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FIBER GYPSUM CONCRETE COMPOSITES WITH USING VOLCANIC TUFF SAWING WASTE

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ABSTRACT

The results of studies on the development of gypsum fibre concrete composites with using of volcanic tuff sawing wastes, which provides a reduction in specific consumption of gypsum binder by 30, 5-31, 7 % without reducing the strength of gypsum concrete are presented. The new formations in the gypsum lime tuff concrete composite are established. The effect of granulometric composition of tuff stone sawing waste on the strength characteristics of the gypsum concrete composite is revealed. The structure of gypsum lime vermiculite tuff composite is designed and their flame retardant properties are investigated by experimental and computational methods. The influences of the parameters of disperse reinforcement on the properties of fiber gypsum tuff concrete and fiber gypsum vermiculite tuff composites are defined. Developed fiber gypsum vermiculite tuff composites have higher strength and fire resistant properties. The proposed algorithm of calculation with finite-difference implicit scheme for solving the heat conduction problem and the sweep method allows selecting and specifying the coefficients and the functional dependencies included in the mathematical model, and only approximately known a priori and provides an acceptable coincidence with the experimental data.

Keywords: vermiculite, tuff sand, gypsum, lime, composites, ferrocement, fire resistance.

INTRODUCTION

Prime cost reduction of construction products is the main task of construction. In assessing the competitiveness of construction materials, products and structures it must be taken into account that the cost of energy has raised sharply recently, also transport costs have increased. Therefore, the urgent task is the development of new effective composite materials on the basis of technogenic raw materials and local materials that have low prime cost and improved physical and mechanical characteristics.

In the new economic conditions of managing the development of materials and construction production is aimed at meeting the needs of major construction of effective, qualitative, ecologically safe, construction materials and products modern in design, including concrete.

The main mineral binder in the production of building materials at the moment is Portland cement, the production and use of which is more than 80 % of the total mineral binders in our country [1]. However, the production of Portland cement is associated with high capital investments, energy costs, and allocation of by-products in the form of gases and dust into the environment. The production of concrete products based on Portland cement is characterized by high energy costs.

Developments in the field of gypsum binders, materials and products, as well as favorable ecological and techno-economic aspects of their production and use indicate that all necessary conditions are provided for extending the application in new construction and renovation and repair of existing buildings and structures [2, 3, 4, 5].

Natural raw gypsum and gypsum-containing wastes are widespread on the territory of the Russian Federation; their processing into gypsum binder is a simple and environmentally safe process. The North Caucasus has huge reserves of natural gypsum raw materials. Fuel consumption and energy on production of gypsum products is 4-5 times less than in the manufacture of cement. Gypsum enterprises are characterized by low specific investment and material consumption of equipment in comparison with cement (respectively 2 and 3 times less); turnover of forms in the manufacture of products is in 10-15 times faster.

Plaster products are distinguished by light weight, durability, low heat and sound conductivity. In addition, the gypsum materials have sufficient fire resistance, the ability to maintain a favorable microclimate in the premises due to the ability to absorb and produce excess moisture [6, 7, 22, 23].

Along with a number of positive technical properties gypsum binders and products have the following disadvantages: a significant fragility, low water resistance, low cold resistance, high creep strength when wetting.

To reduce the consumption of gypsum binder and reduce deformation of the products during drying organic or inorganic fillers are implemented at the molding material [2]. But, as a rule, fillers to some extent reduce the mechanical strength of gypsum products.

Inorganic fillers - sand, ash, slag and others - lead to significantly better values of physical and mechanical properties of gypsum concrete. Using them the mechanical strength of plaster elements decreases to a lesser extent and the weather resistance of the wall elements are higher.

Overcoming many of the disadvantages of gypsum binders and products is possible in the creation of composites using effective fillers and disperse reinforcement [8]. The fiber concrete compared to conventional concrete has higher strength characteristics, crack resistance and impact resistance [9, 10, 11, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33]. At present quartz sand, ash, slag are used as the inorganic fillers for the production of gypsum concrete that is not always allowed obtaining materials with the desired characteristics with efficient use of gypsum. For gypsum concrete other materials of natural and technogenic origin can be effectively used as the filler and active mineral additives [12, 13]. Such materials are volcanic tuff sawing wastes that are not previously used in the manufacture of fiber gypsum concrete.

Aim and tasks

The aim of this work is to develop effective fiber gypsum concrete composites with improved physical and mechanical properties using of volcanic tuff sawing wastes. To solve this goal compositions of gypsum tuff concrete composites are developed and their properties are investigated depending on the ratio of gypsum, tuff sand and quicklime, the composition of gypsum lime vermiculite tuff concrete composite and their flame retardant properties are investigated by experimental and computational methods, the influence of the parameters of particulate reinforcement on the properties of fiber gypsum concrete and gypsum vermiculite tuff concrete composites.

METHODS AND MATERIALS

Overcoming many of the disadvantages of gypsum concrete is possible in the result of the use of efficient fillers and disperses reinforcement. The volcanic rocks in the first place - tuff, ash, pumice are of great practical interest. The reserves of volcanic rocks in the Kabardino-Balkar Republic can meet the needs not only of the Republic, but also the needs of the surrounding areas of the North Caucasus and south of the Russian Federation [12]. Volcanic tuff sawing wastes, volcanic ash and ash pumices can serve in gypsum concrete at the same time as the active mineral additives and filler, from 60 to 75% of silica included in the composition 30-35 % is in the amorphous (active) state.

