Investigation of mechanical properties of fiber-cement board reinforced with cellulosic fibers

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Abstract. The article presents experimental research on the development of the optimal composition of cement-fibrous composite material for the manufacture of autoclaved fiber-cement boards with high physical, mechanical and economic parameters. The effect of the cement-sand ratio of the matrix, the specific surface area of the sand and the cellulosic fibers content on the physical and technical properties of the material is shown. It is established that the optimum cement-sand ratio of the matrix associated with a specific surface area of quartz sand 310 m²/kg is 1:2. The optimal content of cellulosic fibers according to the criterion of increasing the strength is 5-7.5%.

1 Introduction

Hinged ventilated facades find their application for finishing the facades of newly erected buildings, as well as for the insulation of reconstructed buildings. Currently, various materials are used as a protective and decorative screen, but the questions associated with the development of new environmentally friendly and low cost materials that combine high decorative and performance qualities, are remain relevant. Fiber-cement boards attract particular attention in this regard [1, 2-4].

Fiber-cement boards are deservedly demanded by architects, designers and builders. They are used for finishing the facades of the accommodation building, office buildings, educational institutions, banks, metro stations and train stations, tunnels, bridges, racks [5].

These boards are an artificial composite stone building material resulting from solidification of a mixture consisting of cement, fibers (≈5-20% by weight of cement) and water. Nonlinear deformation models that have a high degree of reliability are used to assess the strength and deformability of composite materials, in particular concrete [6, 7].

The most common type of fiber cement is asbestos cement products. They have low cost and compete with other roofing and facade materials. However, asbestos fibers are carcinogenic, therefore, in...
many countries around the world, especially where natural reserves of asbestos are lacked, research related to the partial or complete replacement of asbestos with other types of organic or inorganic fibers remains relevant.

In this regard, the use of environmentally friendly raw materials of low cost required technical properties should be taken into account in the attempt to develop new cement-fiber composite materials.

The most significant effect can be achieved with the introduction of new asbestos-free cement-fiber materials on existing traditional production lines for the production of asbestos cement sheets with maximum use of existing equipment. There are studies of fiber-cement materials based on alkali-resistant glass grades (S-15GT) and basalt fibers [8], according to which the complete exclusion of asbestos from the composition and their replacing with glass or basalt fiber with respect to existing round-grid machines is practically impossible. It is caused by low cement-holding capacity of such fibers. Zone dispersed reinforcement with metal fibers, despite its effectiveness, does not provide the required corrosion resistance of thin-walled materials that are operated in humid environments [9].

The experience of using carbon fibers in fiber-cement boards is known, but high cost does not allow them to be fully utilized [10]. The use of basalt and glass fibers in cement systems is limited due to their low resistance to cement hydration products. However, currently this problem is being solved by modifying the surface of such fibers [11, 12].

The most preferred type of fibers, allowing to achieve high technical results, are cellulosic fibers [13]. A number of authors have shown the efficiency of using cellulosic fibers from bamboo [14, 15], rice straw [16]. Good quality results were obtained by VNII-project through creating the cement-fiber products with partial cement (up to 50%) replacing asbestos with cellulose fibers [17]. Cellulose was served as the fibrous material: HC-2 unbleached sulphate and bleached sulphite. Cellulose fiber-based sheets have passed a 10-year life cycle test. Strength and aesthetic properties of sheets have not deteriorated. Factory production of fiber-cement boards reinforced with cellulosic fibers in Russia is established at OAO LATO. Products fully meet the performance requirements [18].

According to the classification of dispersion-reinforced concrete [19], reinforcing fibers were proposed to be divided into two types: low-modulus and high-modulus, which are divided into metal, mineral and organic. Specifications, some of them are presented at the Table 1.

### Table 1. Technical characteristics of fibers.

| Fiber      | Density, g/cm³ | Tensile strength, MPa | Modulus of elasticity, MPa | Elongation at rupture, % |
|------------|----------------|------------------------|----------------------------|------------------------|
| Polypropylene | 0.9            | 400-770                | 3500-8000                   | 10-25                  |
| Polyethylene | 0.95           | 700                    | 1400-4200                   | 10                     |
| Nylon      | 1.1            | 770-840                | 4200                        | 16-20                  |
| Acrylic    | 1.1            | 210-420                | 2100                        | 25-45                  |
| Polyether  | 1.4            | 730-780                | 8400                        | 11-13                  |
| Asbestos   | 2.6            | 910-3100               | 68000                       | 0.6                    |
| Cellulose  | 1.2            | 300-500                | 10000                       | 0.5-4                  |
| Glass      | 2.6            | 1050-3850              | 70000-80000                 | 1.5-3.5                |
| Steel Fiber| 7.8            | 800-3150               | 200000                      | 3-4                    |
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| Material          | Length | Diameter | Density |
|-------------------|--------|----------|---------|
| Carbonic          | 2.0    | 2000     | 245000  |
| Carboniferous     | 1.63   | 7800     | 380000  |
| Nylon             | 0.9    | 720      | 1900    |
| Viscose           | 1.2    | 660      | 5600    |
| Basalt            | 2.6    | 1600-3600| 80000-110000 |
| Wollastonite      | 2.9    | 200-400  | 10000   |
| Kevlar            | 1.45   | 3600     | 150000  |
| Polyacrylonitrile | 1.2    | 900      | 20000   |

Cellulosic fibers according to this classification can be attributed to high modulus, organic, since the elongation at rupture is 0.5-4%, tensile strength 300-500 MPa, average fiber diameter 10-35 microns, length 200-1000 microns and more. Such characteristics of cellulosic fibers provide high impact strength and flexural strength of a composite material.

