Influence of the processes taking place in the contact zone "masonry - plaster coating" on the destruction of the wall structure

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Abstract. To create the optimal composition of the plaster solution with the preassigned properties, it is necessary to know the processes taking place in the "masonry-coating" system, including in the contact zone between it and the masonry, the mechanism of its destruction. The purpose of the presented work was to describe the processes of occurrence and growth of cracks in the plaster coating and its contact zone with the masonry, in the process of its application, hardening and operation of the wall structure. In recent years, significant progress has been made in analyzing the reliability of plaster coatings, their behavior during operation, however, there are problems in predicting the evolution of damage in terms of initiation and growth of cracks, which ultimately leads to cracking and delamination of the plaster coating from masonry. The behavior of the plaster coating largely depends on its structure and the structure of the contact zone. The state of the "masonry-coating" system was described and this made it possible to obtain data on the process of its destruction, the appearance and spread of cracks. The system was destroyed according to two main schemes: formation and development of cracks in the coating and in the contact zone. Thus, these researches make it possible to reduce the number of defects in the contact zone with the masonry and increase the service life of the wall structure.

1. Introduction and literature review

The use of plaster coatings is due to the need to ensure a longer service life of the wall structure. To create a plaster mortar with desired properties, it is necessary to know the processes taking place in the "masonry-coating" system, including in the contact zone between it and the masonry, the mechanism of its destruction.

In recent years, there has been significant progress in the analysis of the reliability of plaster coatings [1,2], their behavior during operation, but nevertheless, there are problems in predicting the evolution of damage in terms of initiation and growth of cracks, and this leads to cracking and delamination of the plaster coating from the masonry [3].

The behavior of the plaster coating largely depends on its microstructure [4,5] and the structure of the contact zone. Plaster mortars are hierarchical composites consisting of fine aggregates and inorganic compounds - brittle minerals, cement hydration products, the structure of which and the contact zone with masonry is formed as a result of processes occurring during application, hardening, operational influence and the environment [6].

Investigation of the state of the "masonry-coating" system allows obtaining data on the process of its destruction, the appearance and propagation of cracks. The article discusses a model of the stress-
strain state of the system. It destruction according to two main schemes: formation, development of cracks in the coating and its contact zone with the masonry.

After applying the mortar mixture to the masonry, cracks form on the surface of the plaster coating, the cause of which is the shrinkage of the cement stone due to its hydration, the suction of moisture by the masonry, its evaporation under the influence of the sun and wind (figure 1, b, c).

The concept and view of the problem disclosed by the authors in this article is a unique and independent scientific direction in previously published works [7-11], the processes occurring in a plaster coating during its application and hardening, the destruction mechanism of the system “masonry - plaster coating” are considered. It was revealed that the system is destroyed according to two main schemes: the formation and development of cracks in the plaster coating and its contact zone with the masonry. The reason for this is the stress caused by: shrinkage of the material due to moisture loss and hardening of cement, structural heterogeneity, deformation of the coating, masonry and their difference, etc.

![Image](image1.jpg)

**Figure 1.** Cracking in the plaster coating (b, c) and its contact zone with the masonry (a)

### 2. The aim of the work

The aim of the work is to describe the processes of occurrence and growth of cracks in the plaster coating and its contact zone with the masonry, in the process of its application, hardening and operation of the wall structure.

### 3. Materials and research methods

The rate of occurrence of new cracks is determined by the stiffness of the coating. In hard plastering coatings, breaking stress is achieved as a result of less deformation. Therefore, at the initial stage of cracking, the density of cracks grows most rapidly for coatings that are characterized by the maximum modulus of elasticity.

Due to the fact that the masonry restrains the shrinkage deformations of the plaster coating, tensile stresses (σ) appear in it, due to which the cracks formed during shrinkage increase.

Their value is found from the equations [12]:

$$\sigma = \Delta \varepsilon \cdot E / 1 - \mu ; \sigma_y = \Delta \varepsilon \cdot v \cdot E / 1 - \mu$$  \hspace{1cm} (1)

where: $\sigma_y$ – tensile stresses taking into account elastoplastic deformations due to the presence of a gel; $E$ and $\mu$ – modulus of elasticity and Poisson's ratio of plaster coating; $\Delta \varepsilon$ – difference in deformations of plaster and masonry; $v <1$ – coefficient of elastoplastic deformation of the solution under tension.

