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Use of Composite Reinforcement in Fiber-Foam Concrete Production

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***Abstract* – The increase in strength requirements for wall materials for stretching and bending while maintaining or reducing their average density scientifically justified. The research shows that the technology of autoclaved gas silicate currently does not allow achieving the required level of properties. Therefore, the construction industry practically does not produce large-sized products. Fibro-foam concrete is a modern energy-saving building material. It has a universal set of positive operational properties. The possibility of its use in bending elements of building structures is scientifically substantiated and experimentally confirmed. Taking into account modern advances of the development of production technologies of composite materials, the authors propose to consider the possibility of using new types of rod reinforcement in flexible building structures of limited bearing capacity. The results of the experimental evaluation of the adhesion strength of fibro-foam concrete with rod reinforcement (metal and composite) are given. The positive effect of composite rod reinforcement on the magnitude of its adhesion with fibro-foam is established.**

Keywords – fibro-foam concrete; reinforcement; dispersed reinforcement; composite reinforcement; adhesion; porosity; tensile strength in bending.

I. INTRODUCTION

The urbanization of the society of the twenty-first century reflects the fact that modern buildings tend to become higher and higher [1, 2]. This trend forms special requirements for structural and wall materials used in construction [3, 4]. The most important among them is the thesis of increasing strength with a decrease (or preservation) of average density [5, 6]. That is why the technologies of concretes of continuous and cellular structures are actively developing [7–9].

The reduction of the average density of materials used as wall materials allows achieving the following advantages:

- To reduce the consumption of materials of buildings and structures [10];
- To promote energy saving in construction by improving thermal properties [11];
- To increase the dimensions of buildings and the mass of technological equipment without increasing the requirements for the properties of base soils [12], etc.

The analysis of the construction features of residential and civil buildings constructed in the Russian Federation in the twenty-first century shows that the most common method of ensuring their energy efficiency is the use of multilayered enclosing structures [13]. The authors believe that this method is far from desired one due to the following reasons.

A multilayered wall consists of materials that have not only different properties, but also more importantly, different durability [14, 15]. Therefore, if the shortest living layer turns out to be inside the longest living ones, then not only the deterioration of the heat-shielding properties of the enclosing structure occurs. The conditions for violation of sanitary and hygienic conditions inside the premises are formed. In many advertisements, different repair companies offer the service of release from mould.

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The demand for the service arose because of the fact that modern three-layered walling structures in the Russian Federation are arranged mainly with the following sequence of layers - “dense-porous-dense”. Brick and concrete are permeable materials. Therefore, steam diffusing into the porous layer of a wall (cellular concrete or mineral rock wool) or on the border of a dense and porous vapor-proof material (expanded polystyrene, foam plastics, etc.) gradually moistens the inner part of walling. Thus, there are favorable conditions for the development of mould.

Experts believe that the most important direction that improves the quality and energy efficiency of buildings is the use of single-layered enclosing structures [16]. Their use predetermines the reduction in the number of operations and labor costs on the construction site and contributes to the improvement of the quality of construction and installation works [17].

The second half of the twentieth century showed that autoclaved gas silicate is today one of the best wall materials. It has energy efficiency, the lowest possible material consumption and durability [7.9]. The objects of civil and industrial use, the walls of which are made of large-sized autoclaved panels are successfully operated in European countries and the Russian Federation for more than half of a century [9]. However, nowadays such structures are not industrially produced.

The reason for this is the global energy crises [18], which demanded from the population of the planet to reduce thermal emissions into the environment. That is why Europe in the 70s of the last century, the Russian Federation at the turn of the millennia, put forward new claims for the resistance to heat transfer of building enclosures. These claims predetermined the need for a substantial thickening of large-sized gas silicate structures by at least twice. The mechanical properties of this material, tensile strength less than 0.1 of the compressive strength, predetermined the technological transition of the construction industry from large-sized to small-piece products [19].

