

RESEARCH AND DEVELOPMENT OF CERAMIC COMPOSITIONS FOR BUILDING MATERIALS OF HISTORICAL AND ARCHITECTURAL MONUMENTS

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Abstract - Preservation of the exterior and interior of historical buildings built of ceramic bricks in ancient cities around the world is a pressing problem. When restoring historical monuments, it is important to study the building materials used in their construction, not only to open the pages of the history of material culture, but also to take into account the many years of experience of ancient masters in using local raw materials and restoration technologies. This article presents the results of a study on the development of ceramic compositions based on local loess loam and the proposal of a new method of mass processing for the study and repair of building materials for historical architectural monuments. The focus is on the composition of natural local raw materials, mechanical strength, resistance to humid and alkaline environments, and compatibility with historical materials.

Keywords: Historical buildings, Historical building materials, Kilns, Historical building bricks, Loess-like loam, Plastic mass.

1. Introduction

The issues of preservation and use of historical and architectural monuments in the world have been a topic that requires attention to this day. Therefore, the authors' research paper provides information that out of 1007 objects included in the List of World Heritage Sites located in 413 ancient cities at the initiative of UNESCO, 779 are architectural monuments [1].

The Convention concerning the Protection of the World Cultural and Natural Heritage (1972) is a document developed by authoritative organizations such as the UN, UNESCO, and ICOMOS to preserve cultural heritage and pass it on to future generations; International Party for the Protection of Historic Towns (Washington Charter, 1987); Basic Rules for the Registration of Monuments, Groups of Buildings and Places of Interest (1996); Basic Rules for the Analysis, Conservation and Restoration of the Architectural Heritage (2003); Information on international documents such as the Xi'an Declaration (2005) on the preservation of the surroundings of ruins of structures and objects

considered cultural heritage is presented in the following work [2].

This study is devoted to the research of the development of ceramic masses for the production of ceramic bricks based on loess-like sandstones obtained from the Yarmish deposit and waste generated during the production process by "Khorezm Sugar" LLC, physical and chemical processes during firing by introducing recycled loess-like sandy soil components, ceramic brick powder, and carbonaceous components into the brick mass as internal combustion components. Technological firing regimes have been determined. The optimal composition of special ceramic bricks and coatings based on local raw materials and technogenic waste for inorganic parts of cultural heritage sites has been developed [3].

Architectural monuments are subject to damage and deterioration due to time and external environmental influences - the environment, weather, natural disasters, such as the fall of artistic decorations, the erosion of tiles, the opening of cracks, and the impact of groundwater. Therefore, taking measures to prevent natural damage to

cultural heritage sites is currently one of the most urgent problems that requires attention [4].

In particular, little attention has been paid to the structure, properties and production technologies of structural and decorative materials of historical monuments, insufficient information on historical materials and ancient technologies of their production, little attention has been paid to the problem, the study of the structure, properties and production processes of traditional materials and the creation of production technologies for materials, items and parts similar to the original have not been sufficiently studied, which indicates that they require more extensive research [5].

In a scientific study aimed at studying the properties of existing historic brick wall buildings through the microstructural and mineralogical characterization of historic brick binders used in five monuments located in northeastern Poland, the composition of the binder, in addition to the historic brick, was also investigated. The properties of the binders used for historical monuments, such as mineralogical analysis, water absorption, and capillary absorption coefficient, were carried out through laboratory tests. The results of the study were investigated to identify similarities and differences between the binders of buildings of great historical importance from the Middle Ages and Baroque periods, and certain groups of repair binders currently produced. The results of this study contribute to the assessment of the compatibility of repair materials with historically used materials in terms of moisture content, microstructure, mineralogical composition, and mechanical properties in order to achieve successful restoration work [6].

Historical and architectural buildings represent the three-dimensional expression of civilization, culture, and development of different historical periods. Repair work in such structures should reach a level that preserves the value of the parameters related to the criteria arising from the historical content and the requirements of durability and stability. National and international regulations (e.g., UNESCO conventions) play an important role in strengthening heritage. These frameworks set standards for conservation practices and promote the importance of protecting historical heritage, which is an expression of cultural identity and the history of a society.

The research results presented in the article refer to the example of the Costache Conachi Manor building, classified as a historical monument, located in Galați County, Romania. The studies relate to the processes and methods used to determine the current state of the building, including the structural aspect and the materials used, ensuring that the originality is preserved and that the restoration work is compatible with each other.

Overall, these research methods not only help to accurately analyze the materials used in the historic Costache Conachi Manor structure, but also play an important role in advancing knowledge about restoration and conservation practices [7].

