Lightweight Plastering Compound Using Volcanic Tuff

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Abstract: Lightweight reinforced plaster coatings include a group of special types of textile concrete, which also includes concrete sheets, reinforced plaster coatings, including lightweight and heat-insulating ones. The basis for any type of textile concrete is a modified binder, the formulation of which is currently being developed by foreign and domestic research centers. active mineral additives (both natural and by-products of other industries) can be used in the binder, and it is also possible to use construction waste prepared accordingly.
Development of the scientific basis for selecting the composition and the formation of a methodology for selecting the composition of the modified binder as the main component of textile concrete, including the use of finely ground construction waste obtained during the dismantling of construction projects, including within the framework of the housing renovation program.
The purpose of the research outlined in the article was to develop a methodology for selecting the composition of the binder, predicting the properties and optimizing light plaster coatings based on a modified hydraulic binder, volcanic tuff and construction waste.
The use of a composite binder will expand the possibilities of using these materials, and the introduction of finely ground waste will reduce the consumption of Portland cement clinker, which also increases the energy efficiency of such materials.

Key-Words: fine-grained concrete, Modified binder, Construction waste, Polymineral mixture, Light plaster, analytical optimization.

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1 Introduction

Lightweight reinforced plaster compositions are considered as a type of textile concrete. Textile concrete is a group of modern building materials consisting of hydraulically hardened mineral binders and fibers that are either dispersed in the material or woven into meshes of various sizes. In all cases, polymer or mineral fibers can be used, as well as hybrid ones: for example, mineral fiber and carbon fiber, glass fiber, cellulose fiber, composite fibers, etc. [1-3]. All of these elements are also present in reinforced plaster systems.

In classic textile-reinforced concrete, flat meshes of glass or polymer fibers, geotextiles and their analogues are used to strengthen layers of fine-grained concrete. Often used are fiber-reinforced concretes, which are fine-grained concretes reinforced with individual fibers dispersed in the concrete mixture. The fibers are strong and can have a dense structure; they can be used to support loads in shells and structures with thin walls. Cellular concrete blocks are made from a fiber-reinforced material if it has a porous structure, and they perform better than their unreinforced counterparts [4-6].

Concrete sheet is a type of textile-reinforced concrete that has a core of mineral binder and filler and an outer shell formed of two sheets of non-woven material. The fillers used are quartz sand from 0.5 to 1 mm or a mixture of quartz sand and reinforcing fibers (consumed no more than 1.5%). The concrete sheet is transported to the site in rolls; The rolls are laid on the base and, when moistened, the concrete hardens, resulting in the creation of a finished structural element [7-9]. This technology can be implemented both in new construction and in reconstruction.

The properties of the composite binder (and, in fact, fine-grained concrete), which is the basis for any type of material, collectively called textile concrete, largely determine the performance characteristics of the material. Portland cement, Portland cement modified with active additives, including waste from the concrete industry or obtained during housing renovation, as well as gypsum (or modified gypsum) binder can be used as a binder [10, 11].

Gypsum (gypsum polymer) coatings with reinforcement from various fabrics or non-woven materials can be considered as facade materials. Such coatings are applied to any surface during the reconstruction of building facades, including concrete bases (without wall insulation) and facade thermal insulation composite systems [12, 13].

Facade plaster coatings are also a type of textile concrete. In this case, the plaster system is an analogue of fine-grained concrete as a base component of textile concrete or dense concrete, and the glass mesh, which is an essential component of any plaster coating, is a reinforcing component of fine-grained modified concrete. In addition to the decorative qualities and expressiveness of the exterior, the criterion for the façade of a building is also the need for durability, given the fact that the façade is exposed to a whole range of atmospheric variables. Materials used in façade systems must be able to withstand such impacts and maintain structural integrity, as well as have good adhesion to the base [14-16].