As a source of raw materials and components for the development of gypsum composites were used: gypsum binder of the brand G4-II-A according to GOST 125-79 produced by OOO “Kabbalkgypsum”; air quicklime calcium powdered of 3 varieties Zhayukovsk field according to GOST 9179-77; sand from volcanic tuff sawing wastes Zhayukovsk field with maximum size of grains 5 mm; exfoliated vermiculite of Saint-Petersburg mica factory of fraction 0.16-5 mm; basalt fiber produced by JSC “Ivotsteklo"” brand of RNB-9-1200-4c; resin wood saponified (RWS).

For use of latent hydraulic activity of tuff sand in gypsum composites quicklime was used. It should be noted that hemihydrate gypsum is also a pathogen of the latent hydraulic activity of the tuff aggregate.

Production of gypsum specimens from a raw mixture includes the following operations: preparation of tuff sand and burnt lime, manufacturing gypsum mixture, shaping and drying gypsum products. Air lump lime was previuosly crushed in a jaw crusher, and then it was finely crushed in a ball mill. Volcanic tuff sawing wastes were sieved through sieve No. 5 and dried in a drying cabinet to constant weight. The mixture preparation was carried out in the compulsory mixer, in which pre-mixed dry mixture of gypsum, aggregate, lime and basalt fibers was loaded after supplying water, and then mixing all components was continued until a homogeneous gypsum mixture. The sample size 4x4x16 cm was formed by molding method and natural drying in air-dry conditions was carried out. The test of specimens was carried out in accordance with GOST 23789-79.

The studies proposed raw mixture for gypsum composite production, which provides a reduction in specific consumption of gypsum binder by 30, 5 - 31,7 % without reducing the strength of gypsum concrete. Gypsum concrete composite has a high water resistance, the coefficients of softening and water resistance of gypsum concrete composites are equal to 0.65 and 0.7. Furthermore, the addition of lime slows the setting time of the mixture: initial setting time from 5 to 11 min, end of setting from 8 to 14 min. The optimum ratio of components for the manufacture of gypsum concrete composite, max. %: gypsum binder 30,5 - 31,7; tuff sand 30, 5-31,7; quicklime 7, 9-10, 6; water - the rest (Table-1).

Table-1. Influence of ratios of gypsum, tuff sand and burnt lime on the physico-mechanical properties of gypsum concrete composite.

No compositions	The ratio of components in the mixture, max %				Indexes of gypsum concrete composite features				
	Gypsum	Tuff sand	Lime	Water	Average density, kg/m3	The limit of compressive strength (MPa), age, days		The limit of flexural strength (MPa), age, days	
						1	28	1	28
1	2	3	4	5	6	7	8	9	10
1	67,0	-	-	33,0	1232	4,1	10,4	1,9	3.3
2	35,0	35,0	-	30,0	1307	2,1	4,8	0,3	2,0

3	33,0	33,0	4,9	29,1	1340	2,3	9,0	0,3	2,8
4	31,7	31,7	7,9	28,7	1350	2,9	10,3	0,4	3,0
5	30,5	30,5	10,6	28,4	1364	2,9	11,0	0,5	3,3
6	29,3	29,3	13,2	28,2	1371	2,4	9,7	0,4	3,1
7	24,3	48,6	-	27,1	1387	0,6	3,2	0,1	0,7
8	23,1	46,2	3,5	27,2	1381	0,6	4,0	0,1	1,7
9	22,5	45,0	5,6	26,9	1391	0,7	6,0	0,1	1,9
10	21,7	43,4	7,6	27,3	1385	0,6	5,6	0,1	2,4

The ability of the tuff sand fine fraction (d<0.14 mm) to enter into chemical interaction with other active components of the gypsum concrete mixture was investigated. It was found out that at the ratio of lime and tuff sand of 0.9 maximum compressive strength and flexural strength of gypsum concrete composites are achieved. X-ray diffraction study on the diffractometer DIFRAY-401 in JSC "Scientific instruments" showed that in the hardened material hydrosilicates tobermorite brands like 4CaO·5SiO2·5H2O and (Ca, K, NaH_3O) (Si, Al)O3·H2O, as well as ferriferous wollastonite ((Ca, Fe)SiO3) and allophane ($Al_2O_3 \cdot 2SiO_2 \cdot 3H_2O$) are formed.
To determine the effect of larger fractions of filler with 0.14<d<5 mm on the strength characteristics of the gypsum concrete composite in the second stage the simplex-centroid plan of experiment was implemented [14]. On the basis of previous studies the ratio of components of the gypsum concrete composite on mass in weight parts was taken: gypsum - 3; lime - 1; tuff sand with a diameter of grains 0,00<d<0.14 mm - 1.1; tuff sand with a diameter of grains 0.14<d<5 mm - 1.9.
Variables in the experiment were:

- X_1 - the content of grains with a diameter of 0.14<d<0.63 mm in the filler;
- X_2 - the content of grains with a diameter of 0.63<d<2.5 mm in the filler;
- X_3 - the content of grains with a diameter of 2.5<d<5 mm in the filler.

Optimization settings:
- Y_1 – the limit of compressive strength R_{cs}, MPa;
- Y_2 – the limit of tensile strength in bending R_{ben}, MPa.

After processing the obtained experimental data using computer the following regression equations were obtained:

$$Y_1 = 10{,}8X_1 + 9{,}1X_2 + 12{,}2X_3 + 0{,}6X_1X_2 + 3{,}4X_1X_3 + 0{,}2X_2X_3 - 11{,}7X_1X_2X_3;$$
$$Y_2 = 3X_1 + 2{,}9X_2 + 3{,}8X_3 + 0{,}2X_1X_2 - 0{,}2X_2X_3 + 4{,}5X_1X_2X_3.$$

Diagrams of state "composition - properties" (Figure-1) constructed according to the regression equations showed that the maximum strength of specimens in compression was observed at the optimum combination of mixture of fine and coarse fractions, ensuring the formation of a dense structure of the gypsum concrete composite.

