Study on basalt fiber parameters affecting fiber-reinforced mortar

A A Orlov¹, T N Chernykh¹, A V Sashina¹ and D V Bogusevich¹
¹National Research South Ural State University, Chelyabinsk, 454080, Russia

E-mail: kosheen_s@mail.ru

Abstract. This article considers the effect of different dosages and diameters of basalt fibers on tensile strength increase during bending of fiberboard-reinforced mortar samples. The optimal dosages of fiber, providing maximum strength in bending are revealed. The durability of basalt fiber in an environment of cement, by means of microscopic analysis of samples of fibers and fiberboard-reinforced mortar long-term tests is examined. The article also compares the behavior of basalt fiber in the cement stone environment to a glass one and reveals that the basalt fiber is not subject to destruction.

1. Introduction
Fiber concrete, as well as regular concrete, is composite material including fiber rebar distributed in the volume. Dispersive fiber reinforcement to a great extent allows compensation of concrete shortcomings - low tensile strength and low strain at fracture. Fiber concrete has several times higher tensile and shearing strength, impact and fatigue strength, fracture and crack resistance, frost resistance, waterproofing capacity, heat stability and fire resistance [1, 2, 3, 4].

Current study is aimed at defining the most effective dosages and diameters of basalt fiber when reinforcing cement composites.

2. Methods and materials
BFC 300 (compatible satisfying requirements of Russian National Standard GOST 31108–2003 – ЦЕМ II/А–Ш 22,5 Н) produced by “Magnitogorsk Cement and Refractory Works” JSCO was used in the study to define the most effective dosages and diameters of basalt fiber. The aggregate used was sand wash sized to 0, 16…2 satisfying requirements of Russian National Standard GOST 8736-93 “Sand for construction works. Technic specifications”. Fiber reinforcement was done with basalt fiber produced by “Russian basalt”, fiber was produced according to TOR-5952-002-91341008-2012, the diameters of fiber used were 10, 15, 20, 25 um, length 12 mm. To compare the behavior with basalt fiber when exploited in alkaline medium of cement matrix, glass fiber made of alkali-nonresistant glass specially produced by “Russian basalt” was also used.

Test methods used in the study are shown in Table 1.

| Test mode                                  | Test method               |
|--------------------------------------------|---------------------------|
| Normal consistency, cement slurry setting  | GOST 310.3-76             |
| time                                       |                           |
| Standard sand-cement mortar consistency,   | GOST 310.4-81             |
| flexural strength                          |                           |
| Longevity of fiber in cement matrix        | Electronic focused beam   |
|                                            | microscope                |

Table 1. Test methods.
3. Results

It is known that cement fibers reinforce only mortar phase of material and therefore they have lower reinforcement effect than cement slurry or mortar. Thus the experiment defining the most effective dosages and diameters of fiber was carried out on sand-cement mortars. To assess the influence of basalt fiber over the mortar strength two-factor experiment was planned. Its factors were:

- x-factor – fiber dosage, factor ranged on 3 values 0.7, 1.1 and 1.5 kg/m$^3$ of concrete mix;
- y-factor – fiber diameter, range values 15, 20 and 25 um.

Composite flexural strength gives initial response to volume micro reinforcement, thus considered to be the primary response. It has been controlled since the first day up to vintage age.

To conduct an experiment a composition of BFC, sand wash and mixing water in the ratio 1:3:0.56 (№ 10 in Table 1) considered to be controlled. Other compositions included basalt fiber according to the experiment plan (Table 2).

Experiment plan and the study results are listed in Table 2, the influence of basalt fiber dosages and diameters over flexural strength is graphically presented in Figures 1, 2.

| Item number | x-factor code | Fiber dosage, kg/m$^3$ | y-factor code | Fiber diameter, um | Flexural strength, mPa | Flow, cm |
|-------------|---------------|------------------------|---------------|-------------------|------------------------|----------|
|             |               |                        |               |                   | day 1 | day 28 |                   |          |
| 1           | -1            | 0.7                    | -1            | 15                | 0.92 | 6.85 | 108,5              |          |
| 2           | 0             | 1.1                    | -1            | 15                | 0.49 | 7.12 | 108,5              |          |
| 3           | 1             | 1.5                    | -1            | 15                | 0.56 | 7.06 | 109                |          |
| 4           | -1            | 0.7                    | 0             | 20                | 1.58 | 7.73 | 108,5              |          |
| 5           | 0             | 1.1                    | 0             | 20                | 1.29 | 7.98 | 109                |          |
| 6           | 1             | 1.5                    | 0             | 20                | 1.14 | 7.07 | 109,5              |          |
| 7           | -1            | 0.7                    | 1             | 25                | 1.75 | 7.8  | 108,5              |          |
| 8           | 0             | 1.1                    | 1             | 25                | 1.85 | 7.61 | 109                |          |
| 9           | 1             | 1.5                    | 1             | 25                | 1.75 | 7.18 | 110                |          |
| 10          | -             | 0                      | -             | -                 | 0.8  | 6    | 108                |          |