In modern construction, the following composite systems using additional insulation are used: facade thermal insulation composite systems (SFTK), ventilated facade systems (SVF), lightweight structural systems using light wooden frames (WLF), light steel frames (LGSF) and 3D sandwich panels (3DSP) [17-19]. These systems make it possible to form structures with the thermal resistance required by operating rules, but they have a number of features. Firstly, this is a multi-component structure, including at least three units for forming the strength of the system. The possibility of destruction of such systems is aggravated by seismic impacts. Secondly, the use of foamed plastics, which are flammable materials, as thermal insulation [20-23]. Thirdly, these systems are recommended for all types of buildings and for all regions of construction without taking into account the climatic characteristics of the regions, which negatively affects their energy efficiency for regions with relatively low cost of natural fuel.

2 Problem Formulation

2.1 performance criteria for insulation systems

As a result of an analysis of the current state of the use of building systems that allow increasing the thermal resistance of the insulating shell, and therefore the durability of these systems, it has been established that building systems that allow the formation of seamless insulating shells are the most effective. The main criteria for the effectiveness of such systems are the reduction of heat losses during the operation of facilities, as well as the creation of comfortable conditions for people and compliance with temperature and humidity conditions for technological processes. It is also important to reduce the fire hazard of insulation systems that may contain flammable components, including flammable thermal insulation materials. For regions with temperate climates, it is possible to use lightweight and heat-insulating plaster coatings based on non-combustible components.

2.2 Research Objective

The objective of the research described in the article was to develop a methodology for selection of composition, prediction of properties and optimization of lightweight plaster coatings based on modified hydraulic binder (containing construction waste) and volcanic tuff. Tuff was considered as a component of the modified binder (finely ground tuff) and as a component (lightweight filler) of the plaster composition.

3 Problem Solution

3.1 Materials and methods

The studies used; Portland cement M500 D 20 (GOST 31108-2020); volcanic tuff (GOST 9479-20112011); recycled waste concrete scrap (GOST R 70102-2022); plasticizer and water-retaining additive (GOST 24211-2008) and reinforcing component. Volcanic tuff was used as a component of a composite binder and as a fine aggregate in a plaster mixture. The binder used volcanic tuff with a specific surface area of 350 m2/kg; the content of volcanic tuff was 20% of the Portland cement consumption; the tuff had medium pozzolanic activity. The processed waste concrete scrap was ground to a specific surface of 250 m2/kg and introduced into the composition of the binder with its additional mixing together with finely ground volcanic tuff in a ball mill. The plasticizer consumption was determined experimentally.

The composition of the plaster mixture included crushed volcanic tuff (70% passing through a sieve with a mesh size of 1 mm; a mesh size of 2 mm - 100%; bulk density 500 kg/m3) in an amount of 25% by weight of the composite binder. Chopped basalt fiber with a diameter of 13-17 microns and a length of up to 6.4 mm (1/4”), without sizing, was used as a reinforcing component. The consumption of the reinforcing component is assumed to be constant and equal to 1.0% of the consumption of the binder.

Tests were carried out to assess the adhesion of the plaster coating to the base (brick or concrete wall) using the DYNA device. The test diagram is shown in Fig. 1.

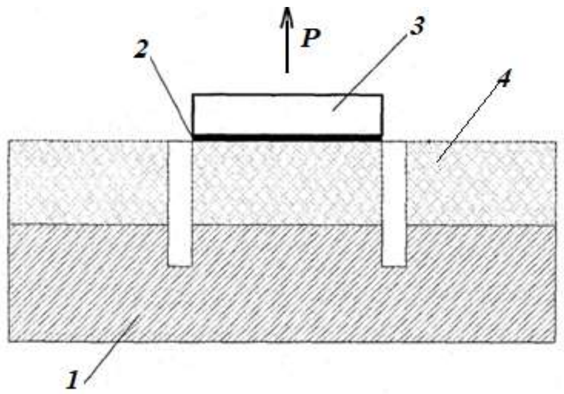

Fig. 1. Scheme of the pull-off test: 1 – base material (supporting structure); 2 – polyepoxy glue; 3 – metal disk; 4 – plaster coating; P – direction of tension (application of load generated by the testing device)

Using drilling, an incomplete (partial) sample with a diameter of 50 mm was taken perpendicular to the surface, the core (sample) passed through the interface (plaster coating and base material) into the base material. A metal disk was attached to the surface of the core using epoxy resin and, after curing, a pull-out force was applied to this disk.