To calculate stresses (σ) and simplify, we assume that the shrinkage of the aerated concrete masonry has stopped, i.e. $\Delta \varepsilon = \varepsilon_{pl}$ ($\varepsilon_{pl}$ – shrinkage deformations of plaster). Then for plaster mortar M25, with modulus of elasticity $E = 4 \cdot 10^3$ MPa [13], shrinkage deformation $\Delta \varepsilon = \varepsilon_{pl} = 0.3...0.8$ mm/m $30...80 \cdot 10^{-5}$; Poisson's ratio $\mu = 0.3$; coefficient of elastoplastic deformation of the solution under tension $v = 0.5$ [14], with minimal shrinkage:

$$\sigma = 30 \cdot 10^{-5} \cdot 0.5 \cdot 4 \cdot 10^3 / 1 - 0.3 = 0.85 \text{ MPa}>0.3...0.4 \text{ MPa}$$  \hspace{1cm} (2)

- at maximum shrinkage:

$$\sigma = 80 \cdot 10^{-5} \cdot 0.5 \cdot 4 \cdot 10^3 / 1 - 0.3 = 2.28 \text{ MPa}>0.3...0.4 \text{ MPa}$$  \hspace{1cm} (3)
They are significantly higher than the calculated tensile resistance for the calculation of the formation of cracks equal to 0.3 MPa and the destruction stress equal to 0.4 MPa [13].

For plaster mortar M50, with modulus of elasticity $E = 6 \cdot 10^3$ MPa [13], at shrinkage deformation $\Delta \varepsilon = \varepsilon_{pl} = 0.3...0.8$ mm/m or $30...80 \cdot 10^{-5}$; at Poisson's ratio $\mu = 0.3$; coefficient of elastoplastic deformation of the mortar under tension $\nu = 0.5$ [14], with minimal shrinkage, the stresses will be:

$$\sigma = \Delta \varepsilon \cdot \nu \cdot E / (1 - \mu) = 30 \cdot 10^{-5} \cdot 0.5 \cdot 6 \cdot 10^3 / (1 - 0.3) = 1.28 \text{ MPa} > 0.35 ... 0.5 \quad (4)$$

at maximum shrinkage:

$$\sigma = \Delta \varepsilon \cdot \nu \cdot E / (1 - \mu) = 80 \cdot 10^{-5} \cdot 0.5 \cdot 6 \cdot 10^3 / (1 - 0.3) = 3.42 \text{ MPa} > 0.35 ... 0.5 \quad (5)$$

These stresses are also significantly higher than the calculated tensile resistance for the calculation of the formation of cracks equal to 0.35 MPa and the destruction stress equal to 0.5 MPa [13].

In the contact zone "masonry-coating", due to the suction of moisture by the masonry from the mortar mixture and its shrinkage, horizontal cracks are also formed (figure 1.a) [15, 16].

Cracks formed on the surface of the plaster coating "grow" both along the plane and into its depth, initially vertically, to the intersection with the plane of the "masonry-coating" contact zone, and then horizontally, along the contact zone. The direction of growth of these cracks is determined not only by the geometry of stresses, but also depends on the presence of previously formed shrinkage cracks in this zone.

The reasons for the destruction of the plaster coating and the contact zone are also the deformation of the wall structure due to the effect of temperature (figure 2a, b), static and dynamic loads (figure 2c) and stresses caused by them (figure 3). The plaster coating under these conditions works in shear and bending.

![Figure 2](image1.png)

**Figure 2.** Deformations in a wall structure at positive (a) and negative temperatures (b), diagram of static and dynamic loads (c)

![Figure 3](image2.png)

**Figure 3.** Influence of variable factors on stresses in the plaster coating at negative (a) and positive (b) temperatures, t / m²

At the same time, a gradual change in its properties is observed. The dynamic type of loading is characterized by the magnitude of the load, the amplitude and frequency of the load application. Even if the value of the applied load is significantly lower than the breaking stress of the contact zone, there is still a gradual decrease in its strength and the value of adhesion of the coating to the masonry. This
loss of strength is called fatigue. Under the cyclic loads occur degradation processes and causes an irreversible change in the properties of the material of the contact zone.

In bearing wall structures made of autoclaved aerated concrete, deformations of the masonry are added to these deformations, due to the constant load, which reach 1.2–2 mm / m [17]. As a result, in the contact zone, cracks of normal separation and flat shear are developing (figure 4). At the initial stages, the crack propagates according to the mechanism of normal separation, then longitudinal shear begins to prevail (figure 4).

