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Scientific basis of design structures plaster solutions

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High-rise construction volume increase and new wall materials use require changing the approach to the design of plaster mortar compositions. The analysis has showed that it is possible to reduce the number of cracks in the plaster coating by increasing the water holding capacity of the mortar mixture. To optimize the prescription parameters of the mortar mixture, the five-factor experiment with fine aggregate and the filler with a low modulus of elasticity, disperse polymeric powders and cellulose ethers, a polymer fiber for microdispersed reinforcement has been used. The obtained data indicate that the proposed approach enables to obtain plaster mortars with physic mechanical characteristics that provide optimal working conditions “masonry - plaster coatings”.

Keywords: plaster solutions, new basic principles for designing their compositions

Наукові основи проектування складів штукатурних розчинів

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Збільшення висотності будівель, застосування нових стінових матеріалів, вимагає переосмислення підходу до проектування складів штукатурних розчинів. Вирішити поставлене завдання в рамках існуючих принципів неможливо. У статті проведений аналіз системи «штукатурне для кладки покриття» на стадіях твердіння і експлуатації, виявлені руйнівні чинники і механізм її руйнування. Відмічено, що основною причиною руйнування системи є деформації і напруги, що виникають в кладці, штукатурному покритті і контактній зоні між ними, із-за силових дій, температури і вологості, агресивних рідин і газів. Проведений аналіз показав, що зменшити кількість тріщин в штукатурному покритті, на стадії тверднення, понизити напругу в системі, можна шляхом підвищення водоутримуючої здатності розчинної суміші, зменшення усадки і модуля пружності штукатурного покриття, підвищення його еластичності. Для цього запропоновано використовувати дрібний заповнювач і наповнювач з низьким модулем пружності, редісперсні полімерні порошки і ефіри целюлози, полімерну фібру для мікродисперсного армування та ін. Для оптимізації рецептурних параметрів розчинної суміші використовували п'ятифакторний експеримент. Отримані дані свідчать про те, що запропонований підхід дозволяє отримувати штукатурні розчини з фізіко-механічними характеристиками що забезпечують оптимальні умови роботи «кладки- штукатурне покриття». Застосування запропонованих компонентів дозволяє підвищити водоутримуючу здатність розчинної суміші, зменшити усадку штукатурного покриття і кількість тріщин на стадії тверднення. Збільшити еластичність і знизити модуль пружності штукатурного покриття, напруги в ньому і швидкість розвитку тріщин на стадії експлуатації, що дозволить підвищити його довговічність і стінової конструкції.

Ключові слова: штукатурні розчини, нові базові принципи проектування їх складів

Introduction

The increase of high-rise construction share and the widespread use of new wall materials require changing the approach to the design of plaster mortar compositions. Is is due to the fact that the impacts and loads on the plaster coating located on the 24th floor of the building are significantly different from those that it experiences on the 1st to 3rd floors (Fig. 1).

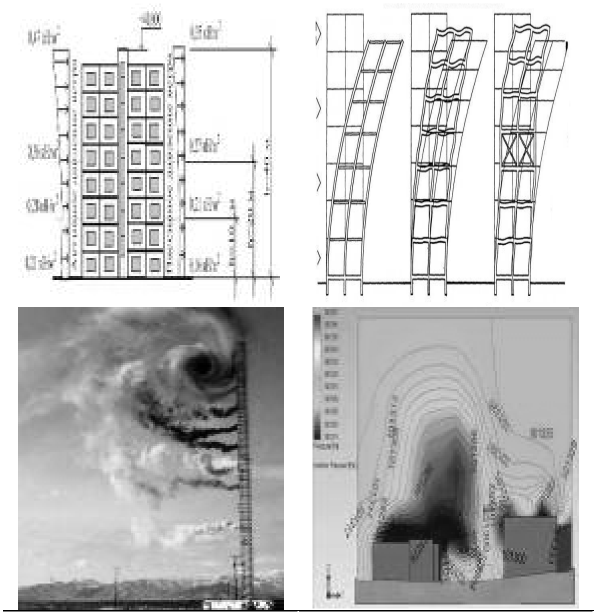


Figure 1 – Change impacts and loads on the plaster coating while increasing high-rise buildings

It is also necessary to consider the fact that when building high-rise buildings on the territory of Ukraine, the autoclaved aerated concrete with an average density of 150-600 kg / m3 is mainly used. Its properties (compressive strength, modulus of elasticity, temperature deformation) depend on the average density and significantly differ from the properties of traditional wall materials (ceramic and silicate bricks, blocks of lightweight concrete and rocks).