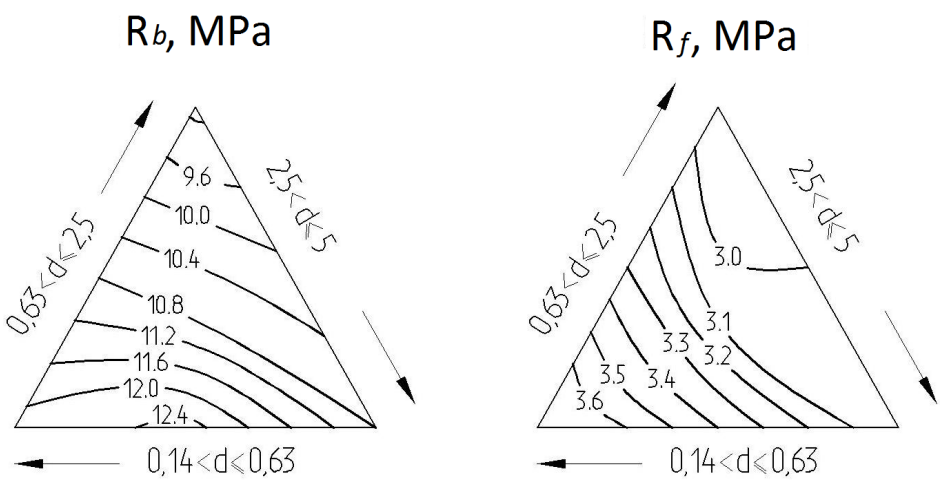

Figure-1. Diagrams of state "composition – properties". Here: R_{cs}, MPa - the limit of compressive strength; R_{ben}, MPa - the limit of tensile strength in bending

Strength on bending is maximum with content in the mixture of smaller fractions of tuff sand because of their partial participation in the process of hydration. However, the need for screening involves the installation

of additional equipment that increases the cost of production, which can only be justified with a substantial improvement in the strength characteristics of gypsum concrete composite, which can be achieved, for example, with dispersed reinforcement.

Based on the analysis of existing types of non-metallic fibers and their requirements for obtaining gypsum concrete composites with improved strength and other characteristics for dispersed reinforcement basalt fiber was selected [9, 10, 11, 15]. To study the influence of dispersed reinforcement parameters on the properties of fiber gypsum tuff concrete an experiment with rotatable plan of the second order type of a regular hexagon was made [16].

As the investigated factors the main parameters of dispersed reinforcement were taken: X_1 – percentage of reinforcement by volume μ_v, %; X_2 – the ratio of the length of the fibers to their diameter l/d.

As parameters of optimization were considered: Y_1 – the limit of compressive strength R_{cs}, MPa; Y_2 – the limit of tensile strength at bending R_{ben}, MPa.

After conducting the experiment and processing the obtained data the following regression equations in coded form were received:

$$Y_1 = 14 - 0{,}25X_1 + 0{,}2X_2 - 0{,}7X_1^2 - 2{,}66X_2^2 - 0{,}06X_1X_2;$$

$$Y_2 = 6{,}18 - 0{,}11X_1 + 0{,}02X_2 - 0{,}33X_1^2 - 1{,}27X_2^2 + 0{,}15X_1X_2.$$

The analysis of the equations and built on them the surface response (Figure-2) showed that the highest values of the optimization parameters are observed in the central area of a plan with $\mu = 1.15...1.2\%$ and $l/d = 1444$. The limit compression strength of the fiber gypsum tuff concrete composite increases in 1.42 times, while bending in 1.82 times compared to the strength of the original matrix. Further increase in reinforcement ratio leads to a decrease in strength, due to deterioration of the structure of fiber gypsum tuff concrete composite. Fiber gypsum tuff concrete composites have higher water resistance compared to the original gypsum tuff concrete matrix. The coefficients of the softening point and water resistance are equal to 0.7 and 0.75.

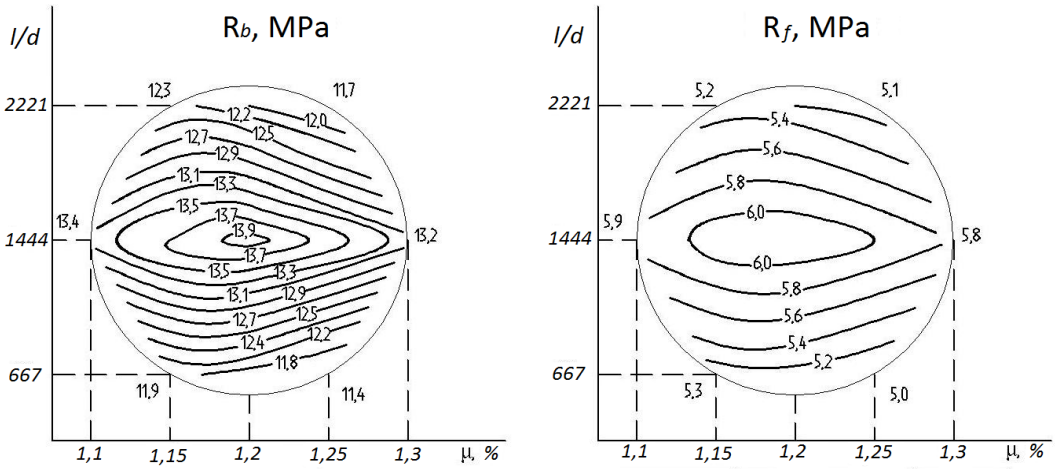

Figure-2. Response surface. Here: R_{cs} – the limit of compressive strength, MPa; R_{ben} – the limit of tensile strength in bending, MPa; l/d – the ratio of the length of the fibers to their diameter; μ – the reinforcement percentage by volume

It is known that the effective means of fire protection of building structures are the plates and plasters based on mineral binders and expanded vermiculite [17, 18, 19, 20]. Based on the results of previously conducted experiments in further studies to develop flame retardant gypsum vermiculite concrete composites as fillers volcanic tuff sawing wastes of fraction 0-0.14 mm, expanded vermiculite of Saint-Petersburg mica factory of fraction 0.16-5mm with a bulk density of 150 kg/m3 were used.