**Figure 4.** Contact zone of the "masonry-coating" system (a), the character of the stresses in it (b), types of cracks in it (c): I. Normal separation; II. Longitudinal shear;

Destructive stress at uniform separation (det), MPa, is determined by the formula:

\[
\sigma_{\text{det}} = \frac{P}{F}
\]

where: \(P\) – destructive load, Н; \(F\) – the area of the contact area of coverage with masonry, м².

4. The results of research

The materials forming the system i.e. masonry and coating differ from each other in their properties. The difference in their coefficients of thermal expansion, moisture deformation, elastic characteristics, causes the occurrence of longitudinal shear stresses along the interface, which also leads to the development of cracks in the contact zone.

The magnitude of these deformations is determined using the equations with the initial data [18, 19, 20]:

\[
\Delta L = L_0 \cdot \alpha_t \cdot \Delta t; \quad \Delta t = t_2 - t_1
\]

where: \(\Delta L\) – relative extension or reduction of the wall structure; \(L_0\) – its length at the time of erection; \(\alpha_t\) – coefficients of thermal expansion: autoclaved aerated concrete \(\alpha_t = 8 \cdot 10^{-6} / ^\circ\text{C}\), lime-sand mortar (1:4) \(\alpha_t = 9 \cdot 10^{-6} / ^\circ\text{C}\); cement-sand (1:4) \(\alpha_t = 10.4 \cdot 10^{-6} / ^\circ\text{C}\), lime-cement \(\alpha_t = 6 \cdot 10^{-6} / ^\circ\text{C}\);

\(\Delta t\) – temperature change of the wall structure; \(t_1\) – temperature of environment at the time of erection of the wall structure; \(t_2\) – maximum or minimum temperature to which wall structure is subjected during the summer and winter periods.

The relative deformation of the masonry compression at -20°C, made at +30°C, will be 0,4 mm/m, and total deformation: with a length, for example, 8m:

\[
\Delta L = L_0 \cdot \alpha_t \cdot \Delta t = 8 \cdot 0.000008 \cdot 50 = 0.0032 \text{m} = 3,2 \text{mm}; \Delta t = 50 ^\circ\text{C}
\]

Relative compression strain of cement-sand plaster coating (1:4) will be 0,55 mm/m, and total deformation:

\[
\Delta L = L_0 \cdot \alpha_t \cdot \Delta t = 8 \cdot 0.0000104 \cdot 50 = 0.0044 \text{m} = 4,44 \text{mm}; \Delta t = 50 ^\circ\text{C}
\]

Relative compression strain of lime-cement plaster coating will be 0,3 mm/m, and total deformation:

\[
\Delta L = L_0 \cdot \alpha_t \cdot \Delta t = 8 \cdot 0.000006 \cdot 50 = 0.0024 \text{m} = 2,44 \text{mm}; \Delta t = 50 ^\circ\text{C}
\]

By the action of heating to a temperature +80°C, the relative deformation of the expansion of the masonry will be 0.4 mm/m, and total deformation:

\[
\Delta L = L_0 \cdot \alpha_t \cdot \Delta t = 8 \cdot 0.000008 \cdot 50 = 0.0032 \text{m} = 3,2 \text{mm}; \Delta t = 50 ^\circ\text{C}
\]

Relative deformation of the expansion of cement-sand plaster coating (1:4) will be 0,55 mm/m, and total deformation:

\[
\Delta L = L_0 \cdot \alpha_t \cdot \Delta t = 8 \cdot 0.0000104 \cdot 50 = 0.0044 \text{m} = 4,44 \text{mm}; \Delta t = 50 ^\circ\text{C}
\]

Relative deformation of the expansion of lime-cement plaster coating will be 0,3 mm/m, and total deformation:
\[ \Delta L = L_0 \cdot \alpha \cdot \Delta t = 8 \cdot 0,000006 \cdot 50 = 0,0024 \text{m}=2,4 \text{mm}; \Delta t = 50^\circ \text{C} \]  \hspace{1cm} (13)

The difference in the deformations of the masonry and the coating causes stresses in the plaster coating and the contact zone, the magnitude of which can be determined by transforming the equation [20].

\[ \Delta L : L_0 = \sigma : E \]  \hspace{1cm} (14)

where: \( \Delta L \) – relative extension or reduction of the wall structure; \( L_0 \) – length of the wall structure at the time of erection; \( \sigma \) – stress in H/mm²; \( E \) – modulus of elasticity in H/mm².

