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RESEARCH OF THE COMPONENT COMPOSITION OF DRYING RENOVATION BRICK CRUMB PLASTER FOR RESTORATION OF ARCHITECTURAL MONUMENTS

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Abstract

The article presents the results of analytical studies to establish the authentic component composition of the brick crumb plaster, which was used to furnish architectural monuments of the 10th – 12th centuries. In laboratory conditions, a number of experimental studies aimed at the production of brick crumb plaster according to the historical recipe were performed. However, a number of requirements were set for such plaster, according to which it must meet European and domestic requirements for drying renovation plasters. The peculiarity of such plasters is low compressive strength (1.5 – 5.0MPa), high porosity (>45 %) and a low coefficient of resistance to water vapour diffusion (<12), which allows drying overmoistened walls and at the same time extracting salts from them and accumulating them in the pores of their volume.
In the process of experimental research, the historical recipe of the plaster was slightly modified, which made it possible to obtain a plaster with the specified parameters. The performance of plastering works with a scientifically based recipe of brick crumb renovation plaster on an architectural monument in the city of Chernihiv gave a positive result with a decrease in salinity and humidity of the walls.

***Keywords**: Architectural monument; Drying renovation plasters; Recipe; Component composition; Physical and mechanical indicators*

Introduction

In Ukraine, a large number of historical objects – monuments of architecture, mainly of religious purpose, in which lime-brick crumb mortars were used, have been preserved. As of the beginning of the war with Russia, the State Register of Ukraine included about 3,700 monuments of national importance, of which 60 – 70% required restoration, and 10% were in a state of emergency. Among the most valuable are the cathedrals of the princely era, in particular St. Sophia Cathedral in Kyiv, churches and other buildings of the Kyiv-Pechersk Lavra, the Church of the Savior on Berestov in Kyiv, the Cathedral of the Savior and St. Elias Church in Chernihiv. It is worth noting that all masonry monuments of architecture before the Mongol era on the territory of Ukraine were built using lime-cement mortars, which by their nature and composition belong to artificial Roman mortars (concretes), which have good drying and hydraulic properties.

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Restoration work on objects of historical and cultural heritage is carried out in accordance with the Venice Charter, the Law of Ukraine "On the Ratification of the Convention for the Protection of the Architectural Heritage of Europe" dated September 20, 2006, in accordance with the Decree of the President of Ukraine No. 1647/2005 "On Priority Measures for the Enrichment and Development of Culture and Spirituality of Ukrainian Society", as well as in accordance with modern restoration norms. It is not allowed to make such additions to the monument that distort its authentic appearance. This creates certain difficulties in carrying out restoration works, since modern materials, firstly, must not disturb the authentic appearance of the monument, and secondly, the principle of reversibility applies to them, i.e. removal if necessary without disturbing authentic parts. Usually, restoration measures require moistened and salted areas of the walls, so drying renovation plasters are used there.

Excess capillary water and soluble chemically active salts (chlorides, sulfates and nitrates) are one of the main destructive factors of masonry and masonry mortars. During the existence of historical buildings, a significant amount of salt accumulates in the layers of materials, which, accordingly, causes chemical corrosion and destruction of these materials and, accordingly, elements of structures and decoration. On the other hand, increased humidity and salinity are interrelated factors, as one causes the other. The negative effect of their interaction is intensified by the temperature difference. This proves the importance of the problem of desalination and drainage of historical objects in restoration activities. One of the effective methods of solving this problem is the use of drying renovation plasters for moistened and/or salt-saturated historical masonry.

The purpose of this study is to present the component composition of the restored historical brick crumb plaster with modern drying and renovation properties for the restoration of architectural monuments of the 10th – 12th centuries in Ukraine.

Matherials and Methods

In accordance with the purpose and objectives of the research, the following general scientific research methods were chosen:

– the method of historical analysis (for the analysis of the original plasters of the pre-Mongolian period and existing publications on this topic);

– the method of comparative analysis (to evaluate the properties of plasters – historical and experimentally reproduced in laboratory conditions);

– experimental method – for conducting studies of plasters in laboratory conditions and on the basis of the conclusions obtained as a result, developing the optimal composition of drying renovation plasters.

