electrochemical corrosion, non-magnetic, dielectric properties, etc.) [2]. The Russian Federation has experience in the organization of composite polymer materials production based on glass-, carbon-, basalt-, aramide and graphite plastic fibers and they (especially fiberglasses) are successfully applied in electronics, aircraft and aerospace, automobile and shipbuilding. However, these materials and constructions based on them are used in the building production in extremely small volumes.
At the same time an opportunity to create on the basis of composites constructional materials with predetermined strength and thermal characteristics allows to project of them bearing construction and spans of bridges, to create a window systems, to use them in the construction of front systems and the production of a huge number of products necessary in the construction of buildings [3].

Despite a large number of studies conducted by domestic and foreign scientists, which confirm the availability of basalt fibers for dispersed concrete reinforcement, the mass use of basalt fiber concrete (BFC) is constrained by insufficient study of their durability and serviceability in a variety of environments. It is caused, in particular, by the ambiguity of the study results of basalt fiber durability in cement.

Investigations of I.V. Borovskikh, N.G. Vasylovskaya, I.G. Kalugin et al. [4, 5] are founded that the interaction of the cement system with the amorphous phase of basalt fiber does not have a significant effect on its reinforcing properties, the strength of the BFC decreases insignificantly with time. In the opinion of other authors (M.S. Aslanova, V.B. Babaev, L.A. Urkhanova, Jongsung Sim et al. [6-9]) basalt fibers are destroyed in the alkaline cement stone environment and, therefore, it can’t work as a reinforcing element of the construction. This is due to the destruction of the silica-oxygen fiber skeleton with the action of hardening cement calcium hydroxide.

The Discrepancy of research results can be associated with the use of different techniques in the study of this question, the difference in chemical basalt fibers compositions and types of the used cements. Besides, the situation is complicated by the fact that the process of the formation of new products on the basalt fiber surface at his interaction with a cement matrix in concrete has uncontrollable character.

Thus, the study of the basalt fiber corrosion processes in the cement stone of BFC, the control of the new products structure formation in order to protect the reinforcing fiber from alkaline destruction and thereby improve the exploitational characteristics of the composite is very important.

2. Methods of fiber’s protect from alkali destruction

At present, various methods to the fibers protect from alkaline destruction are developed. But those methods were rather time consuming and difficult to perform. Their application would necessarily entail the decrease in manufacturability of basalt fiber production. The way of decrease in the cement environment alkalinity by introduction of various nature and dispersion additives is represented to less expensive. However, with this method there is a question of control of structure formation of basalt fiber with a cement matrix interaction products.

The Directed cement system structure formation can be provided by the introduction of nanostructuring components, which is confirmed by the studies of A.N. Ponomareva, G.I. Yakovlev, Simone Musso, Monica J. Hanus et al. [10-13]. However, the effect of their impact on the BFC cement matrix structure, especially in the contact zone with basalt fiber has not been sufficiently studied to date.

Expediency of use of nanostructural additives for improvement of properties of various matrixes is proved by researches of various authors [14,15], but the use of nanostructural modifiers for the basalt fibers protection from destruction in the alkaline cement environment of the BFC and the creation of conditions to control the structure formation in the contact zone "basalt fiber – cement matrix" was not considered.

Based on previous research conducted by the authors [16] it was found that when basalt glass fiber and cement stone interacted, a shell consisting of the reaction products appeared at the interface around the fiber. The structure of these new products is microcrystalline. Their chemical and phase composition corresponds to calcium hydrosilicates, hydroaluminates and hydroferrites emerging at hardening of Portland cement. The crystallite habitus is of a cubic or short-prismatic form. These crystals have a higher mechanical strength than the long-prismatic ones, which leads to a change of the cement stone mechanical properties, but the adhesion of the new product shell to the fiber is below the internal forces of adhesion in fiber or the cement stone, the shell is easily separated from the fiber, and its efficiency, as a reinforcing element, is substantially reduced. This is due to the low BFC durability,
which is characterized by a composite strength decrease in time, caused by the corrosion of the fibers. The increase of the BFC durability is possible due to the basalt fiber protection from alkaline corrosion by controlling the mineralogical composition of the new products and improving their adhesion to the basalt fiber surface in the contact zone "basalt fiber-cement matrix".