Figure 1. Dependence of flexural strength in the 24-hour hardening on the fiber dosages and diameters.

The dependence obtained indicates that fiber diameter and dosage increasing in the 24-hour hardening leads to flexural strength increase, moreover it becomes 2 times stronger in comparison to control composition without fiber. In such event it is fiber diameter that largely affects sample...
strength. Strength increase with bigger diameter is probably connected with the fact that bigger
diameter fibers are less likely to create beams (including vacuos) during formation.

$M(x, y) = 7.78 - 0.17 \cdot x + 0.26 \cdot y - 0.29 \cdot x^2 - 0.32 \cdot y^2 - 0.21 \cdot x \cdot y$

**Figure 2.** Dependence of flexural strength in the 28th day hardening on the fiber dosages and

diameters.

In the 28th day optimum region can be defined in the figure of dependence of flexural strength on
the fiber dosages and diameters, the strength in which is at the maximum point for fiber with the
diameter of more than 20 um in dosages from 0.7 to 1.0 kg/m$^3$. In condition of optimum parameters of
mortar reinforcement more than three times strength increase is reached. The crucial factor is still fiber
diameter, but when dosages used are more than 1 kg/m$^3$ flexural strength get lower. This may be due to
the fact that the excess of optimum dosages leads to an uneven distribution of the fibers in the
material. Part of the fiber bunches into beams of 5…15 grains, inside of which the fibers do not adhere
to the cement matrix and when the material is being damaged they are easily pulled out, which ends up
in lower flexural strength.

To estimate resistance of basalt fiber to alkaline medium of cement matrix a microscopic analysis
of samples of cement matrix with fiberboard grains was performed. Fiberboard grains were in cement
samples for a long time (4 months, under conditions of 100% humidity) (Figure 4). For comparison,
Figure 3 shows photomicrographs of glass fiber of non-alkali glass.

**Figure 3.** Photomicrograph of glass fiber in the cement matrix.

a) photomicrograph         b) silicon distribution
As seen in photomicrograph (Figure 3a) hydrate layer was formed on glass fiber. And silicon distribution is uneven; hydrate layer differs from glass fiber and cement hydration product in chemistry indicating the chemical processes occurring on the surface of the fiber.

![Photomicrograph of basalt fiber in the cement matrix.](image)

**Figure 4.** Photomicrograph of basalt fiber in the cement matrix.

Basalt fiber micrograph has clear boundaries; there are no visible traces of destruction. This is confirmed by distribution pattern of silicon, there is clear boundary between the cement matrix and the fiber, i.e. there is no zone of variable composition, and fiber is well preserved in the alkaline medium of the cement matrix.

The results of the microscopic analysis of the samples with fiber are confirmed by bar (4x4x16) tests at different hardening ages. Test results of bar specimens are tabulated in Table 3.

| Composition number | Fiber type, diameter | Flexural strength, mPa |
|--------------------|----------------------|------------------------|
|                    |                      | 28 days | 2 months | 3 months | 4 months |
| 1                  | without fiber        | 6.0     | 6.5      | 7.1      | 7.9      |
| 2                  | glass fiber, 13 um   | 7.27    | 7.10     | 6.2      | 4.55     |
| 3                  | basalt fiber, 25 um  | 7.8     | 8.5      | 8.9      | 9.4      |

**4. Conclusions**

The study indicated that basalt fiber is suitable for application in cement-based materials and having optimal parameters of micro rein for cement (diameter 20-25 um in dosages ranging from 0.7 to 1.1 kg/m³) is able to increase their flexural strength more than 1.5 times. It is also shown that the positive effects of fiber usage remain after contacting with cement matrix for a long time.

**References**

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