Increasing the durability of fibrous cement compositions by impregnating the porous space of fiber concrete

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Abstract. Fiberglass reinforcement is the most effective method of increasing the strength of concretes because fiberglass has high mechanical strength and high modulus of elasticity. The low corrosion resistance of fibers to the alkaline environment of concrete plays the role of the limiting factor to the widespread use of fiberglass reinforcement. As the process of corrosion of fiberglass largely depends on the porosity of the composition, the authors have conducted a study of the impregnation of the porous space of the fiberglass by specifically developed compound of the following composition: the liquid component – liquid glass; the neutral filler - nanodispersed silica Kovelos-05; the hardener of liquid – sodium silicofluoride. As a result of the chemical reaction between the liquid glass and the cement clinker components, colloidal calcium hydrosilicate and sodium aluminate are formed. The set of properties of liquid sodium glass enables it to accelerate the setting of concrete at the appearance of sodium aluminate and to reduce the permeability of the porous space, due to the formation of calcium hydrosilicates. These facts led to the use of liquid glass as a compound for impregnation of fiber concrete.

1. Introduction
Disperse-reinforced concrete is one of the varieties of a large class of composite materials. Disperse reinforcement is carried out by fiber fibers, evenly distributed in the volume of the cement matrix. Different types of metallic and non-metallic fibers of mineral or organic origin are used for this purpose [1]. The nomenclature of artificial fibers is quite vast: from extremely scarce ones, such as the ones made of carbon or wolfram, to relatively available like the ones made of steel, glass, basalt and polymeric materials [2].
2. Literature sources review
Studies on the dependence of concrete strength on such parameters as the percentage of reinforcement, length, and orientation of fibers have been carried out by domestic scientists K.L. Biryukovich, A.A. Paschenko, F.N. Rabinovich [3], B.S. Batalin, E.N. Semkova, K.A. Saraykina [4], as well as a number of foreign researchers: R.F. Cooper, J. B. Fanselow, D. B. Poker, Brian S. Mitchell [5, 6] and others.

Fiberglass reinforcement is the most effective method of increasing the strength of concrete because it has high mechanical strength and the modulus of elasticity. The strength of glass fibers exceeds that of natural ones and of the most synthetic fibers. The elastic modulus of glass fiber is similar to the elastic modulus of steel, and 3.5 times lighter by volume weight; it is about twice as higher than the modulus of elasticity of concrete, so fiberglass takes the main part of the loads applied. To date, fiberglass concrete is one of the most promising building materials in the world. A deterrent to the widespread use of fiberglass reinforcement is the low corrosion resistance of fibers to the alkaline environment of concrete [7].

As the process of corrosion of fiberglass largely depends on the porosity of the composition, the authors have carried out a study of the impregnation of the porous space of the fiberglass concrete by the specifically developed compound of the following composition: the liquid component - liquid glass; the neutral filler - nanodisperses silica Kovelos-05; the hardener of the liquid component – sodium silicofluoride [8]. As a result of the chemical reaction between the liquid glass and the cement clinker components, colloidal calcium hydrosilicate and sodium aluminate are formed. The set of properties of liquid sodium glass allows to accelerate the setting of concrete at the appearance of sodium aluminate and to reduce the permeability of the porous space, due to the formation of calcium hydrosilicates. These facts led to the use of liquid glass as a compound for impregnation of fiber concrete. To evaluate the alkali resistance of fiberglass, an accelerated method was used, which is boiling the fibers in a saturated lime solution according to the method by Paschenko A.A. [9].

3. The purpose of the study
The purpose of the study is to evaluate the alkali resistance of the fiberglass in the alkaline medium of the fiberglass cement matrix after impregnation with a compound.