The effective fire resistant gypsum concrete composites with the use of the following materials were developed: gypsum hemihydrate; calcium air lime; expanded vermiculite; volcanic tuff sawing wastes in Zhayukovsk field; surface-active air entraining agent LMS (Table-2).

Table-2. The ratio of the components in the mixture and physico-mechanical properties of gypsum vermiculite concrete flame retardants.

No compositions	The ratio of components in the mixture, wt. %				Average density ρ, kg/m^3	The limit of strength, MPa	
	Gypsum	Vermiculite	Tuff sand	Lime		On compression	On bending
1	2	3	4	5	6	7	8
1	71,9	28,1	-	-	750	1,6	1,1
2	41,3	29,8	15,2	13,7	760	1,55	1,1
3	62,1	37,9	-	-	560	0,8	0,55
4	35,8	39,1	13,2	11,9	570	0,75	0,5

From Table-2 it follows that the proposed compositions at the same density, compression strength and flexural strength fire resistant concretes reduce significantly the consumption of gypsum. The use of burnt lime as a causative agent of latent hydraulic activity of tuff sand can reduce the consumption of gypsum by 26.3-30.6 % without reducing the strength of fire resistant concrete. In addition, setting time is slow down, and the coefficient of water resistance of gypsum composites is increased. With the insertion of air-entraining additives PSIA 0.15 - 0.2 % by weight of the binder the water consumption for mixture significantly reduced, the average density of the gypsum vermiculite tuff concrete composite is reduced by 30-40 kg/m3 without changing the compressive strength and bending strength.

To reduce the average density of gypsum lime vermiculite tuff concrete composites, to improve the workability and fire retardant properties the influence of air-entraining additives PSIA was investigated.

The limit of compressive strength and flexural strength were determined on samples beams 4x4x16 cm. Strength characteristics and the average density of gypsum lime vermiculite tuff concrete was determined at 28 days of air storage.

The study of influence of additives PSIA on the properties of gypsum lime vermiculite tuff concrete was carried out under the condition of equal mobility of the mixtures with the additive and without it, the diameter of spreading mixture of 180 ± 5 mm (Table-3).

Table-3. The influence of additives PSIA on basic physical and mechanical properties of gypsum lime vermiculite tuff concrete composite.

No compositions	The ratio of components in the mixture, wt. %				The number of PSIA in % by weight of the binder	Water/binder	Average density ρ, kg/m^3	The limit of strength, MPa	
	Gypsum	Lime	Tuff sand	Vermiculite				On compression	On bending
1	2	3	4	5	6	7	8	9	10
1	41,3	13,7	15,2	29,8	-	1,25	760	1,55	1,1
2	41,3	13,7	15,2	29,8	0,05	1,2	750	1,55	1,1
3	41,3	13,7	15,2	29,8	0,1	1,15	740	1,6	1,05
4	41,3	13,7	15,2	29,8	0,15	1,1	725	1,65	1,1
5	41,3	13,7	15,2	29,8	0,2	1,1	720	1,65	1,1
6	41,3	13,7	15,2	29,8	0,25	1,08	715	1,6	1,05
7	41,3	13,7	15,2	29,8	0,3	1,08	715	1,60	1,05
8	35,8	11,9	13,2	39,1	-	1,55	570	0,75	0,55
9	35,8	11,9	13,2	39,1	0,05	1,5	570	0,75	0,55
10	35,8	11,9	13,2	39,1	0,1	1,45	560	0,8	0,55
11	35,8	11,9	13,2	39,1	0,15	1,35	540	0,85	0,6
12	35,8	11,9	13,2	39,1	0,2	1,3	540	0,85	0,6
13	35,8	11,9	13,2	39,1	0,25	1,25	535	0,85	0,55

14	35,8	11,9	13,2	39,1	0,3	1,25	535	0,8	0,55

The experiments showed that when the content surface-active additives PSIA 0.15 to 0.2 % by weight of the binder the water consumption for mixture reduced significantly, the average density of the concrete composite is reduced by 30-40 kg/m3. Strength characteristics of gypsum lime vermiculite tuff concrete with the additive and without it at 28 days remain almost unchanged.

To study the flame retardant properties of the proposed compositions ferro cement slabs with fire-retardant layer were made. Researches of fire resistant properties of gypsum concrete composites were conducted with a fire test of specimens with dimensions of 190×190 mm in an electric furnace in a horizontal position at temperature mode "standard" fire, regulated by GOST 30247.0-94. The fire resistance rating for load-bearing capacity (R) of ferro cement slabs was evaluated by heating the woven mesh in the structural layers (the boundary layers) to 300 ° C. Humidity of fine-grained concrete ferro cement layer and a flame retardant to the time of testing were respectively 3-4% and 8 -10 %.