The load was applied at a constant speed until failure. Adhesive strength was determined as the ratio of the recorded breaking load to the cross-sectional area of the cylindrical sample. At the same time, the type of destruction and where the destruction occurred were taken into account: along the base material, along the contact zone (interface) or along the plaster layer. Only the destruction that occurred at the interface between materials was taken as an indicator of adhesive strength.

The research also developed the fundamentals of a methodology for selecting the composition and predicting the properties of plaster mixtures based on a composite binder using construction waste. Optimization of the equations was carried out using the analytical method. This method was developed at the National Research University MGSU and tested in the analysis of various technologies and formulations of building materials from thermal insulation to special types of concrete [24, 25]. The method is based on the following provisions: the resulting digital models (statistical regression equations) adequately describe the technological process being studied; each equation is an algebraic function of several variables (according to the number of significant varying factors) and methods of mathematical analysis are applicable to study this function.

The costs of Portland cement (X1), finely ground waste concrete scrap (X2), and plasticizer (X3) were taken as variable factors. Water consumption is set in accordance with the W/C according to the required workability of the mixture (Mobility P3) and is not an independent factor. The response functions take the compressive strength of the plaster material (U1) and its average density (U2) at a consumption of light aggregate (20%). The experimental conditions are presented in table. 1 .

Table 1. Experimental conditions

Factor name	Symbol, Xi	Average factor value, $\overline{Xi}$	Variation interval, ΔXi	Factor values at levels	
				-1	+1
Portland Cement Consumption, PCC, kg/m^3	X_1	450	50	400	500
Plasticizer Consumption, PC, kg/m^3	X_2	2	0,5	1,5	2,5
Consumption of finely ground waste, CFG, kg/m^3	X_3	105	25	80	130

The active experiment was carried out on the basis of a matrix of a complete three-factor experiment with processing of the results in the Statistika program and testing of statistical hypotheses on the significance of the coefficients of the resulting regression equations and on the adequacy of the resulting models. The confidence values of the coefficients, determined by the Student criterion, were for compressive strength 0.4 MPa and for average density 8 kg/m3.

3.2 Research Results and Discussion

Based on the results of an active experiment and their statistical processing, the type of digital models has been established - algebraic polynomials that establish dependencies between variable factors and response functions:

- for compressive strength: $У1 = 16.5 + 1.8X1 + 0.8X2 + 0.8X3 + 0.5X1X3 - 0.5X2^2$ (1)

- for medium density: $У2 = 490 + 26X1 + 16X3 + 10X1X3$ (2)

The resulting models were tested for adequacy using the Fisher criterion. It was established that the calculated values of the F-criteria do not exceed the tabulated ones, and with the corresponding confidence probability (90%) the model can be considered adequate. This fact will be taken into account when analytically optimizing mathematical models and their graphical and engineering interpretation.

Analysis of the results (digital models 1 and 2) showed that the consumption of Portland cement has the greatest influence on the strength of the plaster material; the introduction of finely ground waste also has a positive effect on the strength, but to a lesser extent. This influence may be due to the fact that in finely ground (up to a specific surface of 250 m2/kg) concrete waste, grains with binder that has not reacted during the entire operation of the structure are activated, on the one hand, and on the other hand, grains of ground waste can be considered as centers of crystallization new formations, which, from the standpoint of general theories of hardening of composite binders, also has a positive effect on strength. The average density in the experiment changed slightly and depended on the consumption of Portland cement and finely ground waste.

Analysis of the polynomial describing the relationship between compressive strength and variable factors shows that this function (which is inherently a function of several variables) for one of these variables, namely polymer consumption (X2), has a local extremum. Therefore, we can use the mathematical apparatus of analytical local optimization.