The difference in the values of deformations, elasticity moduli of masonry and plaster coating are the cause of shear deformations and stresses (\( \tau \)), in the contact zone between them (figure 5), which predetermine the development of a crack in the contact zone. The shear stress in the contact zone is equal to:

\[ \tau = \left[ \Delta T_1 \alpha_1 - \Delta T_2 \alpha_2 \right] \left[ \frac{1}{E_1} + \frac{1}{E_2} \right] \]  \hspace{1cm} (15)

where: \( \tau \) – shear stress due to thermal deformations, kgf/cm²; \( \Delta T_1, \Delta T_2 \) – temperature difference at the time of installation and operation of the plaster coating and masonry, ºС; \( \alpha_1, \alpha_2 \) – coefficient of thermal expansion of masonry and plaster coating; \( E_1, E_2 \) – moduli of elasticity of masonry and plaster coating, kgf/cm².

The contact zone works for shear along the axis of the interface and for tension-compression, perpendicular to this axis.

(a) (b)

**Figure 5.** Difference between deformations of masonry and coating (a) and shear deformation in the contact zone "masonry-plaster coating" (b)

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**Figure 6.** Deformations (a) and shear stresses in the contact zone (b)

Destructive shear stress (sd, MPa) is determined according to the formula:

\[ \sigma_{sd} = \frac{P}{F} \]  \hspace{1cm} (16)

where: \( P \) – destructive load, H; \( F \) – the area of the contact area of coverage with masonry, m²

The contact zone transfers normal and tangential stresses through shear deformation and tension/compression in the z direction. The resulting stresses in the contact layer are not the same in different places of the contact area due to the presence of cracks and hollows in it.

Shear stresses are imposed on tangential stress (due to the mass of the plaster coating (figure 7):

\[ \tau_k = \rho \cdot \left( -\frac{15 \cdot \delta^3}{h^2} - 4 \cdot \delta \right) \]  \hspace{1cm} (17)
Figure 7. Shear stresses in the contact zone "masonry-plaster coating"

where: \( \delta \) – plaster coating thickness, m; \( \rho \) – average density of plaster mortar, kg/m\(^3\); \( \tau_k \) – stresses in the contact zone; \( h \) – the height of the plaster coating, m;

The described actions cause tensile and compression loads (figure 8a, b), shear loads and splitting loads (figure 8c, d) in the contact zone.

Deformations of the plaster coating and the "coating-masonry" contact zone are the sum of three components: elastic deformation, reversible in phase with stress, completely irreversible - residual, highly elastic, reversible, but not in phase with stress. The competition of the above described fracture mechanisms in the coating - masonry system with an increase in the degree of deformation leads either to the formation of secondary cracks in the coating of normal separation or to the formation of shear cracks at the interface.

Due to the fact that the strength of the connection between the coating and the masonry at shear \( \tau_k \) and uniform separation \( \sigma_k \) depends on the destructive load and the area of their contact, then with a decrease in the contact area, the crack growth and delamination of the coating from the masonry becomes easier

\[
\tau_k = \frac{F_p}{A} ; \quad \sigma_k = \frac{F_p}{A}
\]

where: \( F_p \) – destructive load, \( A \) – contact area.

The growth of the main crack occurs due to merging with pore-like cracks, which originate in the zone in front of the apex. This leads to the propagation of a crack along the coating-masonry interface, a decrease in the area of their contacts, as a result of which there is a widespread delamination of the coating (figure 9).

Figure 8. Types of loads on the contact zone of the system "masonry-plaster coating"
The development of the main crack occurs until the plaster coating is detached from the base and the denudation of the masonry (figure 9).

5. Conclusion
The choice of the components of the mixture, the selection of its composition of the mixture must be made, taking into account the processes of destruction occurring in the system "masonry-plaster coating" during the operation of the wall structure. The article discusses a model of the stress-strain state of the system. Its destruction occurs as a result of the growth of many cracks formed in the zone where the local stress exceeds the local strength of the material. It collapses according to two main schemes: formation, development of cracks in the coating and its contact zone with the masonry. The reasons for the appearance and development of cracks are shrinkage of the plaster coating during hardening, deformation of the wall structure due to the effect of temperature, static and dynamic loads and stresses caused by them. Therefore, for the selection of the components of the mortar mixture, their ratio, it is necessary to take into account the factors. It is necessary to increase the water-retaining capacity of the mortar mixture and reduce the stresses in the coating and the contact zone during operation. The proposed actions will make it possible to reduce the number of shrinkage cracks at the stage of coating hardening, prevent the formation and development of cracks in it and the contact zone during the operation of the wall structure, slow down the rate of its destruction, and increase the time of its operation.

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