The results of fire tests of ferro cement slabs with gypsum vermiculite concrete fire resistant layer were shown in Figure-3. During testing of two-layer elements for fire resistance integrity infringement was not detected.

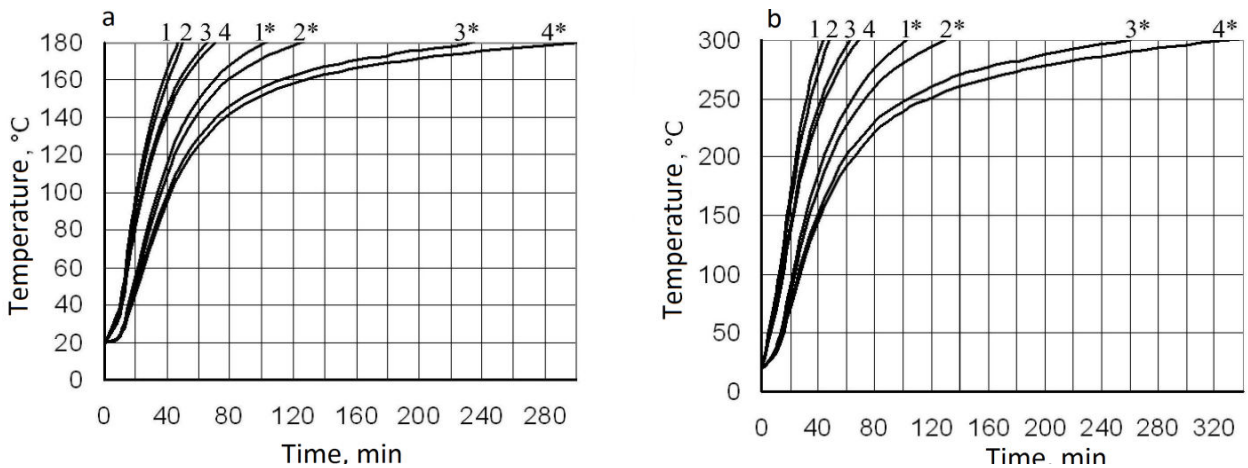

Figure-3. Experimental curves of temperature change on the unheated surface (a) and at the level of the woven mesh (b) double-layer ferro cement samples:
1, 3- gypsum vermiculite concrete composites with average density 750 kg/m^3 and 560 kg/m^3 respectively, layer thickness 15 mm;1*, 3* -the same, thickness 25 mm; 2, 4- gypsum lime vermiculite tuff concrete composites with an average density of 720 kg/m^3 and 540 kg/m^3 respectively, layer thickness 15 mm; 2*, 4* - the same, thickness 25 mm

For the calculation of fire resistance of building constructions in the country numerical and analytical methods are developed. The greatest preference is for numerical methods because of their simple implementation using modern computer technology.

We developed an algorithm of thermal and technical calculation of the fire resistance of multi-layered building constructions, providing acceptable coincidence of calculated values with experimental data [21]. The algorithm for calculating the fire resistance of building constructions with fire resistant layer is reduced to the solution of the thermal and physical problem.

We made software thermal and technical calculation of the fire resistance of ferroconcrete structures with fire-resistant layer of gypsum vermiculite concrete. With the use of PC calculations with a precision equal to 0.001 were made and the expressions for the coefficients of thermal conductivity and heat capacity were obtained:

ferrocement - $\lambda_a(t) = 0{,}83 - 0{,}0004t, \quad c_a(t) = 770 + 0{,}8t$;

gypsum vermiculite concrete composite with density 750 kg/m^3 - $\lambda_o(t) = 0{,}12 + 0{,}00012t, \quad c_o(t) = 748 + 0{,}63t$;

gypsum vermiculite tuff concrete composite with density 720 kg/m^3 - $\lambda_o(t) = 0{,}115 + 0{,}0001t, \quad c_o(t) = 748 + 0{,}63t$;

gypsum vermiculite concrete composite with density 560 kg/m^3 - $\lambda_o(t) = 0{,}102 + 0{,}00007t, \quad c_o(t) = 748 + 0{,}63t$;

gypsum vermiculite tuff concrete composite with density 540 kg/m^3 - $\lambda_o(t) = 0{,}098 + 0{,}00064t, \quad c_o(t) = 748 + 0{,}63t$.

The dependence of the fire resistance of ferroconcrete structures from the thickness and composition of the gypsum layer obtained by the calculation method using the algorithm and software of the

thermal engineering calculation of the fire resistance of multi-layered building structures is shown in Figure-4.