Analytical optimization is based on the fact that the functions for strength and density У1 = f1(X1, X2, X3) and У2 = f2(X1, X3) are algebraic polynomials and it is permissible to apply methods of mathematical analysis to them, provided that the adequacy condition will be violated. In the case under consideration, the following scheme is adopted:

- the equation Y1 = f1(X1, X2, X3) is differentiated with respect to X2 and equated to zero, determining the extremum of the function Y1 with respect to X2;

- solve the functions Y1 = f1(X1, X2, X3) and Y2 = f2(X1, X3) with X2 = opt and carry out local optimization.

Analytical optimization includes the following sequence of actions:

1). We determine the value of the local extremum of the function У1 = f1(X1, X2, X3) by X2:

$$\partial Y_1 / \partial X_2 = 0,8 - 1,0X_2 = 0 \rightarrow X_2 = 0,8$$

2) We calculate the natural value of the plasticizer consumption (corresponding to the possible obtanig of maximum compressive strength of the hardened plaster mixture), using the factor decoding formula:

Рп = 2,0 + 0,8×0,5 = 2,4 кг/м^3

3) We calculate mathematical models (polynomials) for the optimized value of factor X2 = 0.8:

- for compressive strength: У1 = 16.8 + 1.8X1 + 0.8X3 + 0.5X1X3 (3)

- for medium density: U2 = 490 + 36X1 +26X3 + 10X1X3 (4)

Graphic interpretation of the obtained dependencies (3) and (4) made it possible to develop a nomogram (Fig. 2), with the help of which it is possible to solve the direct and inverse problem of digital modeling. Interpolation solutions over the entire range of changes in the consumption of Portland cement and the consumption of finely ground waste (factors X1, X3) with an optimized value of factor X2 (optimal plasticizer consumption 2.4 kg/m3) are presented graphically (Fig. 1) in the form of a nomogram. In sector I of the nomogram, compressive strength is determined; in sector II - the average density is determined.

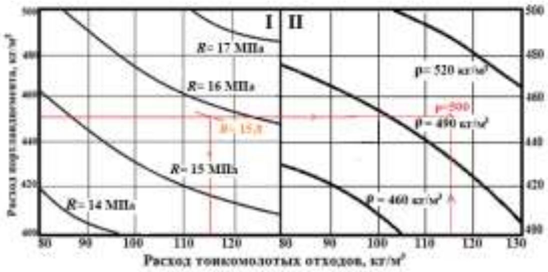

Fig. 2. Nomogram for assessing the properties of a plaster mixture based on the composition of the composite binder (red lines 1); optimal plasticizer consumption 2.4 kg/m3.

The nomogram can be used to predict the properties or select a hardened plaster mixture. To evaluate the properties of a plaster mixture with a finely ground waste content of 115 kg/m3 and a Portland cement consumption of 450 kg/m3, it is necessary to perform the actions shown in the red line in Fig. 2 (example 1). And points Rpc = 450 we draw a straight line parallel to the abscissa axis through sectors I and II. In each sector we raise perpendiculars from points Pto equal to 115. At the intersection of these lines, we determine by interpolation the compressive strength (R = 15.8 MPa) and the average density of concrete (ρ = 500 kg/m3).
Prediction of the properties of a composite binder can also be carried out using a special computer program, the algorithm of which includes a data input and coding block (reduction to the interval [-1, 1]), a calculation block (based on two-factor polynomials (3) and (4)), a block that displays results on a computer display or for printing.

To assess the accuracy of predicting the value of the characteristics of the plaster mixture, conducting a control series of experiments and determining the difference between the values of strength and density calculated from digital models and from the results of an active experiment (Table 2). The compressive strength of the hardened plaster mixture was taken as an evaluation parameter.

