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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 and reinforced plaster coatings, including lightweight and heat-insulating ones. Any type of textile concrete starts with a modified binder, whose composition is currently under development by international and domestic research institutions. 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 article talks about research that aimed to create a way to choose the binder's ingredients, guess its properties, and get the best light plaster coatings using a new 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.

1 Introduction

Lightweight reinforced plaster compositions are considered 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 is fiber-reinforced concrete, which is fine-grained concrete 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

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are made from a fiber-reinforced material if it has a porous structure, and they perform better than their unreinforced counterparts [4–6].

A 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].

Modern buildings use facade thermal insulation composite systems (FTICS), ventilated facade systems (VFS), lightweight structural systems with light wooden frames (LWF), light steel frames (LSF), and 3D sandwich panels (3DSP) [17–19]. It all uses composite systems with extra insulation. 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 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 in regions with relatively low costs of natural fuel.

One of the promising directions for the development of composite building systems is the realization of systems based on foamed glass and foamed glass-ceramics [23, 24]. Foamed glass can be used both as plate insulation and as foam glass rubble as filler, including lightweight plaster mixtures. The material is non-combustible and has low thermal conductivity and relatively high strength properties [25, 26].

2 Problem formulation

2.1 Performance criteria for insulation systems

The most effective building systems are those that allow seamless, insulating shells to be formed. This was found by looking at how other building systems are used to increase the thermal resistance of the insulating shell and, by extension, how long they last. 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.

With this in mind, one solution could be to use light, heat-insulating plaster mixtures that are spread out in several layers and reinforced with alkali-resistant meshes made of glass fiber or basalt fiber. The use of such systems allows for the thermal resistance of the insulating shell, which corresponds to the normative requirements. At the same time, the use of only mineral components belonging to the group of non-combustible materials will contribute to the fire safety of structures. Like-for-like materials added to plaster mixtures, such as mineral-modified bind aggregate and aggregate meshes made from materials derived from mineral melts, could make the insulation shell and, by extension, the building easier to damage.

2.2 Research objective

The article talks about research that aimed to create a way to choose the right ingredients, guess their properties, and get the best results for lightweight plaster coatings made from a modified hydraulic binder that includes construction waste and volcanic tuff. Tuff was considered a component of the modified binder (finely ground tuff) and 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 9479-2011); recycled waste concrete scrap (GOST R 70102-2022); plasticizer and water-retaining additive (GOST 24211-2008); and reinforcing components. 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 plaster mix had 25% by weight of crushed volcanic tuff (70% going through a sieve with a mesh size of 1 mm; 100% going through a sieve with a mesh size of 2 mm; bulk density of 500 kg/m3) as 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.

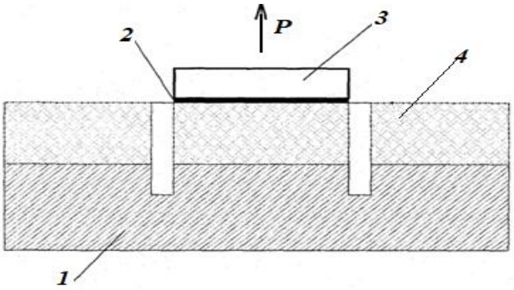

Fig. 1. Scheme of the pull-off test: 1: base material (supporting structure); 2: poly epoxy glue; 3: metal disk; 4: plaster coating; P: direction of tension (application of load generated by the testing device).

Using drilling, an incomplete (partial) sample with a diameter of 50 mm was taken perpendicular to the surface, and 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. The method is based on the following rules: The digital results that are made (statistical regression equations) accurately describe the technological process that is being studied; each equation is an algebraic function of several variables (depending on the number of important factors that change), and mathematical analysis methods can be used to study this function. The statistical regression equations that are generated are good representations of the technological process being studied. Each equation is an algebraic function of several variables, depending on the number of important factors that change. Mathematical analysis methods can be used 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 (У1) and its average density (У2) 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, $X\bar{i}$**	**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 based on a matrix of a full three-factor experiment. The results were processed in the Statistika program, and statistical hypotheses were tested on the significance of the coefficients in the regression equations that were made and on how well the models were made. The confidence values of the coefficients, determined by the Student criterion, were for compressive strength 0.4 MPa and for average density 8 kg/m^3.