In accordance with the purpose of the study, the following sources were used:

1) normative legislative framework [1];

2) the issue of preserving the authenticity of the historical and cultural environment [2, 3];

3) the basics of restoration activities and a description of the renovation and restoration of outstanding monuments of Ukraine [4 – 9];

4) problems of restoration of churches in post-totalitarian states [10];

5) specific restoration technologies to restore the structure and bearing capacity of historical objects [11 – 18];

6) artistic aspect in modern restoration activities [19 – 24];

7) the issue of professional training of restorers [25].

Studying the source base proved that there are a number of problems that are relevant for many countries in the case of restoration of architectural monuments, and one of these problems is the problem of desalination and removal of excess moisture.

Results and Discussion

The on-site examination of the ancient masonry and plasters of the ancient princely period conducted by the authors proved that they used brick crumb mortars, which are noted for their durability, which, in fact, led to the long existence of historical churches to this day (Fig. 1 and Table 1).

The question of the chemical composition of mortars from the time of Kyivan Rus has been of interest to researchers since the end of the 19th century: here it is worth mentioning the article by Academician V. Suslov in the journal "Zodchestvo" dated 1894, which is considered the first scientific work on the study of ancient masonry mortars of princely times. The peculiarity of his research was based on visual examination. In the first decades of the 20th century, the approach to the study of ancient mortars changed fundamentally: for example, the research of B. Shvetsov and V. Surovtsev in 1930 was based on chemical analysis and the study of the physical and mechanical properties of ancient mortars.

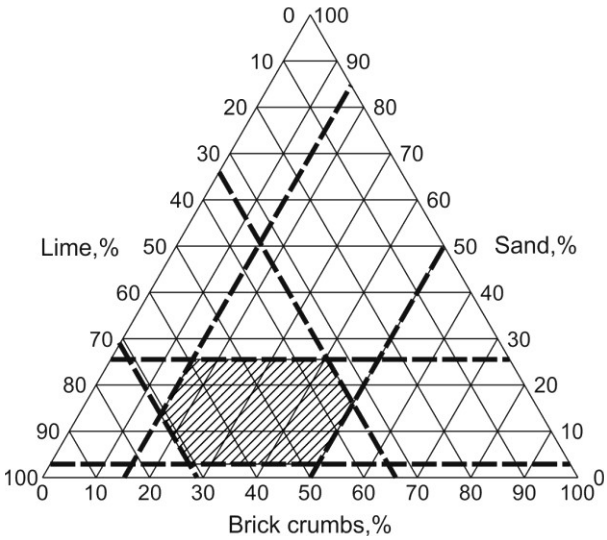

Fig. 1. The area of the component composition of the historical brick crumb mortar

The work of L. Papkova in the middle of the 20th century was a continuation of the research, the main achievement of which was the establishment of the ratio of the mortar components in terms of dry matter (air-slacked lime – 2 parts by mass, brick crumb – 1.5 parts by mass, sand – 2 parts by mass or binder – 2 parts by mass, aggregate – 3.5 parts by mass), which creates a ratio of 1:1.75.

The authors of the study analyzed the works of scientists regarding the specified ratio of components, including P. Rappoport, Yu. Strilenko, E. Miednikov, A. Pieskov, H. Ivakin, and L. Papkova. On the basis of these sources, it was established that the majority of scientists cite the following composition of brick crumb mortars of the ancient princely era of the 10th – 13th centuries: lime:aggregate = 1:0.5; 1:1; 1:1.5.

By the middle of the 19th century on the territory of Ukraine, such a concept as restoration was not used. That is why ordinary repair work was carried out on buildings that over time had a damaged plaster layer or masonry. The main purpose of such works is to protect the building structures from the environment and restore the original appearance of the building. In the process of carrying out repair work, ordinary lime-sand mortars were usually used, despite the fact that authentic mortars could have a completely different component composition and physical and mechanical parameters. With the appearance of cement, at the beginning of the 20th century, plaster mixtures based on it were widely used for the arrangement of plaster coatings in new construction and restoration of architectural monuments. After some time, this led to negative consequences, because the buildings that needed restoration were mostly built using lime mortars that had low compressive strength (0.32MPa), high porosity (31.5%), and low coefficient of resistance to water vapour diffusion (10.4). These mortars were incompatible with cement mortars, which, on the contrary, had high compressive strength (15MPa), low porosity (14.8%) and high coefficient of resistance to water vapour diffusion (30). The low compressive strength of brick walls made with lime mortars and the high strength of cement plasters disrupt the thermodynamic balance and create additional stresses. In most cases, this leads to the rejection of cement plasters with the destruction of masonry. The negative experience of using cement binders, in the middle of the 20th century, gave an impetus to limit their use during the construction of monuments built of bricks on lime mortars.