To achieve goal in the framework of existing ideas and principles is not possible. They are applicable for solutions used in low-rise construction. Normative requirements for plaster mortars for autoclaved aerated concrete walls are also not considered; they are contradictory and, in our opinion, are not substantiated. For example, compressive strength should be from 1.5 to 7.5 MPa (Russia), 2.5 MPa (Ukraine) and 10 MPa (Germany). The flexural strength should be from 1 to 1.25 MPa (Ukraine) and 2 MPa (Russia). The value of adhesion to aerated concrete laying should be from 0.15 to 3 MPa (Russia) and 0.5 MPA (Ukraine).

Problem statement

To achieve the required goals, the development of new scientific bases for the design of plaster mortar compositions is required. It is necessary to analyze the processes occurring in the plaster coating when it is applied and hardened, the knowledge of the destruction mechanism of the system "masonry - plaster coating", calculation and account of stresses.

The durability of the wall structure depends to a large extent on the number of defects in the plaster coating and the contact area between it and the masonry. The destruction of the system "masonry - plaster coating" is due to the accumulation and development of micro- and macro-cracks in it. To assess the service life of such a system, it is necessary to determine the internal and external factors, their impact degree, the calculation of the stress state, knowledge of the nucleation processes, the accumulation of damage and the macrocracks growth. The assigned physical and mechanical parameters and compositions of plaster solutions should ensure the "work" of the system at the maximum level of such stresses.

Basic material and results

Masonry made of autoclaved aerated concrete has a high capillary potential due to the considerable pore volume (520 mm^3/g) and their high specific surface area (22-34 m^2/g) [1]. During the application of the mortar mixture to the masonry, because of its low water-retaining capacity, the liquid is pumped out of it, with lyophilic pores and capillaries of the masonry material (Fig. 2a). The pore filling rate (v) is determined by the Poiseuille equation

$$v=-\frac{r^2\Delta_p}{8\eta l}\ , \qquad (1)$$

when l – length of the area of the absorbed liquid;
η – viscosity of the absorbent section;
Δ_p – the pressure drop across section l, equal to the capillary pressure of the meniscus

$$\Delta_p=\frac{-2s_{12}\cos q}{r}\ . \qquad (2)$$

Therefore, the dissolution of cement and the formation of a supersaturated solution mortar with reduced water content. Because of this, incomplete hydration of cement occurs, nonequilibrium, metastable neoplasm of the following type is formed:

$$\begin{aligned}&1{,}83(3CaO\cdot AI_2O_3)+1{,}48(CaSO_4\cdot 2H_2O)+\\&+3{,}38Ca(OH)2+16{,}67H2O\rightarrow\\&0{,}42(3CaO\cdot AI2O3\cdot 6H2O)+\\&+1{,}42\ (3CaO\cdot AI2O3\cdot CaSO4\cdot 12H2O)\\&+3{,}38Ca(OH)2+0{,}07CaSO4\cdot 2H2O\end{aligned} \qquad (3)$$

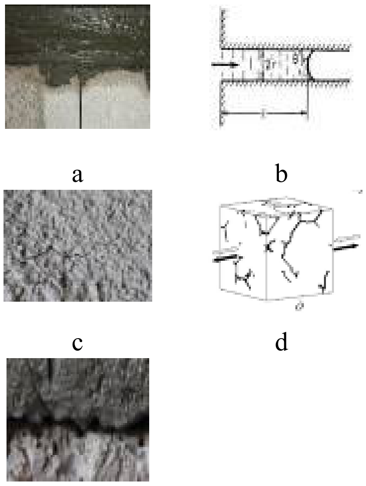
The loss of water leads to shrinkage of the plaster solution - 2.5 ... 5.8 mm/m [2]. And since the aerated concrete masonry "holds back" these deformations, it leads to stresses in it (δ), which are seven times higher than its tensile strength

$$\delta=\frac{\Delta\varepsilon^{*}\cdot E}{1-\mu}\ . \qquad (4)$$

when E and μ – modulus of elasticity and Poisson's ratio of plaster coating;
$\Delta\varepsilon^*$ – difference in deformations of plaster and aerated concrete base [5].