3.2 Research results and discussion

A digital model has been made using the statistical analysis of the results of an active experiment. It is made up of algebraic polynomials that show how variable factors and response functions are connected.

- for compressive strength:

$$Y_1 = 16.5 + 1.8X_1 + 0.8X_2 + 0.8X_3 + 0.5X_1X_3 - 0.5X_2^2 \quad (1)$$

- for medium density:

$$Y2 = 490 + 26X1 + 16X3 + 10X1X3 \quad (2)$$

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 interpretations.

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. The reason for this effect might be that in finely ground (up to a specific surface area of 250 m2/kg) concrete waste, grains with binder that have not reacted during the whole structure's operation are activated. On the other hand, these grains can be thought of as crystallization centers for new formations, which, according to general theories of how composite binder hardens, also makes the structure stronger. The average density in the experiment changed slightly and depended on the consumption of Portland cement and finely ground waste.

When you look at the polynomial that illustrates how various factors affect compressive strength, you can see that this function (which consists of a number of variables) has a local extremum for one of these variables, polymer consumption (X2). Therefore, we can use the mathematical apparatus of analytical local optimization.

The idea behind analytical optimization is that the functions Y1 = f1(X1, X2, X3) for strength and density and Y2 = f2(X1, X3) for density are algebraic polynomials. This means that mathematical analysis methods can be used on them as long as the adequacy condition is not broken. 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 $Y_1 = f_1(X_1, X_2, X_3)$ by X_2:

$$\frac{\partial Y_1}{\partial X_2} = 0.8 - 1.0X_2 = 0 \rightarrow X_2 = 0.8$$

2) We use the factor decoding formula to find the natural value of the plasticizer consumption that corresponds to the highest possible compressive strength of the hardened plaster mixture:

$$PC = 2.0 + 0.8 \times 0.5 = 2.4 \text{ kg/m}^3$$

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

- for compressive strength:

$$Y1 = 16.8 + 1.8X1 + 0.8X3 + 0.5X1X3 \quad (3)$$

- for medium density:

$$Y2 = 490 + 36X1 + 26X3 + 10X1X3 \quad (4)$$

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. There is a nomogram (Fig. 1) that shows the interpolation solutions for all possible changes in the amount of Portland cement and finely ground waste used (factors X1, X3). The best value for factor X2 is 2.4 kg/m3, which is the optimal amount of plasticizer used. In sector I of the nomogram, compressive strength is determined; in sector II, the average density is determined.

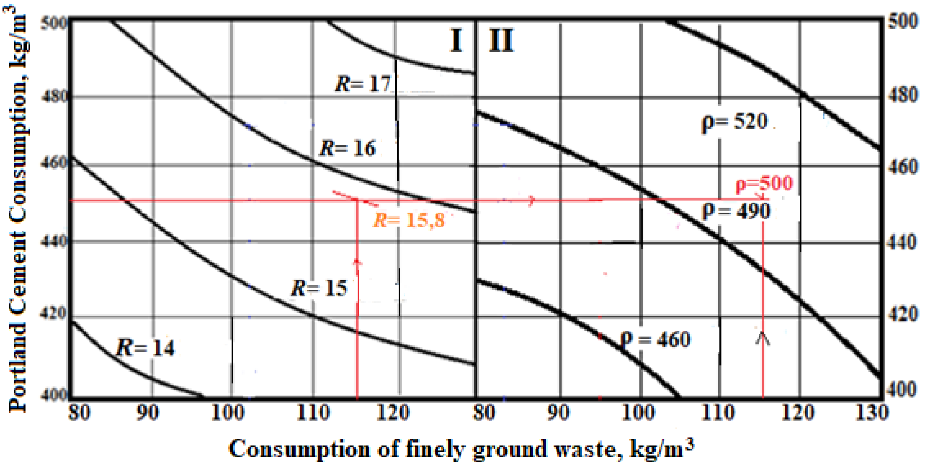

Fig. 2. A graph showing how to judge the properties of a plaster mixture based on the composite binder's make-up (red lines 1); the best amount of plasticizer to use is 2.4 kg/m^3. The strength *R* is measured in MPa, the average density ρ is in kg/m^3