Table 2. Checking the reliability of the results obtained at an optimal plasticizer consumption of 2.4 kg/m ^{3}

№	Factor values:		Compressive strength, MPa		
	Portland cement consumption, kg/m3	Consumption of finely ground waste, kg/m3	Calculated	Experimental	Δ, %
1	400	90	18,9	18,2	3,7
2	450	90	14,9	15,9	6,2
3	500	90	17,3	16,3	5,9
4	400	110	15,0	16,0	5,8
5	450	110	16,8	16,1	4,2
6	**500**	**110**	**18,6**	**18,0**	3,4
7	400	130	16,2	16,0	1,3
8	450	130	17,6	16,6	6,0
9	**500**	**130**	**19,7**	**19,0**	3,6
			Average deviation::		4,6

The average deviation of the calculated values of compressive strength from the experimental strength values obtained as a result of an active experiment was determined by the formula:

$$\Delta = \left|\frac{y - R_{exp}}{y}\right| \times 100$$

The average deviation in compressive strength was 4.6% (less than 5%, which corresponds to the accepted statistical probability of predicting the result of 95%). The highest compressive strengths of the hardened plaster coating correspond to experiments 6 and 9. Thus, we accept the following basic composition of the plaster mixture: Portland cement consumption 500 kg/m3; Consumption of finely ground waste Pto = 90-130 kg/m3; plasticizer consumption 2.4 kg/m3; consumption of ground volcanic tuff in the binder: Рт = 100 kg/m3; consumption of volcanic tuff as fine aggregate Ртз = 0.2×(500+120+100) = 120-160 kg/m3; consumption of the reinforcing component: Ra =0.01×(500+120+100) = 7.2 kg/m3; water consumption 300 dm3/m3.
An assessment of the adhesive strength of contact between the plaster coating was carried out for a base plaster mixture selected as a result of previously conducted studies of the base composition. The experiment showed that the adhesive strength of the plaster coating to the base material is in the range of 3.7-3.9 MPa. The type of base (dense concrete or ceramic facing brick) has little effect on strength. When applying a plaster coating to a structure made of cellular concrete blocks, destruction occurred along the cellular concrete. Tests in a climate chamber showed that as a result of 50 cycles of alternating freezing and thawing, adhesive strength is reduced by 15-20%.

The result of using a composite binder in light plaster mixtures is an increase in the durability and operational resistance of building systems, which is one of the factors in increasing their energy efficiency. Increasing the service life of the structure reduces the frequency of major repairs, and, consequently, the costs of operating the structure. The second component that determines the increase in energy efficiency is the use of construction waste, which reduces the area of territories alienated for the storage of construction waste while reducing the negative load on the environment. The third factor is associated with a reduction in the consumption of expensive and energy-intensive Portland cement clinker as part of the binder, which allows not only to optimize the costs of binder production, but to reduce the amount of harmful emissions into the environment.

4 Conclusion

The development of textile concrete technologies is one of the promising areas of domestic construction. Varieties of this material are used in various fields of construction. The basis of textile concrete of any modification is fine-grained modified concrete, reinforced with meshes, fiber or fiber based on mineral, metal and less often polymer or carbon materials, and the basis of this concrete is a composite hydraulic binder, which may include active mineral additives and processed products concrete waste.

An important aspect of the development of the construction industry is the use in the formulation of building materials of industrial waste (secondary products), concrete technology or products obtained as a result of the demolition of dilapidated or renovation housing. Such waste is produced and accumulated, but is little used. Therefore, the development of technologies for recycling concrete scrap is relevant

The methodological basis of the research was the mathematical planning of the experiment using the method of analytical optimization. The fundamentals of a methodology for selecting and optimizing the composition of a modified binder using construction waste as a basis for facade plaster coatings have been developed.

The group of special types of textile concrete includes concrete sheet, reinforced plaster coatings, including lightweight and heat-insulating ones. the use of a composite binder will expand the possibilities of using these materials, and the introduction of finely ground waste will reduce the consumption of Portland cement clinker, which also increases the energy efficiency of such materials.

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