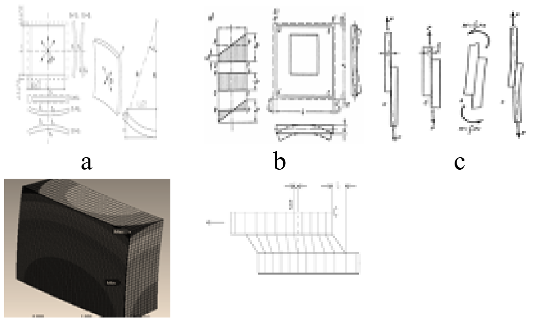
Because of these stresses and the fact that a decrease in the degree of cement hydration has led to a decrease in the ultimate extensibility of the material (by 20 ... 50%) [4, 7, 8], cracks develop in the plaster coating (on the surface and in the volume of the material), as well as in the contact zone with the masonry (Fig. 2c, 2d, 2e).

During operation they "evolve" and merge into trunk. The causes of cracks are temperature and humidity deformation plaster and masonry [3,4] and the difference between them (Fig. 3c, 3e), the voltage caused by them (Fig. 3d), moisture, ice, corrosive materials.



a b c d e

Figure 2 – Cracking in the plaster coating and the contact zone between them



a b c d e

Figure 3 – Temperature and humidity deformation of the masonry (a, b) and stresses in it (d)

Cyclic temperature-humidity effects lead to deformation (ΔL_p, ΔL_c, ΔL_{tv}) and additional stresses in the plaster coating (δ), which are the development cause of the whole family of main cracks.

$$\Delta L_p = \alpha\, \Delta T^p\, L\ ; \quad (5)$$

$$\Delta L_c = \alpha\, \Delta T^c\, L\ ; \quad (6)$$

$$\Delta L_{tv} = \alpha\, \Delta T\, L\, F_m + \Delta L_q\, L\ .; \quad (7)$$

where: ΔL_p, ΔL_c – deformation of tension and compression;

ΔL_{tv} – heat and humidity deformation;

α – coefficient of temperature elongation of the material;

ΔT^p, ΔT^c – is the temperature difference;

L – is the wall element length;

F_m – an indicator of material defects;

ΔL_q – humidity deformations [3].

$$\delta = k\sqrt{[a_t + b(L-c)]\cdot\delta^*}\ ; \quad (9)$$

$$\delta^* = E\cdot a_t\cdot\Delta t\ ,$$

where E – modulus of elasticity;

α_t – coefficient of linear expansion of plaster coating;

Δt – calculated temperature drop.

Masonry and plaster coating have different in magnitude thermal deformations. The magnitude of these deformations is determined from the expression [5]:

$$\Delta L = L_0 \cdot \alpha_t \cdot \Delta t\ ; \quad (10)$$

$$\Delta t = t_2 - t_1\ , \quad (11)$$

where ΔL – the wall structure elongation or contraction is relatively;

L_0 – the length of the wall structure at the time of construction;

α_t – coefficient of thermal expansion and autoclaved aerated plaster coating [1,5];

Δt – changing the temperature of the wall structure;

t_1 – environmental temperature at the time of construction of gas concrete masonry and applying stucco coatings;

t_2 – the maximum and minimum temperature, which affects the wall structure in summer and winter periods;

In winter, at -20°C, for a laying length of 8 m, made in summer at a temperature of + 30°C, with a coefficient of temperature expansion of aerated concrete laying of 8 · 10-6 grad^{-1} and a temperature change from +30 to -20°C, e=50°C, the total compression deformation is 3.2 mm. In summer, when heated to + 80°C [1], the expansion deformation is 3.2 mm.

In winter, the compression deformation of the plaster solution (1:4) is 0.55 mm/m, and the total deformation of the compression, the plaster coating of the wall 8 m long, is 4.4 mm. In summer of the total deformation expansion of the plaster coating is 4.4 mm. Deformations of expansion and contraction cause tension (σ) in the masonry and the plaster covering which can be determined by converting the equation:

$$\frac{\Delta L}{L_0} = \frac{\sigma}{E} \quad (12)$$

where ΔL – the elongation or contraction of the wall structure;

L_0 – length of the wall structure at the time of erection;

σ – stresses in H/mm^2;

E – is the modulus of elasticity in H/mm^2 [5].