3. Results and discuss
For this research nanostructural carbon systems (dispersion of MWNTs) and highly active metakaolin (HAM) were chosen as the modifiers, which are providing these functions [17,18].

The research result was revealed [19] that the modification of basalt-fiber concrete by the dispersion of multi-walled carbon nanotubes contributes to the directional formation of new products in the cement matrix, which causes compaction of interphase layers of a system "matrix – basalt fiber", and the high active metakaolin introduction in basaltfiberconcrete provides the binding of portlandite to low-basic calcium hydroaluminosilicates, Thereby reducing the aggressive effect of the cement environment on the reinforcing fibers properties.

To assess the complex effect of HAM and MWCNTs on the BFC strength was carried out full central two-factor experiment with change of factors at three levels. The fiber content and W/C was taken equal to 0.4% and 0.4 for each composition, respectively. The results were processed using the software package "STATISTICA".

As can be seen from the data presented in figure 1 and figure 2, the best BFC strengthening effect is observed with the complex introduction of HAM and MWNTs in an amount of 3-3.5% and 0.0048-0.005% of cement mass, respectively. The increase of flexural strength up to 25%, and compression strength – 45% relative to the strength characteristics of the control sample.

![Figure 1. The response surface of flexural strength function.](image1)

![Figure 2. The response surface of compression strength function.](image2)

On microphotographs of the BFC structure, which is modified by HAM and MWNTs (figure 3), it can be observed that the reinforcing fibers are covered with a shell of new products of a fine-crystalline octahedral crystal form, which differs from the cuboidal form in a dense adhesion to the fiber surface, which indicates the improvement of adhesion in the contact zone. At the same time, there are no numerous new portlandite products in the cement matrix. Is indicates that its binding with the metakaolin to the calcium hydroaluminate, that further compact the basaltfiberconcrete structure, which leads to the increase of strength characteristics.
A similar model of modifier action in the basaltfiberconcrete composition allows to assume, that due to the directional crystal growth and compaction of the structure of hydroaluminate calcium. The number of micropores and capillaries, contributing to the water filtration into the concrete body decrease. It increases its exploitational characteristics, and, consequently, the basaltfibercomposition durability.

While nanostructuring of basaltfiberconcrete observed the increase of water resistance, which indicates the increase of the concrete structure density with the modifier introduction, the reduce of micropores and capillaries that contribute to permeability of the composite. This increases durability of modified basaltfiberconcrete, since the greater the concrete water resistance, the less impact it has on both the water and dissolved aggressive substances.

Table 1. Results of definition of nanostructured basaltfiberconcrete exploitation characteristics.

| Basaltfiberconcrete          | Water resistance | Open porosity, % | Frost resistance |
|------------------------------|------------------|------------------|-----------------|
| W4                           | 6.19             | F100             |
| Nanostructured basaltfiberconcrete | W10 4.31       | F150             |

The metakaolin, when it interacts with the calcium hydroxide, forms calcium hydroaluminate, that increase the concrete density, while the dispersion of nanotubes contributes to the fuller flow of the hydration process of cement and directed the new product formation in the concrete body. There is a kolmatation of pores and capillaries in a composite matrix to formation of conditionally closed micropores. Its result is improvement the water resistance of basaltfiberconcrete.

The increase of the strength and water resistance of nanostructured basaltfiberconcrete should be associated with a decrease in the open porosity by more than 30%. As is known [20], water absorption depends on the size and character of pores in the composite, therefore, analyzing the dynamics of changes of water absorption, we can conclude that there is a compact of the contact layers of the matrix, filler and reinforcing component, and reduce the number of open pores available for penetration of water.

The nanostructured additives positive influence on the BFC exploitational properties is also confirmed by the results of the frost resistance tests: mark on frost resistance of modified composite made up F150, which exceeds the frost resistance of the unmodified BFC by 1.5 times (F100).

As the results of microstructural analysis (figure 4 and figure 5), basaltfiberconcrete durability increase according to the criterion of frost resistance should be associated with a significant compaction of the concrete structure. This is due to the intergranular voids and micropores filling by metakaolin with portlandite (calcium hydroaluminate) interaction products and the directed their structure formation in the interfacial layers due to the introduction of MWCNT. This contributes to the
colmatation of the capillaries in the concrete body and to the conditionally closed micropore system formation that prevent the penetration of water into the concrete body.