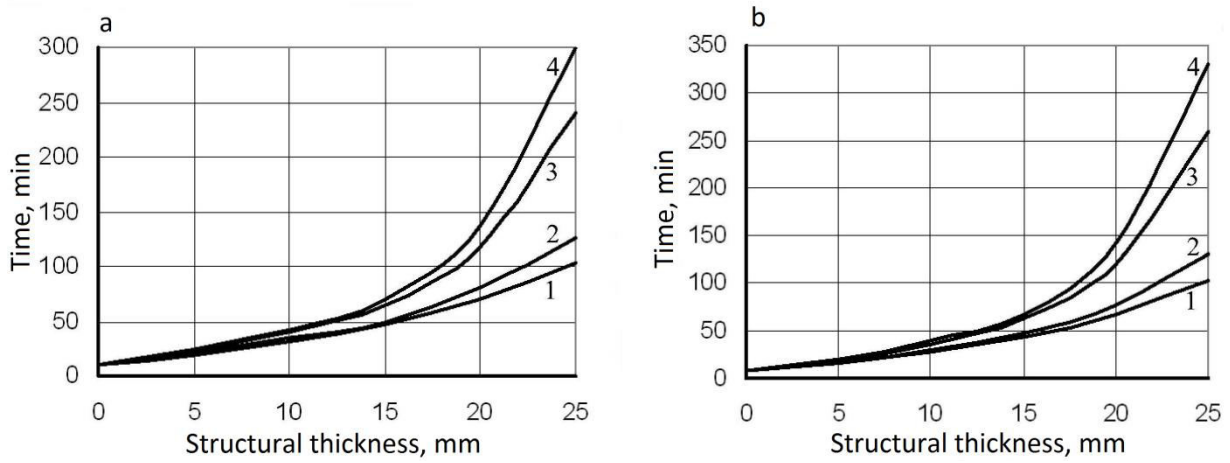

Figure-4. The dependence of the limit of fire resistance of double-layered ferro cement elements on the basis of the loss of insulating ability (a) and loss of bearing capacity (b) from the thickness and composition of the gypsum concrete layer (1, 2, 3, 4 – see Figure-3)

The calculated dependence of the fire resistance gypsum concrete plates on the grounds of loss of insulating ability from the thickness and composition of the vermiculite concrete is shown in Figure-5.

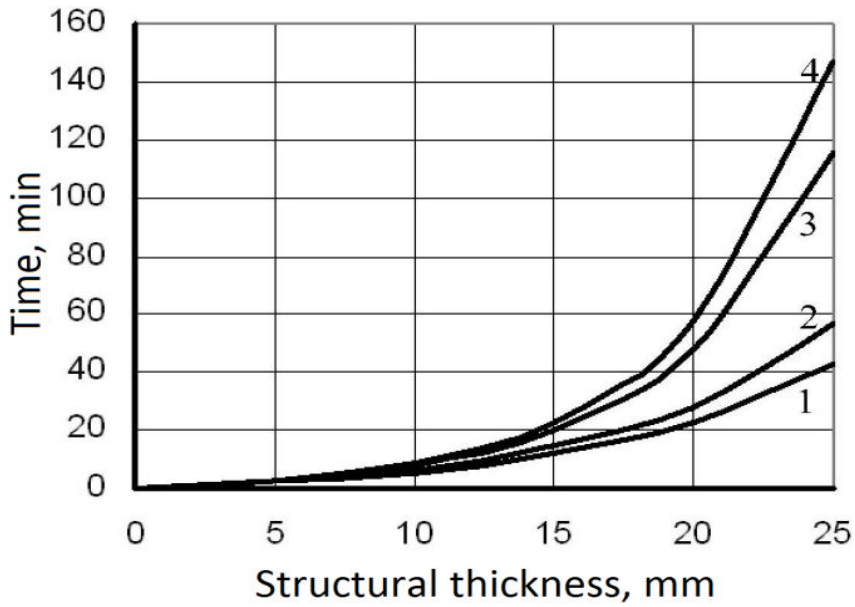

Figure-5. The dependence of the fire resistance of gypsum concrete plates on the grounds of loss of insulating ability from the thickness and the gypsum concrete composition (1, 2, 3, 4 - see Figure-3).

Thus, the application of the developed fire resistant gypsum lime vermiculite tuff concrete composites can significantly reduce the consumption of plaster while improving their fire retardant properties. Using the obtained expressions for the coefficients of thermal conductivity and heat capacity of gypsum concrete, the resistance of two-layer structures can be calculated by numerical methods with application of the developed software.

Developed gypsum lime vermiculite tuff concrete composites have such disadvantages as brittleness, relatively low strength in bending and compression. The insertion of basalt fiber in a mixture is to eliminate these disadvantages and to increase flame retardant properties by ensuring better preservation of the flame retardant layer at influence of high temperatures.

The composition of the original concrete matrix and its physico-mechanical properties for reinforcement of the basalt fibers are shown in Table-4.

Table-4. The ratio of components in the mixture and physico-mechanical properties of the gypsum lime vermiculite tuff concrete composite.

No composition	The ratio of components in the mixture, wt. %					Average density, ρ, kg/m^3	The limit of strength, MPa	
	Gypsum	Vermiculite	Tuff sand, d<0,14 мм	Lime	PSIA		On compression	On bending
1	2	3	4	5	6	7	8	9
1	35,8	39,1	13,1	11,9	0,1	540	0,85	0,6

To study the impact of fiber reinforcement on the properties of the fiber gypsum lime vermiculite tuff concrete composite rotatable plan of second order type of a regular hexagon with the central point was implemented. As the investigated factors the main parameters of dispersed reinforcement were taken:

- X_1 - the percentage of reinforcement by volume μ_v;
- X_2 - the ratio of the length of the fibers to their diameter l/d (varied by changing the length of the fibers l).

As parameters of optimization were considered:

- Y_1 - the limit of compressive strength R_{cs}, MPa;
- Y_2 - the limit of strength in bending R_{ben}, MPa.

After conducting the experiment and processing the data obtained the following regression equation in coded form was received:

$$Y_1 = 1 + 0{,}09X_1 + 0{,}014X_2 - 0{,}2X_1^2 - 0{,}21X_2^2 + 0{,}03X_1X_2;$$
$$Y_2 = 1{,}1 - 0{,}083X_1 - 0{,}075X_1^2 - 0{,}275X_2^2 + 0{,}058X_1X_2.$$

The above equations the response surface was constructed (Figure-6).