Table 1. Component composition of historical brick crumb mortars

No.	**Object of sampling**	**Ratio of mass weight parts of components, % * (by insoluble residue)**				**The amount of aggregate in mass fractions from the weight parts of lime = 1**			**The amount of aggregate in mass fractions from the weight parts of lime = 1**
		Lime	**Brick crumb**	**Sand**	**Clay**	**Brick crumb**	**Sand**	**Clay**	
1	Tithe Church in Kyiv	58.7	37.3	0.3	2.8	0.64	–	0.05	0.69
2	St. Sofia Cathedral in Kyiv	55.6	35.5	8.9	–	0.64	0.16	–	0.8
3		38.9	48.0	8.6	3.5	1.23	0.22	0.08	1.54
4	Golden Gate in Kyiv	38.2	50.7	9.6	1.4	1.33	0.25	0.03	1.62
5	Vydubytskyi Monastery in Kyiv	52.1	31.1	9.8	6.4	0.6	0.18	0.12	0.91
6		40.1	40.7	9.6	7.7	1.01	0.23	0.19	1.44
7	Assumption Cathedral in Kyiv	48.4	44.5	8.5	1.2	0.92	0.17	0.02	1.12
8	Trinity Church in Kyiv	48.4	43.5	6.5	1.6	0.9	0.13	0.03	1.07
9	Church of Archangel Michael in Kyiv	41.6	44.6	1.4	12.3	1.07	0.03	0.29	1.4
10	Church of the Savior on Berestov in Kyiv	54.5	20.3	2.8	21.5	0.37	0.05	0.39	0.82
11	Cathedral of the Savior in Chernihiv	34.3	46.5	10.6	5.2	1.36	0.3	0.15	1.82
12		61.8	31.4	–	6.8	0.51	–	0.11	0.62
13	Assumption Cathedral in Chernihiv	68.4	24.8	5.4	1.0	0.36	0.07	0.01	0.46
14	St. Elias Church in Chernihiv	72.2	16.7	–	11.1	0.23	–	0.15	0.38
15	St.Borys and St. Hlib Cathedral in Chernihiv	56.6	17.4	–	26.0	0.31	–	0.45	0.76
16	Bishop's Gate in Pereiaslav	63.0	29.8	–	6.6	0.47	–	0.1	0.57
17	St. Michael's Cathedral in Pereiaslav	55.1	32.9	2.7	9.8	0.6	0.04	0.17	0.81
18	Assumption Church on Podil in Kyiv	40.2	49.2	5.3	5.2	1.22	0.13	0.12	1.47
19	Church on Shchekavytsia in Kyiv	65.7	20.6	–	13.7	0.31	–	0.20	0.51
20	Gateway church of Vydubytskyi Monastery	63.4	21.3	–	14.0	0.34	–	0.22	0.56

* – the sum of mass fractions is not 100% according to the primary source [3].

In 1964, architects and technical specialists for historical monuments developed and adopted the Venice Charter, which regulates the activities of restorers throughout the world, and the European note WTA 2-2-91/D [26] regulates the requirements for the physical and mechanical parameters of restoration plasters (Table 2).

Table 2. Physico-mechanical parameters of renovation plaster

No.	Indicator name	Unit of measurement	Requirement
1	Porosity,Vp	%	> 45
2	Water vapour diffusion resistance coefficient, μ	–	< 12
3	Capillary water absorption,W24	kg/mm^2	> 0,3
4	Depth of water penetration, h	Mm	< 5
5	Compressive strength, Rcp	MPa	1.5 – 5
6	Strength of adhesion to the base, Rbf	MPa	> 0,4
7	Salt resistance	–	Resistant

The porosity of renovation plasters should be high (over 45%), the water vapour diffusion resistance coefficient should be low (less than 12), and the capillary permeability in the upper layer of such plaster should be significantly reduced due to the hydrophobic additive. This ensures the retention of salts in the plaster, while evaporating excess moisture through the upper layer (Fig. 2) [27]. Renovation plasters with drying properties are designed for a service life of 10 to 15 years, depending on the degree of moisture and salinity of the masonry.