4. Materials and methods
To evaluate the alkali resistance of fiberglass, an accelerated method was used, which is boiling the fibers in a saturated lime solution according to the method by Paschenko A.A. The samples of the original glass fiber were boiled in a saturated solution of calcium hydroxide pH = 9.1 for 4 hours. Glass fibers weighing of 2 g were placed in a heat-resistant flask of 500 ml volume, then 250 ml of saturated solution Ca(OH)\textsubscript{2} were poured into the flask, then the flask was sealed with a tube filled with lime and placed in a thermostat at a temperature of 90°C. The saturated solution, simulating the liquid phase of the solidifying cement, consists of the following components: 2.28 g/l Na\textsubscript{2}O is added to 1 liter of water; 2.38 g/l K\textsubscript{2}O; 1.00g/l CaO. For comparison, the fiberglass was boiled in a calcium hydroxide solution with the addition of nanosilica in the amount of 0.8% by weight of cement.

5. Results and discussion
Figure 1 shows images of the glass fiber samples extracted before and after the boiling process. The images are taken by a scanning electron microscope (SEM) at 1000 times magnification.

The original fiber before the boiling procedure is characterized by a smooth and smooth surface (Figure 1a). After boiling we can see visible traces of interaction of lime with the fiber, which caused the appearance of defects and new formations on the fiber surface (Figure 1b).

The surface of the fiber boiled with the addition of nanosilica to the solution remained smooth and even with slight inclusions of the new formations, the products of the interaction of the nanosilica with lime (Figure 1c). Analyzing the strength rates of the compositions with the original fiber and after boiling with the addition of nanosilica, it should be noted that the effect of increasing the strength was 57%65% compared with the control sample.
Studies have shown that nanosilica because of its developed specific surface area and high chemical activity, interacts with the lime, which is formed during the hydration of cement and prevents the corrosion of the glass fibers. This has the effect of increasing the strength of the cement stone and strengthening the glass fiber reinforcing effect.

**Figure 1.** Scanning electron microimages of the glass fiber surface: a - initial state, b - after boiling in a lime solution, c - after boiling with the addition of nanosilica.

As is known [10], 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. Changes in the physical and mechanical characteristics of glass fiber cement compositions are associated with changes in their microstructure and porosity. Electron microscopic studies were carried using the scanning electron microscope JSM6390LV (Jeol, Japan). In the mode of secondary electrons, the study of the morphology of the fractures surface was carried out in the samples. The study of the fracture surface for this material reflects the features of the structure more objectively since the fracture reveals defective areas and allows assessing the degree of structural perfection of the sample by its morphological features. In micrographs taken under magnifications (up to 1,000X), one can see the natural roughness of the fracture surface, to estimate the porosity at the micron level, to perform a comparative analysis of the texture of the samples, to estimate the microporosity and to detect submicron structural components.

Figure 2 shows that the pores filling effect created by pozzolanic spherical microparticles of nanosilica (2a), allows reducing the porosity of concrete, partially. During the hardening process, the pores will be filled with crystals of lime Ca(OH)$_2$. The microstructure of the samples with liquid glass impregnation (2b) is denser than the composition without impregnation. The introduction of the impregnating fluid during internal evacuation of the product leads to a decrease of capillary porosity and increase of density.

Based on previous research conducted by the authors [11] 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. To assess the durability of fiberglass in alkaline cement environment, non-alkaliproof fiberglass in the composition of fiber concrete have been investigated for 1 year without impregnation and impregnation. Figure 3 shows that unprotected fiberglass, actively interacts with a solution of Ca(OH)$_2$, absorbing CaO from it. There is a rather thick area of detachment with an uneven surface on the surface of the fiber. These morphological features indicate the process of etching of the fiber in the alkaline environment of the hardening concrete.
Figure 2. Fiberglass structure with nanosilica without impregnation (a) and with impregnation (b).

Figure 3. Electron microscopic images of fiber concrete reinforced with fiberglass without impregnation during 1 year.

With the time, the size of the spherical particles and their number increases, as well as the thickness of the corrosion shell over them. The profound changes in the morphology, elemental and phase composition that occur with the fiber in an alkaline environment lead to a loss of mechanical strength, which, in turn, significantly reduces the positive effects of its addition.

6. Conclusions
The use of non-alkali-proof fiberglass is possible in the case of using the developed intensive mode of impregnation of fiberglass concrete with a compound based on liquid glass, which will not only prevent the corrosion of the fiber inside the cement environment but also fill the porous space of the body of the concrete.

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