The advances of modern materials science show that any materials of a fibrous form (100… 1000 times longer than the cross-sectional dimensions) have better mechanical properties than those that undergo phase transition “from viscous to solid” in a volume, the dimensions of which in the directions of space are less than 100 [20]. Therefore, in the last quarter of the twentieth century the specialists of the scientific school named after I.A. Lobanov, developed the technology of non-autoclaved foam concrete dispersedly reinforced with fibers. Dispersed reinforcement of foam concrete with synthetic fibers can significantly increase the tensile strength and energy intensity of the destruction of building materials. As a result, the manufacture of building structures based on such materials improves the sanitary and hygienic conditions of the premises.

The analysis of the indicators of the properties given in the table showed that fibro-foam concrete density:

- 600 kg / m3 have the same vapor permeability as pinewood;
- 800 kg / m3 will provide structures with better thermal performance than lightweight brick masonry with the same compressive strength;
- 400 ... 500 kg / m3 - will provide unique operational properties of the wall as a result of an effective combination of such properties as strength, frost resistance and vapor permeability.

TABLE I. PHYSICAL AND MECHANICAL PROPERTIES OF FIBRO-FOAM CONCRETE

Density, kg/m^3	**Strength, MPa**		**Steam permeability, mg/m^2·h**	**Frost resistance, cycles**	**Heat Conductivity, Wt/(m·^{0}C)**		
	compression	***bending tension***			***dry***	***А***	***Б***
400	0,7…1,5	0,35…1,0	0,20	≥ 50	0,075	0,09	0,14
500	1,0…2,5	0,5…1,5	0,17	≥ 50	0,095	0,12	0,17
600	1,5…3,5	0,7…2,5	0,15	≥ 80	0,113	0,17	0,21
700	2,5…4,0	1,0…2,8	0,13	≥ 80	0,142	0,21	0,24
800	3,5…5,0	1,5…3,0	0,10	≥ 100	0,171	0,24	0,27
900	5,0…7,5	1,5…3,0	0,07	≥ 100	0,21	0,27	0,31
400	0,7…1,5	0,35…1,0	0,20	≥ 50	0,075	0,09	0,14

Foam concrete, dispersion-reinforced with synthetic fibers, is fundamentally different from the known types of cellular concrete by the nature and intensity of destruction under the action of loads [21], therefore, the use of this material may be appropriate not only in enclosing structures, but also in load-bearing loads with limited values.

Traditionally, bridges are made from concrete of the continuous structure of classes B15 ... 20. Such a concrete has a tensile strength in bending of 1.5 ... 3 MPa. The tests of fiber bridges made of concrete reinforced with metal frames, similar to those used in traditional products, showed that they are able to withstand the effects of regulatory loads. Comparing the indicators of tensile strength in bending of concrete of joint structure of the above mentioned classes, it is important to note their coincidence in magnitude with the same properties of fiber-foam concrete with density of 700 ... 800 kg / m3 (Table 1). The experience of using (from 2004 to the present) fiber-foam concrete bridges of civilian buildings in the construction of the city of Rostov-on-Don [22] showed that fiber-foam

concrete of the specified density is a reliable material for this type of wall products.

The use of bridges made of fiber-foam concrete makes it possible:

- eliminating "cold bridges" in the window and door openings of buildings;
- increasing the range of maintainability of structures due to the coincidence of the temperature deformations of the contacting materials;
- excluding the possibility of their fragile fracture even under the influence of shock loads.

The above-mentioned fact makes it possible to predict an increase in operational reliability and a decrease in the accident rate in construction in the case of the widespread use of fiber-foam concrete structures. It is especially important for construction sites that are in emergency caused by an earthquake or explosion. Fragile collapsing building structures lead to a large number of victims. At the same time, the gradual destruction of fiber-foam concrete structures will either avoid them altogether or sharply reduce the severity of the consequences.

II. Problem Statement

The increase in the bearing capacity of building structures operating on bending arises as a result of their reinforcement with a metal bar of a periodic profile. The adhesion forces between them reason the transfer of stresses from one material to another. Most authors, who studied the problems of adhesion of reinforcement to concrete, emphasize that in order to increase the adhesion strength, it is necessary for concrete to have minimal porosity [23].