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/m^3 and a Portland cement consumption of 450 kg/m^3, it is necessary to perform the actions shown in the red line in Fig. 2 (example 1). At 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 P 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/m^3).

Prediction of the properties of a composite binder can also be carried out using a special computer To see how well the digital models can predict the properties of the plaster mixture, do a set of control experiments and compare the strength and density values that were calculated from the models to those that were obtained from an actual experiment (Table 2).

To see how well the digital models can predict the properties of the plaster mixture, do a set of control experiments and compare the strength and density values that were calculated from the models to those that were obtained from an actual 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 (see Fig.3).

№	**Factor values:**		**Compressive strength, MPa**		
	Portland cement consumption, kg/m^3	**Consumption of finely ground waste, kg/m^3**	**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 following formula determines the average difference between the calculated compressive strength values and the experimental strength values obtained as a result of an active experiment:

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

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/m^3; consumption of finely ground waste 90-130 kg/m^3; plasticizer consumption 2.4 kg/m^3; consumption of ground volcanic tuff in the binder: 100 kg/m^3; consumption of volcanic tuff as fine aggregate 0.2×(500+120+100) = 120-160 kg/m^3; consumption of the reinforcing component: 0.01×(500+120+100) = 7.2 kg/m^3; water consumption 300 dm^3/m^3.

An assessment of the adhesive surface 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 shows Tests in a climate chamber revealed that after 50 cycles of alternating freezing and thawing, adhesive strength decreases by 15-20%. 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 revealed that after 50 cycles of alternating freezing and thawing, adhesive strength decreases by 15-20%. The structure of the multilayer plaster coating is shown in Fig. 3.

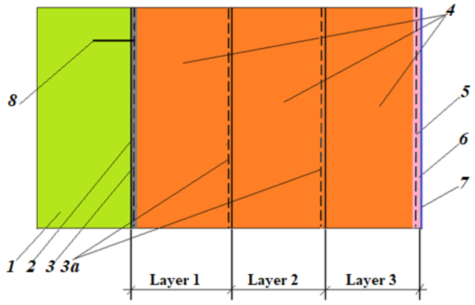

Fig. 3. Structure of plaster coating: 1: bearing wall; 2: priming layer; 3: primary reinforcing mesh; 3a: reinforcing mesh of plaster layers made of lightweight construction mixture; 4: plaster layers made of lightweight construction mixture; 5: finishing layer of plaster; 6: reinforcing mesh of finishing layer; 7: decorative and protective coating; 8: fastening element.

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 clinkers as part of the binder, which allows not only to optimize the costs of binder production but also to reduce the amount of harmful emissions into the environment.

4 Conclusion

The development of textile concrete technologies is one of the most promising areas of domestic construction. Varieties of this material are used in various fields of construction. Any kind of textile concrete starts with fine-grained modified concrete that is strengthened with meshes, fiber, or fiber made from mineral, metal, or less often polymer or carbon materials. This concrete also has a composite hydraulic binder that can include active mineral additives and processed concrete waste.

An important aspect of the development of the construction industry is the use of industrial waste (secondary products), concrete technology, or products obtained as a result of the demolition of dilapidated or renovated 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 basic steps for choosing and improving the make-up of a modified binder that uses construction waste as a base for plaster coatings on the outside of buildings have been worked out.

The group of special types of textile concrete includes concrete sheets and 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. The prospect for further research is to study the durability of seamless insulation systems in different climatic conditions, including hot climates.

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