Thus, the complex modification of BFC with nanostructured additives provides for an increase in its durability and exploitative properties due to the basalt fiber protection from alkali corrosion by reducing the alkalinity of the environment, to the compact of the contact zone "basalt fiber - cement stone" and to the control of the cement matrix new products structure and morphology over the fiber surface.

4. Conclusion

The modifier introduction is provided to create a dense packing of new products on the limits of the solid phases, including the surface of the reinforcing basalt fibers. This contributes to the formation of spatial frame cells based on the modified cement matrix, which lead to an increase in the strength and performance characteristics of the composite as a whole.

References

[1] Florence Sanchez and Chantal Ince 2009 Microstructure and macroscopic properties of hybrid carbon nanofiber/silica fume cement composites Composites Science and Technology 69 1310

[2] Alekseeva L L 2010 Innovative technologies and materials in the construction industry (Angarsk: Angarsk State Technical University) p 32

[3] Naaman A E and Reinhardt H W 1995 High performance fiber reinforced cement composites 2 (HPFRCC2) (Ann Arbor, RILEM Workshop)

[4] Borovskikh I V and Morozov N M 2012 Increase of durability of basalt fiber cement concretes Kazan State University of Architecture and Engineering news. Building materials and products 2(20) 160

[5] Vasilovskaya N G, Endzhievskaya I G and Kalugin I G 2011 Cement compositions disperse-reinforced by the basalt fiber Vestnik of Tomsk State University of Architecture and Building 3 153

[6] Aslanova M S 1969 The influence of various factors on the mechanical properties of glass fibers Glass and ceramics 3 12

[7] Babaev V B 2013 Fine-grained cement concrete using basalt fiber for road construction (Belgorod: BSTU named after V.G. Shukhov) p 84

[8] Urkhanova L A, Lkhasaranov S A, Rozina V E and Buyantuev S L 2015 Fine basalt-fibrous-
concrete with nano-silica Building materials 6 45
[9] Jongsung Sim and Cheolwoo Park 2005 Do Young Moon Characteristics of basalt fiber as a strengthening material for concrete structures Composites Part B: engineering 36 504
[10] Ponomarev A N 2009 High performance concrete. Analysis of possibilities and practice of using methods of nanotechnology Engineering and construction magazine 6 25
[11] Yakovlev G I 2014 Nanostructuring of composites in building materials science: monograph (Izhevsk: Kalashnikov ISTU) p 38
[12] Musso Simone, Tulliani Jean-Marc, Ferro Giuseppe and Tagliaferro Alberto 2009 Influence of carbon nanotubes structure on the mechanical behavior of cement composites Composites Science and Technology 69 1985
[13] Hanus Monica J and Harris Andrew T 2013 Nanotechnology innovations for the construction industry Progress in Materials Science 58 1056
[14] Petrunin S Y 2015 Increasing the strength of concrete with carbon nanotubes using hydrodynamic cavitation (Moscow: Moscow state university of civil engineering) p 88
[15] Konsta-Gidoutos M S, Metaxa Z S and Shan S P 2008 Nanoimaging of highly dispersed carbon nanotube reinforced cement based materials Symposium on Fibre Reinforced Concrete: Design and Applications 125
[16] Saraykina K A, Golubev V A and Yakovlev G I 2014 Structuring the cement stone on the surface of reinforcing basalt fibers Intelligent Systems in Manufacturing 2(24) 203
[17] Saraikina K A, Golubev V A, Yakovlev G I, Sen’kov S A and Politaeva A I 2015 Nanostructuring of cement stone at disperse reinforcing with basalt fiber Building materials 2(722) 34
[18] Batalin B S and Saraykina K A 2014 Interaction of Glass Fiber and Hardened Cement Paste Glass and Ceramics vol. 71 7-8 294
[19] Saraykina K A, Shamanov V A, Golubev V A and Yakovlev G I 2017 Prediction of durability basaltfiberconcrete modified with nanostructural additives Building materials 1-2(745) 41
[20] Volzhensky A V 1979 Mineral binders (technology and properties): textbook for High Schools (Moscow: Stroyizdat) p 142