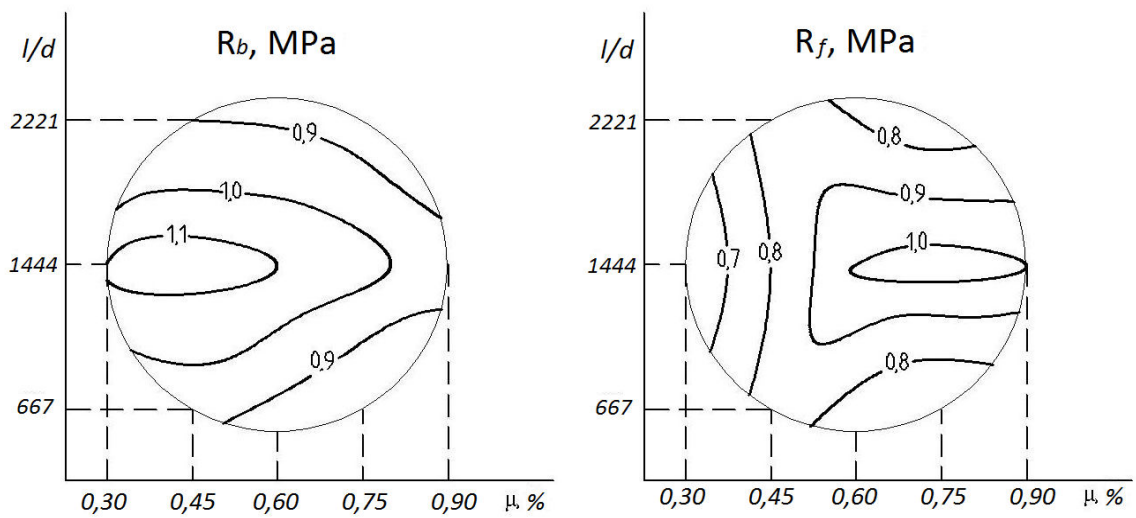

Figure-6. Response surface. Here: R_{cs} - the limit of compressive strength, MPa; R_{ben} - the limit of strength on bending, MPa; *l/d* - the ratio of the length of the fibers to their diameter; μ– the percentage of reinforcement by volume.

The analysis of the obtained equations and response surfaces showed that the highest values of compressive strength are observed in the plan area with $\mu_v \approx 0{,}45\,\%$ and $l/d = 1444$, and bending strength - $\mu_v \approx 0{,}75\,\%$ and $l/d = 1444$. Further increase in percentage of reinforcement leads to a decrease in strength, due to violation of the structure of fiber gypsum lime vermiculite concrete composite.

Studies of flame retardant properties of the developed fiber gypsum lime vermiculite concrete composite reinforced with basalt fibers on the previously described method were conducted and the following curves were obtained (Figures 7 and 8). The thickness of ferroconcrete and fire resistant layers was 20 mm.

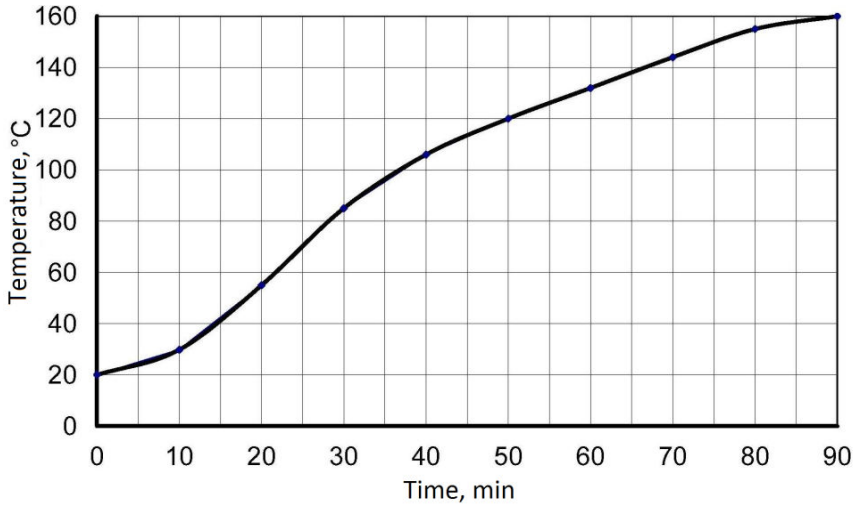

Figure-7. A graph of the temperature change on the unheated surface of a two-layer ferro cement samples.

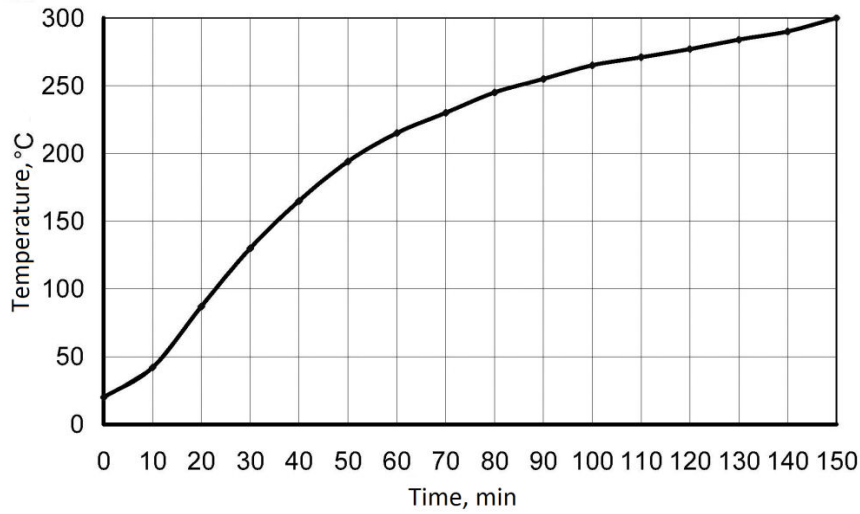

Figure-8. A graph of temperature changes on the level of the woven mesh of a two-layer ferro cement samples.