Renovation plasters of European production have a complex composition based on cement, light fillers, polymer and mineral additives, which increases their cost tenfold compared to ordinary lime-sand plaster, while the applying technology remains traditional.

The results of research by I. Znachko-Yavorskyi and L. Papkova regarding the physical and mechanical properties of ancient princely mortars were analyzed separately. The analyzed data was presented in tabular form.

The experimental part of the presented research consisted of the following. In the laboratory, samples of brick crumb mortar were made according to the historical recipe – lime: brick crumb:sand = 1:0.64:0.16; 1:1.23:0.31; 1:1.35:0.46, from modern materials, to study their physical and mechanical properties and compare them with the properties of historical mortars (Table 3).

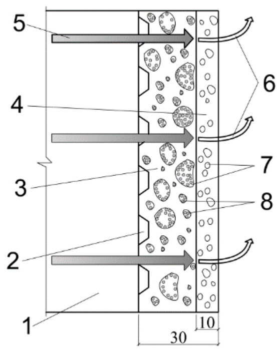

Fig. 2. Design scheme and principle of operation of drying renovation plaster:
1 – base; 2 – contact layer; 3 – salt-accumulating porous layer; 4 – evaporation layer;
5 – movement of aqueous salt solution; 6 – evaporation of water;
7 – pores; 8 – accumulation of salt in the pores

During the experimental testing of solutions made according to the historical recipe, the following components were used in the ratio of parts: lime dough with a density of 1,300kg/m^3 and a moisture content of 66%; fine-grained sand with a bulk density of 1,540kg/m^3, a coarseness modulus of 1.36, and a moisture content of 21%; brick crumb for mortar is made by crushing yellow brick (fired at a temperature of 1,100ºC from clays of the second horizon, Krenychanske deposit, Kyiv region) with a water absorption of 25%, with a granulometric composition given in the Table 4.

Table 3. Physico-mechanical properties of the historical mortar and the one reproduced from modern materials

No.	Place of sampling	Volumetric weight, g/cm³	Water absorption, %	Porosity by water absorption, %	Porosity by WTA, %	Compressive strength, MPa
1	Golden Gate in Kyiv	1.58	24.4	38.6	–	9.8
2	St. Sofia Cathedral in Kyiv	1.55	22.9	25.5	–	7.06
3	Assumption Cathedral in Kyiv	1.53	20.2	37.3	–	7.3
	Average values	1.55	22.5	37.1	–	8.05
4	Made by us using a historical recipe	1.39	26.4	36.6	44.18	0.89
	The value of the modern mortar properties as a percentage of the historical one	89.7 %	117.3 %	98.6 %	–	11 %

Table 4. Granulometric composition of brick crumb, which we used in the experiment

Residues on the sieves, in percent by mass, with the size (in mm) of the sieve cells												
<0.063	0.063	0.125	0.20	0.25	0.355	0.5	1.0	1.4	1.6	2.5	3.0	4.0
20.55	5.3	8.75	1.4	6.73	8.35	18.35	11.35	4.0	9.35	1.2	2.54	0.75

The data shown in Table 3 proved that all the given characteristics of the mortars, except for strength, are practically the same, but the compressive strength of the samples from the modern mortar is 9 times lower than the strength of the historical samples and is only 11%. It should be noted that the high strength of historical plasters can be acquired during a long period of resistance, that is, it increased over time. It was concluded that during the restoration of historical plasters, it is not necessary to use a mortar with a strength of about 8MPa, because, for example, WTA recommends a minimum strength of 1.5MPa for plaster mortar, which is only 1.7 times higher than the existing one, and for laying massive thick walls, in many cases, a strength of 0.89 MPa can be sufficient.

As a result of the conducted experimental research, it was established that the porosity of the reconstituted plaster was determined by the method recommended by WTA (using isopropanol and vacuum). As can be seen from Table 2, the porosity of the restored plaster is slightly lower (44.18%) than the recommended one (>45%).

We note the following feature of the principle of action of renovation plasters. The accumulation of salts in the lower layers of plaster frees ancient masonry from an excessive amount of harmful salts and prevents them, due to the reduced capillary conductivity of water, from reaching the surface, causing corrosion and destruction of building materials. The upper layers of renovation plasters carry out intense (much higher than usual) evaporation and thereby ensure a significant reduction in the moisture of the masonry and prevent the areas above it from becoming clogged. Due to its reduced capillary water conductivity (hydrophobicity), the upper layer prevents the penetration of atmospheric moisture from the outside. Thus, renovation plasters are not closing systems, they serve to normalize (restore) the state of masonry and are conservation systems according to their functional tasks.