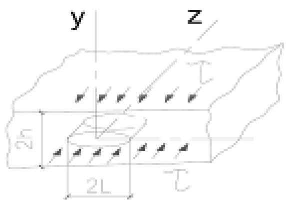
The difference between the deformations, the elasticity modules of the masonry and the plaster coating, is the reason for the shear strains in the contact zone "masonry - plaster coating" (Figures 3e, 4a) and stresses (τ) (Fig. 4b), which predetermine the development of a crack in the contact zone:

$$\tau = \frac{\Delta T_1 \alpha_1 - \Delta T_2 \alpha_2}{\dfrac{1}{E_1} + \dfrac{1}{E_2}}, \quad (13)$$

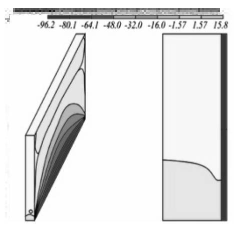
where τ – shear stress from temperature deformations, kgf/cm^2;
ΔT_1, ΔT_2 – the temperature difference at the time of installation and operation of the plaster coating and masonry, ºC;
α_1, α_2 – coefficient of thermal expansion of masonry and plaster coating;
E_1, E_2 – elasticity module of masonry and plaster coating, kgf/cm^2.

Atmospheric moisture, penetrating into the cracks of the plaster coating, and through them into the contact zone, creates a wedging pressure at the top of the crack. Thus, tensile stresses appear in this zone (Fig. 5a), which leads to further development of the main cracks plaster coating and its contact zone with the masonry.

At minus temperatures, in winter, the development of cracks is accelerated due to the transformation of water into ice (Fig. 5b, 5c), which ultimately leads to the destruction of the plaster coating and the wall structure (Fig. 5d, 5d).



a



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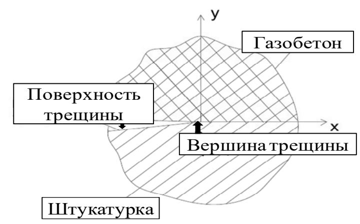


c

Figure 4 – Deformations (a), stresses in the contact zone (b) and development of the main crack (c)

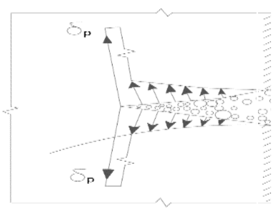
In order to prevent the destruction of the plaster coating, it is necessary to calculate the values of its physic mechanical characteristics (compressive and bending strength, elastic modulus, etc.), considering the stresses in it and the contact zone with the cladding that arise when the solution is hardened and the wall structure is deformed. In this case, the maximum permissible voltage, should be less than destructive. Selection of the composition of the solution must also be carried out taking into account the processes occurring during the application and hardening of the mortar to the masonry. It is necessary to increase the water-retaining capacity of the mixture, to reduce the shrinkage of the plaster coating during hardening, to reduce the number of cracks that occur during hardening and to prevent or slow down their development.

The aim of the research was to obtain plaster solutions with high crack resistance, while ensuring the requirements of normative documents for medium density, compressive strength and bending, and other parameters.

In the experiment, to reduce the shrinkage of the plaster coating and prevent the appearance of shrinkage cracks, a small filler and a filler with a low modulus of elasticity (vermiculite and from aerocrete battles (mix No. 1), limestone stone waste and pearlite waste (No. 2 mix) were used.

The resulting effect was enhanced by the addition of redispersible polymer powder Winnapas 5043 H and cellulose ethers Tylose MBZ 15009. Their presence enables to reduce the modulus of the plaster coating elasticity and the stress in it and the contact zone, and with the polymer fiber addition, the cracks development rate is reduced, which increases the durability of the coating and the wall structure.

To determine the properties of the plaster solution, samples of a 40×40×160 mm beam were made on a gas-concrete base. Curing regime air-dry, simulating the work of plaster coating in real conditions.