From the test results it follows that the reinforcement with basalt fiber of gypsum lime vermiculite tuff concrete matrix improves the flame retardant properties. Reinforcement of the original matrix with an average density of 540 kg/m^3 with basalt fibers can reduce the thickness of the fire resistant layer from 25 mm to 20 mm.

Economic calculations showed that the effect of the application of the developed fiber gypsum tuff concrete composites at a cost of materials 1 m^2 area of partitions is 47 rubles 20 kopecks in comparison with plaster. The application of the proposed fire-resistant fiber gypsum lime vermiculite tuff concrete composites reduces the cost of 1 m^2 of fire protection by 35-40 rubles compared to gypsum vermiculite concrete ones.

RESULTS AND CONSIDERATION

Thus, the developed fiber gypsum concrete composites using volcanic tuff sawing waste provide a reduction in specific consumption of gypsum binder by 30.5-31.7 % with a significant increase in bending strength and compression of the gypsum concrete. In addition, they have a high water resistance. In the hardened material hydrosilicates tobermorite brands like $4CaO{\cdot}5SiO_2{\cdot}5H_2O$ and (Ca, K, NaH_3O) (Si, Al)$O_3{\cdot}H_2O$, as well as ferriferous wollastonite ((Ca, Fe)SiO_3) and allophane ($Al_2O_3{\cdot}2SiO_2{\cdot}3H_2O$) were formed.

Granulometric composition of tuff stone sawing waste has no significant effect on the strength characteristics of the gypsum concrete composite.

The effective fire resistant gypsum concrete composites with the use of expanded vermiculite and tuff sand were developed. Composites with an average density of 540-570 kg/m^3 have the highest fire resistant properties.

The optimum ratio of components of the composites was revealed. The insertion of burnt lime (30 % by weight of gypsum) and tuff sand with a grain size of 0-0.14 mm with a ratio of 0.9 in gypsum vermiculite concrete composite can significantly reduce the consumption of gypsum and improve fire resistant properties. The insertion of additives PSIA of 0.2-0.4 % by weight of the binder in the mixture and improves its flow characteristics, and reduces the average density of the composite by 30-50 kg/m^3 and contributes to the improvement of fire retardant properties.

The compounds of gypsum lime vermiculite tuff concrete composite of reducing consumption of Portland cement by 50% without loss of strength were designed.

The influence of the parameters of dispersed reinforcement on the properties of fiber gypsum vermiculite tuff concrete composites is determined. The highest values of compressive strength of fiber gypsum vermiculite tuff concrete composites were observed on the plan area with $\mu_v \approx 0{,}45\ \%$ and $l/d = 1444$, and flexural strength – $\mu_v \approx 0{,}75\ \%$ and $l/d = 1444$.

The expressions of the coefficients of thermal conductivity and heat capacity of fiber gypsum concrete composites for thermal and technical calculation of fire resistance of building structures by numerical methods were obtained.

CONCLUSIONS

Thus, the article considers a number of fundamental issues related to obtaining effective fiber gypsum concrete composites with the use of volcanic tuff sawing wastes. The raw mixture for production of gypsum concrete composite, which provides a reduction in specific consumption of gypsum binder by 30.5-31.7 % without reducing the strength of gypsum concrete, was offered. Gypsum concrete composite has a high resistance; the coefficients of softening and water resistance of gypsum concrete composites are respectively equal to 0.65 and 0.7. The optimum ratio of components for the manufacture of gypsum composite, wt. % was revealed: gypsum binder 30.5 – 31.7; tuff sand 30.5 – 31.7; quicklime 7.9 – 10.6; water – the rest. X-ray diffraction study on the diffractometer DIFRAY-401 in JSC "Scientific instruments" showed that the hardened material hydrosilicates tobermorite brands like $4CaO{\cdot}5SiO_2{\cdot}5H_2O$ and (Ca, K, NaH_3O) (Si, Al)$O_3{\cdot}H_2O$, as well as ferriferous wollastonite ((Ca, Fe)SiO_3) and allophane ($Al_2O_3{\cdot}2SiO_2{\cdot}3H_2O$) were formed.

The effect of granulometric composition of tuff stone sawing waste on the strength characteristics of the gypsum concrete composite was revealed. The maximum strength of specimens in compression was observed at the optimum combination of mixture of fine and coarse fractions, ensuring the formation of a dense structure of the gypsum concrete composite. Strength on bending is maximum in the content in the mixture of smaller fractions of tuff sand, because of their partial participation in the process of hydration.

The compounds of gypsum lime vermiculite tuff concrete composite of reducing consumption of Portland cement by 50% without loss of strength were designed, and their flame retardant properties of experimental and computational methods were investigated, which showed high fire resistant properties of the developed composites.

The influence of the parameters of dispersed reinforcement on the properties of fiber gypsum tuff concrete and fiber gypsum vermiculite tuff concrete composites was determined. The highest values of compressive strength of fiber gypsum vermiculite tuff concrete composites on the plan area with $\mu_v \approx 0{,}45\ \%$ and $l/d = 1444$, and flexural strength – $\mu_v \approx 0{,}75\ \%$ and $l/d = 1444$ were observed.

The proposed algorithm of calculation with the use of finite-difference implicit scheme for solving the heat conduction problem and the sweep method allows selecting and specifying the coefficients and the functional dependencies included in the mathematical model, and only approximately known a priori and provides an acceptable coincidence with the experimental data.

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