Therefore, drying renovation plasters have specific properties aimed at keeping structures dry and desalting masonry: high porosity (at least 40% /45% for renovation layers) of the plaster volume (determined by isopropanol in a vacuum) and vapour permeability (vapour diffusion resistance coefficient water – no more than 18, and for renovation layers – no more than 12), as well as a combination of hydrophilic and hydrophobic layers.

As a rule, the set strength of drying renovation plasters takes place in wet conditions, and therefore the binder must be sufficiently hydraulic and resistant to the action of salts, like all system components. At the same time, they should also be frost-resistant and strong enough to withstand pressure and dynamic loads. That is why the existing drying renovation systems are prepared on a cement or lime-cement binder, which is quite satisfactory for masonry with a cement binder and is far from always suitable for historical masonry. Such plasters are especially dissonant for monuments of the pre-Mongol period, which were built on a lime-brick crumb mortar. Therefore, the transition to drying renovation systems based on lime-brick crumb mortars (or at least cement-lime-brick crumb mortars), which by their nature are close to historical materials (and in their essence can be considered restoration materials), is an urgent task of applied restoration.

In the course of further research, it was discovered that during the production of samples in laboratory forms, the samples had a normal appearance, while on the plaster applied from such a mixture on a brick wall, after a few days, cracks with different width and depth of opening were formed. Based on this, all further research was directed to the formation of the component composition of the brick crumb plaster, which will not crack when applied to the base and will gain strength in wet conditions and on wet surfaces. That is why a small percentage of cement binder was introduced into the component composition, which made it possible to increase the strength of the plaster and slightly increase the crack resistance.

Therefore, further research was carried out with the following component composition of brick crumb mortar: 0.8 weight part of lime; 0.2 weight part of cement; 1.5 weight part of brick crumb. This composition was adopted because of the 20 considered historical component compositions, 19 have less than 10% of the weight part of sand, and 10 have 5...0% of the weight part of sand, i.e., on the territory of Ukraine, there are different brick crumb mortars – with and without the addition of sand.

It is known that cracks in hardened plaster are formed due to an excess of binder or moisture in the mortar. Since the amount of binder in the mortar cannot be changed, in further studies the amount of water was reduced by 50%, and to ensure the fluidity of the mortar of 9 cm, the powder superplasticizer Melflux 2651F was introduced into it in the volume of 0.3 and 0.4% from the weight of the binder. The mixture prepared by this method was applied to the brick base. An examination conducted after 24 hours showed that there were cracks in the plaster layer.

From the analysis of the scientific literature, it was established that to reduce the shrinkage of mortars, it is possible to replace a certain part of the lime dough, which is part of the brick crumb mortar mixture, with quicklime.

To study the effect of quicklime on the elimination of shrinkage cracks in plaster, four different plaster mixtures of the adopted composition were prepared. In these mixtures, lime dough in the amount of 0.8 weight part partially, in a volume of 10; 20; 30; 40% was replaced with quicklime. The composition of plaster mixtures – lime-dough : quicklime : cement : brick crumb in mass fractions was as follows:

1) 0.72 : 0.08 : 0.2 : 1.5;
2) 0.64 : 0.16 : 0.2 : 1.5;
3) 0.56 : 0.24 : 0.2 : 1.5;
4) 0.48 : 0.32 : 0.2 : 1.5.

Plaster mixtures were applied to the brick base and inspected after a day. The number of cracks in the samples decreased with an increase in quicklime in the plaster, but all samples had cracks (Table 5).

Table 5. Characteristics of cracks in plaster samples when replacing lime dough with quicklime

Parameters of cracks in plaster	Value of the cracks' parameters with the amount of quicklime in the plaster mixture in percentages:				
	without additive	10 %	20 %	30 %	40 %
Width, mm	3	3	2 – 3	2	1 – 2
Total length, mm	660	655	580	525	430

Taking into account the recommendations of scientific literature, a decision was made to replace all lime-dough in the component composition of brick crumb plaster with quicklime and to add gypsum dihydrate as a retarder of lime quenching.

