Resistance of basalt fiber to alkaline environment of hydrated Portland cement

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Abstract. The article shows a study of the effect of hydrated Portland cement, aggressive towards basalt fiber, and more aggressive saturated lime solution over time. The degree of destruction of basalt fiber over time has been established.

The possibility of using basalt fiber in cement composites is fairly widespread [1-4] and largely depends on its resistance to the action of cement hydration products, primarily to Ca (OH)₂ alkali. Kanaev S.F. [5] found that the durability of basalt fiber and basalt-plastic reinforcement is superior to that of fiberglass.

F.N. Rabinovich and his co-authors [6, 7] determined a high degree of destruction of the mineral fiber in an alkaline environment. Aluminium borosilicate monofilament aged for 12 months in a saturated solution of lime has lost 72% of its original strength. At the same time, the strength of basalt fiber after its exposure to similar conditions decreased by only 26-32%. The author indicates a tendency to attenuation of the reaction processes of basalt fibers with CaO over time. The most intensive leaching processes are observed during the first three months.

A.A. Pashchenko and his co-authors [8, 9] in studies of the resistance of mineral fibers in inorganic binders confirms the higher resistance of basalt fibers in aggressive environments of cement stone and in a saturated solution of lime. Thus, after three years of testing, the strength of basalt fiber decreased by only 12-15%.

Due to the ambiguity of the literature data [5-9], we tested the resistance of basalt fiber in a saturated solution of Ca(OH)₂, the main component of the liquid phase of hydrated Portland cement by CaO absorption, in accordance with the procedure [10]. Tests of two types of basalt fiber (staple and continuous) and initial natural basalt were carried out for three years in a saturated solution of Ca (OH)₂, as well as boiling in this solution for 4 hours, which as Pashchenko reported [9] is equivalent to 10 years of exposure in cement concrete.

Evaluation of chemical resistance of basalt fiber during its exposure for three years in a saturated solution of Ca(OH)₂, as well as when boiling in this solution for 4 hours [10].

The results of the study on CaO absorption are presented in Figure 1 and Figure 2.
As Figure 1 shows the basaltic rock has the highest activity towards CaO, despite the fact that the specific surface of the powder obtained from it is \( S_{\text{specific surface}} = 2500 \text{ cm}^2/\text{g} \). Comparison of these substances recalculating CaO absorption on 100 m\(^2\) of surface is more correct. The staple fiber has the highest activity (0.31 kg/m\(^2\)). CaO absorption by continuous basalt fiber is 0.18 kg/m\(^2\). This happens due to the largest developed surface, defects on the surface of the staple fiber obtained by melt blowing, in contrast to the smooth texture of continuous basalt fiber obtained by the method of stretching from the melt through a die. Microphotographs of the fibers are represented in Figure 3.

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Figure 3. Microphotographs of basalt fibers (x320)

The effect of these two types of fibers on flexural strength of cement stone, as can be seen from the histograms of Figure 4, leads to the conclusion that staple fiber is unsuitable for dispersed reinforcement of cement concrete.

Therefore, further studies were carried out with fiber from chopped roving 9 mm long.
With the use of an optical microscope local areas of neoplasms (growths) were found on the surface of the fiber, increasing its diameter and roughness, which can contribute to better adhesion to the cement matrix (Figure 5a, b).

**Figure 4.** The influence of type and content of the fiber weight % by the strength of cement stone in bending (28 days).

**Figure 5.** Microphotographs of basalt fibers (x1000): continuous fiber.

Figure 6 shows that as a result of exposure of the basalt fiber for 3 years in a saturated solution of Ca(OH)$_2$, the length of the neoplasms on the fiber surface of the total length is approximately 12%. In a section of basalt fiber subjected to 4-hour boiling in a saturated solution of Ca(OH)$_2$ (Figure 6b), the length of the fiber fragment under consideration.

The obtained data on the change in the surface of basalt fibers were confirmed by statistical processing of linear measurements of six similar images of fragments of basalt fibers, both for basalt fiber aged for 3 years in a saturated solution of Ca(OH)$_2$ and after 4 hours of boiling in this medium.

**Figure 6.** Microphotographs of basalt fibers (x320): continuous fiber.
For the first test variant, the average value for 6 measurements is 11.7%, the standard deviation is 0.4%, and the coefficient of variation is 3.4%. The sufficient accuracy of the average value is 1.39%, which meets the requirements of GOST 8.207-76 “Direct measurements with multiple observations.”

For a fiber aged for 4 hours in a boiling solution of Ca(OH)$_2$, the average value for 6 measurements is 15.3%, the mean square deviation is 0.64, and the coefficient of variation is 4.2%. The sufficient accuracy of the average value is 1.71%, which meets the requirements of GOST – (no more than 5%).

The results of the compressive strength test of a cement stone reinforced with fiber (3 wt.%), boiled in expansive mortar (1), aged in this mortar for 3 years (2) and the original (3) are shown in Figure 7.

As can be seen from Figure 7 cement stone with fiber aged for 3 years in saturated solution of lime, showed a strength of 90 MPa. This is only 7% inferior to the control composition with the original fiber, the strength of which was 96 MPa at 28 days of storage under normal humidity conditions.

The tensile strength when cracking cement stone of the same compositions is presented in Figure 8.

As can be seen from Figure 8. tensile strength of a cement stone when cracking with the same basalt fiber content in the compositions (3%) shows that a composition with a fiber aged for 3 years in a saturated lime solution showed a strength of 10.6 MPa, where there is only 6% less control composition with the original fiber, the strength of which was 11.4 MPa. A sample with basalt fiber, boiled for 4 hours in a saturated lime solution, showed a strength of 10.2 MPa, which is 10% less than the strength of the control sample.
Direct tests were carried out of the tensile strength of basalt fiber after boiling in a saturated solution of lime.

Samples were prepared from segments of a basalt tow of length 150 mm, which, in turn, consists of an average of 700 thousand monofilaments with a diameter of 10 microns.

The ends of a basalt tow 15 mm long were placed in a steel cylinder with a diameter of 20 mm and were filled with an epoxy compound and kept for curing for 3 days at 200 °C. Then six samples were subjected to 4-hour boiling in a saturated solution of lime. The results of fiber tensile testing are presented in Figure 9.

As can be seen from Figure 9, the tensile strength of the boiled fiber is 8% lower than that of the control fiber. This confirms our assumption about the higher resistance of basalt fiber to alkaline environments, cement concrete, than indicated in well-known literature sources.

Thus, according to the results of microscopic analysis, indirectly confirmed by tests on the strength of cement stone and direct tensile tests of basalt fiber, it should be concluded that continuous basalt fiber reacts with the products of hydration of Portland cement. However, the reaction is limited to 10-12% of the surface of the fibers, which slightly reduces their strength and does not affect the strength of the entire fiber-reinforced composite as a whole. Considering that the formation of Ca(OH)₂ occurs immediately after its mixing with water, it is possible by introducing pozzolanic additives, for example, silica fume, etc., to reduce the possibility of the reaction of Ca(OH)₂ with the surface of the fiber.

![Figure 9. Tensile strength of basalt fiber tows.](image)

The results obtained are well correlated with the data of the authors [11], who conducted long-term (up to 15 years) tests of basalt-fiber concrete and established the decaying nature of strength reduction (after 10 years - 12%, after 15 years - 7%). In their opinion, this is connected with the formation of a layer of insoluble hydro silicates on the fiber surface that impede the development of corrosion. In our opinion, finishing with epoxy emulsion is a radical way to prevent alkaline corrosion of basalt fiber.

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