Any types of cellular concrete have a porosity that is many times greater than the volume of pores in the concrete of joint structure. However, the results of the tests showed that not only the porosity of concrete has an impact on the amount of adhesion of the reinforcement of a periodic profile with a cement stone.

Given the fact that:

- previously performed experiments showed a positive effect of reducing the material consumption of building products when using structural fiber-foam concrete;
- modern industry offers the building complex an extensive list of basalt and carbon fiber reinforcement of a periodic profile, it decided to experimentally test the influence of the real nature of the periodic profile bars on the strength of their adhesion to fiber-foam concrete.

III. Experimental Studies

During the course of experimental studies, the adhesion strength of metal and basalt plastic reinforcement of a periodic profile with a diameter of 12 mm was determined by tearing a rod from a concrete sample.

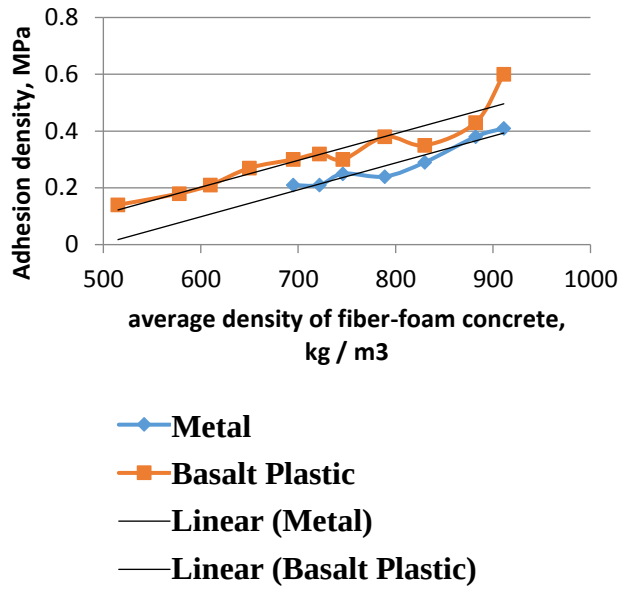

Fig. 1. Graph of bond strength of fiber-foam concrete of various average density with metal and basalt plastic reinforcement of a periodic profile.

According to the obtained data it follows that the strength of adhesion of fiber-foam concrete with rod reinforcement depends on the real nature of rods and average density of fibro-foam concrete.

IV. Results

The theoretical analysis of the causes of the established differences suggests the following. In foam concrete mixtures, the most intensive period of the formation of the contact zone between the components of a dispersed system is the period of initial structure formation, which lasts from the moment when the mixture is placed in forms until the end of the binder setting. During this period, the most intense phenomena of mass transfer are observed. It is manifested in the movement of the smallest particles of the dispersed phase to the surface. In this experiment, the longest surfaces were reinforcing bars.

Since the rods of different material nature were fixed in mixtures from the same batch, the samples hardened under the same conditions, the differences in adhesion strength should be attributed to the effect of the surface potential of the rods on the mass transfer rate. In this case, it is necessary to exclude scale factor, since the diameters of the reinforcing bars were the same.

V. Conclusion

The authors believe that the most important reasons for the established adhesion strength of fiber-foam concrete in the zone of contact with basalt-plastic reinforcement are:

- Increased intensity of mass transfer in the period of early formation of the mixture structure is reasoned by the higher energy potential of the polymer surface compared to metal, which ensured a tight packing of the hydrated new formations of the binder on the surface of the rods of a periodic profile;

- Contribution to the resistance to pulling out an additional volume of concrete, which was included in the work using a fiber located in interporous partitions.

It follows that in the manufacture of construction products from fiber-foam concrete in order to increase the bearing capacity of energy-efficient building structures it is advisable to use rod composite reinforcement or combine it with metal in cases where fire protection requirements do not impose restrictions on the possibility of using composite reinforcement.

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