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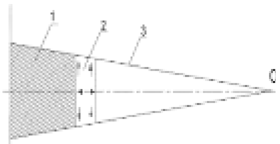

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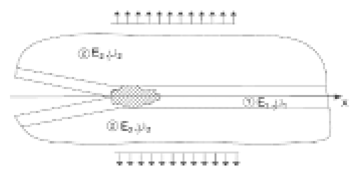

c

d

e

Figure 5 – Development of the main crack in the contact zone due to the action of water (a), ice (b, c), and destruction of the plaster coating (d, e)

Table 1 – Factor variation range

Type of mixture	The range of variation	Binder consumption, kg/m^3	Filler and aggregate consumption, m^3/m^3	Fiber consumption, kg/m^3	Redispersible polymer powder consumption Winnapas 5043 H, %	Consumption Tylose MBZ 15009,%
		X1	X2	X3	X4	X5
Mix №1	1	500	1,05/1	1,2	5	0,5
	0	400	1,05/1	0,9	3	0,3
	-1	300	1,05/1	0,6	1	0,1
Mix №2	1	400	1,05/1	1,2	5	0,5
	0	300	1,05/1	0,9	3	0,3
	-1	200	1,05/1	0,6	1	0,1

Curing regime air-dry, simulating the work of plaster coating in real conditions. After 28 days of hardening were determined: compressive strength and bending strength, high density, etc. Fracture toughness was determined visually by the presence of cracks in the coating and calculating the fracture toughness ratio, as the ratio of the bending strength to compressive strength.

The result is plaster solutions with the following properties:

Composition No.1 (Fig. 6a-d):
– average density of 600-1500 kg/m^3,
– bending strength 12-18 kg/cm^2,
– compressive strength 18-36 kg/cm^2,
– crack resistance coefficient 0.56-0.74.

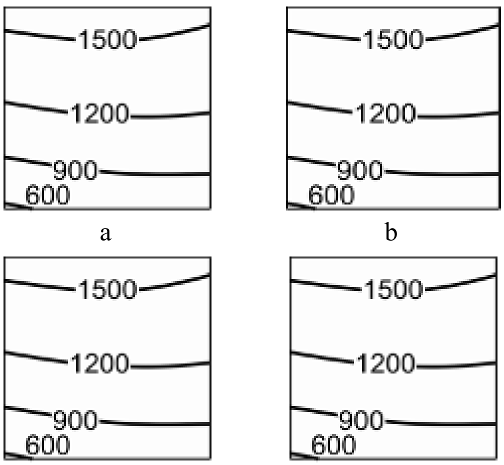

Figure 6 – Average density (a), flexural strength (b) and compression (c), crack resistance (d) of composition №1

Composition No.2 (Fig. 7a-d):
– average density of 700-1100 kg/m^3,
– bending strength 10-25 kg/cm^2,
– compressive strength 15-35 kg/cm^2,
– crack resistance coefficient 0.25-1

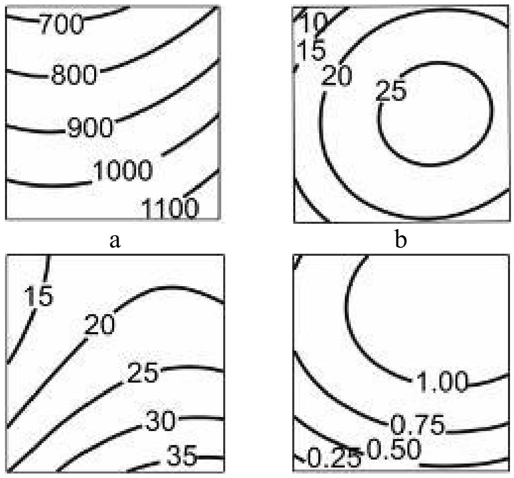

Figure 7 The average density of (a), flexural strength (b), the compressive strength (c), the crack resistance coefficient (d) the composition №2

The obtained plaster solutions meet the requirements of normative documents for medium density (600-1600 kg/m^3), flexural strength (10-25 kg/cm^2) and compression (25-50 kg / cm2). The plaster coating has a high crack resistance, the crack resistance coefficient is 0.25-1, while the cracking resistance is considered plaster with an index> 0.26.

Conclusions

The increase in the share of high-rise construction and the widespread use of new wall materials, requires the development of scientific foundations, the design of plaster mortar compositions. For this analysis processes occurring in the plasters in its application and hardening, the system is considered failure mechanism "bricklaying - plaster coating" are given formula for calculating stress. The principles and criteria are formulated under which the plaster coating and the wall structure durability is provided, the constituents and the material composition selected.

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