In our opinion, the presence of quicklime will increase the temperature of the plaster mixture due to lime slaking, therefore it will increase the rate of creation of the plaster structure and it will not show shrinkage deformations, and the slaking retarder will somewhat slow down the release of heat and prevent destructive thermal expansion.

In the future, the effect of the amount of gypsum in the plaster cement mixture on the presence of cracks on layered plasters after 24 hours of its hardening was investigated. For this, gypsum was introduced into the composition of the plaster mixture instead of quicklime in the amount of 5; 15; 17% of the initial total weight part of lime. So, the composition of the experimental mixtures in the experiments was as follows:

No.1. 0.76 : 0.04 : 0.2 : 1.5; No.2. 0.68 : 0.12 : 0.2 : 1.5; No. 3. 0.66 : 0.14 : 0.2 : 1.5.

Plaster mixtures with a fluidity of 9cm of cone sediments with different amounts of gypsum were applied by smearing on a brick base with a moisture content of 12%. After 24 hours, the plaster was examined through a magnifying glass. The composition, which contained 17% gypsum instead of quicklime, had the least number of short cracks less than 0.7mm thick.

Based on the recommendations of quicklime researchers, we performed a test experiment with the addition of water to the plaster mixture of composition No. 3, at which the fluidity of the plaster mixture was 16cm.

For the production of laboratory samples of the plaster layer, bricks were placed on the work table with a base measuring 250 x 120mm. A plastic shell with a 30 mm protrusion above the brick was attached to the side face of the brick, and the prepared plaster mixture was poured into the created volume above the bricks. Cracks did not appear on the surface of the samples for 28 days. After 28 days of hardening at a temperature of +20°C and air humidity of 50÷65%, samples were cut from the samples of the layer on the bricks to determine the porosity and coefficient of resistance to the diffusion of water vapour, according to the WTA method, and to determine the compressive strength of the plaster according to the method of DSTU B V.2.7-239:2010.

Studies have shown (Table 6) that the strength of the plaster has dropped to 1.48 MPa, which is 1.35% less than the minimum recommended WTA of 1.5MPa. The porosity of the plaster increased to 48.4%, with a recommended WTA of 45%.

Table 6. The main physical and mechanical parameters of brick crumb plaster made from a soluble mixture with a fluidity of 16 cm

No.	Indicator name	Base dimension	Indicator value	
			According to the results of the experiment	According to the requirements of the norms
1	Compressive strength	MPa	1.48	1.5 – 5.0
2	Porosity	%	48.4	>45
3	Water vapour diffusion resistance coefficient	–	5.5	<12

The water vapour diffusion resistance coefficient remains less than 12 – the recommended value by WTA.

Such changes in the physical and mechanical parameters of the brick crumb plaster can be explained by the fact that during the hardening of the plaster, water evaporates and forms cavities, thereby increasing the porosity and reducing the strength of the plaster.

To increase the strength of the plaster, the dependences of the compressive strength, porosity, and coefficient of resistance to water vapour diffusion of tsemyan plaster on the amount of cement additive in the binder were investigated. The amount of lime decreased by such a weight part as the amount of cement increased.

In laboratory conditions, 4 series of brick crumb plaster samples with different amounts of cement as a binder (20%; 30%; 40%; 50%) were made from a plaster mixture with a fluidity of 16 cm.

The component composition of the plaster mixture in these series was as follows (quick lime : gypsum : cement : brick crumb):

Series No.1 0.664 : 0.136 : 0.2 : 1.5;
Series No.2 0.581 : 0.119 : 0.3 : 1.5;
Series No.3 0.498 : 0.102 : 0.4 : 1.5;
Series No.4 0.415 : 0.085 : 0.5 : 1.5.

After 28 days of hardening, compressive strength, porosity, coefficient of resistance to water vapour diffusion and the presence of cracks were determined in the samples. The results of the research are given in Table 7 and Figure 3.