Cellulosic fiber has the following advantages: easy fluff, sufficient mechanical strength and flexibility, they are not carcinogenic. High adsorption capacity allows it to precipitate and firmly hold cement grains on its surface. Reinforcing ability determines the high mechanical bending and tensile strength of the hardened material. High alkali resistance of such fibers is also advantage.

This paper presents the results of the development of cement-fiber composite material based on cellulosic fibers for the manufacture of pressed autoclaved fiber-cement boards, which, depending on the functional purpose, can be used for cladding the outer walls of buildings, manufacturing suspended ceilings, sandwich panels, interior partitions, window sills slabs, as removable and fixed formwork, etc.

The purpose of the research was to determine the optimal composition of the cement-fibrous composite material for the manufacture of fiber-cement boards. The influence of the cement-sand matrix ratio (C/S), the specific surface area of the sand (SSA) and the content of cellulosic fibers on the physical and technical properties of the material were studied.

2 Materials and Methods

The composites of different composition were produced in thin plates, measuring 220x100x7 mm. The following materials were used: Portland cement CEM II / A-K (SH-P) 32.5H provided by Ulyanovsk Cement Plant, quartz sand from the Kama deposit SSA = 192, 210, 310, 410 m²/kg, pulp of coniferous sulphate unbleached Solombalsky pulp and paper plant (GOST 11 208-82).

Preparation of fiber-cement mixture was carried out in the following order: disintegration of cellulose fibers according to GOST 14363.4-89; after the dissolution was completed, the fiber was filtered through a filter screen; mixing fiber with cement and sand to form fiber-cement mass (FCM) with a concentration in water of 20-25%. After that, FCM was filtered.

Then FCM specimens were put in the mold and pressed according to the following regime: 10 min – pressure rise up to 600 N/cm², at the speed 10 kgf/s, 10 min – curing under pressure.

After curing for 1 hour, the obtained specimens were exposed to steam treatment in the steam chamber (according to the regime: 2 hours - temperature rise to 65 °C, isothermal curing for 4 hours, 2 hours - cooling), and then autoclaved treatment (according to 3 h - rise to a temperature of 175-180 °C, 6 h - isothermal curing, 3 h - cooling).

The tests were carried out according to GOST 8747-88. According to the results of experimental studies, a mathematical dependence of the flexural strength of the fiber-cement boards on the cement-sand ratio of the matrix was obtained, which is expressed by a second-degree polynomial:
\[ R_g = -4.05x^2 + 15.25x - 1 \]  

(1)

under which maximum values are achieved at C/S = 1/1.6-1/2.1.

Hardening of autoclave materials is carried out as a result of chemical reactions between the components of the binder and water under conditions of high pressure and temperature. The main chemical process in autoclave curing is the interaction between calcium hydroxide, silica and water, accompanied by the formation of calcium hydrosilicates, which bond unreacted grains into artificial conglomerates. The reaction rate and strength of conglomerates increase as dispersion of raw materials increase. In this regard, determination of the optimal value of the fineness of the quartz sand used in the manufacture of fiber-cement board samples is of scientific interest. For this purpose, the tests were carried out on tiles samples with different specific surface area of the sand and cement-sand ratio 1: 1, 1: 1.5, 1: 2, 1: 2.5, 1: 3.

3 Results and Discussion

Dependence of the flexural strength of fiber-cement board samples on SSA of the quartz sand is shown in Figure 1.

![Figure 1](image-url)

**Figure 1** – The dependence of the flexural strength of the fiber-cement board samples on the C/S of the matrix with a constant fiber content of 5%, different dispersity of quartz sand (SSA): 1 – 192 m²/kg, 2-210 m²/kg, 3-310 m²/kg, 4-410 m²/kg.

As can be seen from Figure 1, the maximum parameters are achieved when C/S=1:2 and SSA is not less than 310 m²/kg.

The effect of cellulosic fiber content at various values of the fineness of quartz sand on the flexural strength of the fiber-cement board samples are shown in Figure 2.
Experimental studies have shown that maximum flexural strengths are achieved when fiber-cement board samples reinforced with cellulosic fibers of 5-7.5% with C/S = 1:2. While specific surface area of quartz sand increases from 190 to 210, 310, 410 m²/kg, the flexural strength increases by 3, 12 and 16%, respectively.

The best indicator of the specific surface area of quartz sand is a 310 m²/kg. As follows from Figure 2, a further increase of the specific surface area of the quartz sand slightly increases the flexural strength, but significantly increases the energy costs due to grinding time.

Conclusions

The optimal composition of cement-fibrous composite material for the manufacture of fiber-cement autoclaved boards with high physical, mechanical and economic parameters was obtained. The obtained boards have a flexural strength 24.2 MPa, they reinforced with cellulosic fibers 5-7.5% with C/S = 1:2. In this case, the optimal indicator of the specific surface area of quartz sand is a value equal to 310 m²/kg.

The obtained fiber-cement boards are weatherproof and frost-resistant, do not ignite and do not spread fire, have a low coefficient of thermal expansion, shock-resistant, moisture-proof, durable, environmentally safe, resistant to aggressive environment. They are much lighter than porcelain tiles; therefore, they can be successfully used for cladding of buildings with a limited load on the foundation.

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