Table 7. Change in the parameters of brick crumb plaster made by casting when increasing the cement in its composition

No.	No. series of experiments	Compressive strength, MPa	Porosity, %	Water vapour diffusion resistance coefficient	Cracks, mm
1	No.1, 20% of cement	1.48	48.4	5.5	absent
2	No.2, 30 % of cement	1.98	48.5	5.8	absent
3	No.3, 40 % of cement	2.22	47.9	6.1	absent
4	No.4, 50 % of cement	2.61	46.1	6.7	0,1-0,3
5	WTA information letter	1.5 – 5	>45	<12	absent

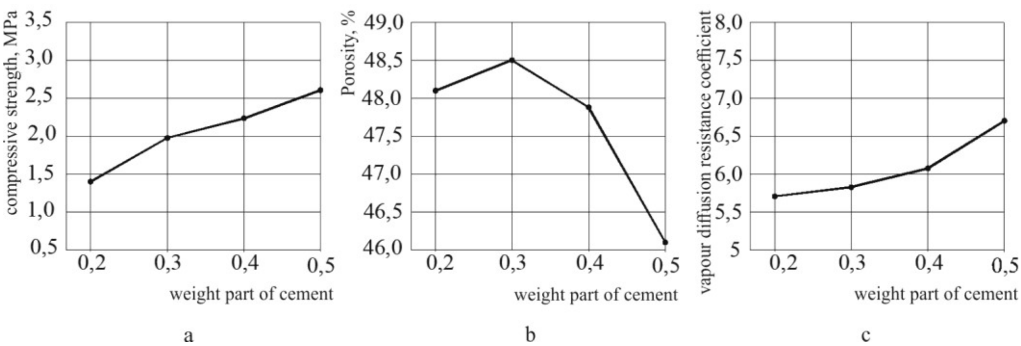

Fig. 3. Graphs of changes in the main parameters of the brick crumb plaster with an increase in the cement in its composition: a – strength, b – porosity, c – water vapour diffusion resistance coefficient

Studies have shown (Table 7 and Fig. 3a) that the strength of the plaster increases almost linearly with an increase in the weight part of cement in the plaster and reaches a value of 1.98 MPa when the amount of cement in the solution is 0.3 weight part of the total amount of binder.

The porosity of the plaster when replacing part of the lime with cement increases slightly (Fig. 3b) with a weight part of 0.3 to 48.5%, and then decreases and with an increase in the weight part of cement to 0.5 reaches 46.1%. In all experiments, the porosity is greater than 45%, which satisfies the WTA recommendations.

The water vapour diffusion resistance coefficient ranges from 5.8 to 6.7 (Fig. 3c), and remains less than 12 – the recommended by WTA.

Therefore, according to the results of a large volume of experimental research, a plaster mixture with a fluidity of 16 cm with a component composition of: quicklime – 0.581 parts by mass, two-water gypsum dihydrate – 0.119 parts by mass, cement – 0.3 parts by mass, brick crumb – 1.5 parts by mass.

The necessary physico-mechanical parameters of brick crumb drying renovation plaster mortars (compressive strength more than 1.5MPa, porosity more than 45%, water vapour diffusion resistance less than 12) are achieved both by the component composition of the plaster mixture and by the technological factor – a high water-binding ratio. At the same time, in future studies of the technology of performing works with the installation of restoration brick crumb plasters, it is necessary to take into account the need to perform a number of preparatory works and take into account the condition of the base [28 – 30].

The results of the research work were put into production during the restoration work on the St. Elias Church of the National Architectural and Historical Reserve “Ancient Chernihiv”. Work was carried out on furnishing the inner part of the altar wall, which was wet and salted (Fig. 4).

Fig. 4. St. Elias Church in Chernihiv, where the results of the study were implemented during the plastering of the altar

Conclusions

Research of the component composition of authentic brick crumb plasters of the 10th – 12th centuries and their reproduction in laboratory conditions proved that the physical and mechanical parameters of the reproduced historical brick crumb plaster made of modern materials do not meet today's requirements for their use as restorative materials. They have low strength (0.89MPa versus 1.5MPa) and insufficient porosity (44.18% versus >45%). In this regard, a complex of laboratory studies aimed at minor modification of the historical plaster was performed to obtain the specified physical and mechanical parameters of the restoration plaster with rehabilitation properties.

According to the results of a large volume of experimental research, a plaster mixture with a fluidity of 16 cm with a component composition of: quicklime – 0.581 parts by mass, gypsum dihydrate – 0.119 parts by mass, cement – 0.3 parts by mass, brick crumb – 1.5 parts by mass.

The necessary physico-mechanical parameters of brick crumb restoration plaster mortars (compressive strength more than 1.5 MPa, porosity more than 45%, water vapour diffusion resistance less than 12) are achieved both by the component composition of the plaster mixture and by the technological factor – a high water-binding ratio.

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