The protection of historic buildings of great importance in the fields of art, architecture, history, and culture ensures the preservation of cultural heritage and at the same time protects the common past of humanity. Proper material selection and appropriate implementation methods are essential to preserving the aesthetic and structural integrity of historic structures and ensuring their survival for future generations. Studying the composition and properties of these materials is crucial for making the right material selection in restoration processes. This research work aims to provide a detailed assessment of analytical methods used in the characterization of historical building materials and to summarize existing findings in the literature in a coherent manner. At the same time, it aims to guide researchers in the field in choosing a methodology by revealing the strengths and limitations of these techniques. In this context, the objectives of the methods used to determine the properties of historical building materials, the processes of sampling and preparing materials for testing, the characteristics of the devices used in the tests, as well as the analysis results of the samples obtained and the methods for their evaluation were considered [8].

Despite ongoing conservation and preservation efforts for historic buildings in Sindh, the use of unsuitable repair materials has significantly exacerbated the deterioration of historic structures, an example of this is the Makli Necropolis, a UNESCO World Heritage Site. This research study investigated several modern materials as alternatives to traditional repair materials. However, since their compatibility with historic bricks has not been sufficiently studied, a comprehensive assessment of repair-substrate compatibility has been identified as a prerequisite for developing effective and durable restoration strategies. It was noted that such an assessment provided a reliable basis for identifying potential repair materials that were closely related to historical substrates. Samples of three leading components, namely lime, gypsum, and brick, were taken for analysis, and their physical, mechanical, chemical, mineralogical, and microstructural properties were studied [9].

This research study presents the use of natural stone, as well as ceramic and faience products made of clay, in cladding new buildings for the period under review, in which the stone surface is decorated with patterns, cut along the lines of these patterns, and finished with ribbon-shaped glazed ceramics [10].

Architectural heritage protection is aimed at preserving historic buildings, while also ensuring environmental sustainability. This includes the use of environmentally friendly materials and methods to ensure that the cultural value of the structures is preserved and their environmental impact is minimized [11].

This paper presents the use of hydroxyapatite (HAp) in brick samples in different combinations, with the aim of identifying the ideal solution to be applied to the entire historic building at the Banloc monument. The research work developed and presented an innovative approach involving the addition of hydroxyapatite to the binder composition. At the same time, the physicochemical, mechanical, architectural, and economic principles of materials were considered [12].

A number of researchers have developed composite materials for the production of ceramic bricks based on loess-like rocks from the Suzanli deposit and waste produced by Khorezm Sugar LLC, and at the same time studied the physical and chemical processes during firing by introducing amorphous silicon and calcium-containing waste into the brick mass as defects.

Technological burning modes have been determined. For the inorganic parts of cultural heritage sites, it was envisaged to develop special ceramic bricks and an optimal composition of bricks based on local raw materials and technogenic waste [13].

Taking into account the above, we set the goal of this research work to study the construction materials, composition, and processing methods of some historical buildings.

2. Materials and Methods

Data on the physical and chemical properties and appearance of ceramic tiles used in the construction of some historical monuments are presented in the works of the following authors [6, 7]. The building materials of some ancient monuments located in Uzbekistan were studied. When studying the building materials of ancient architectural monuments, mainly in the Tashkent, Samarkand, Bukhara, and Khorezm regions, it was found that their composition is mainly products made on the basis of clay raw materials. The results of the study are presented in Table 1.

Table 1. Results of research on building brick samples from historical monuments

№	Composition	ρ , kg/sm ³	W _{absorb.} , %	Mechanical strength limit			Cold resistance, F, cycle	Appearance
				δ_{comp} , MPa	R _{bend} , MPa	R _{fric} , kg/sm ²		
1	X _{aver} (Khiva)	2045	12,60	11,5	11,51	0,21	16	Yellow-red
2	B _{aver} (Bukhoro city)	1850	10.61	14.4	10.22	0.048	16	Yellow-red
3	S _{aver} (Samarkand)	1780	11.04	13.6	9.96	0.082	15	Yellow-red
4	T _{aver} (Toshkent)	1710	11.02	12.5	9.23	0.045	14	Yellowish in color

The scientific significance of the research results is explained by the determination of the process of formation of white spots and the formation of the composition structure in building bricks in historical monuments and for their renovation, as well as the effect of changes in the composition on their physical and mechanical properties and quality indicators.

The practical significance of the research results is that they will help to adopt the right solutions in renovation projects of historical buildings, to correctly select building bricks for the renovation of historical buildings based on local raw materials, depending on the place of use, and to prepare and use compositions.

In carrying out the research work, the objects of the research were easily liquefied local loam,

hydromechanically activated plasticized binder (HAPB), and building bricks obtained on their basis.

3. Results and Discussion

Today, a number of environmental problems are significantly affecting the change in soil composition. The increase in the amount of Sa⁺² salts in the soil and the fact that a certain amount of it remains completely unreacted during the burning process negatively affects the quality of the product [6, 7]. The use of building materials made from clayey raw materials of such composition in the reconstruction of historical monuments poses a number of problems.

Initial analysis of samples taken from the mine for research showed that the samples were light gray in color and were hand-crushed. It foams when

exposed to a 10% by weight hydrochloric acid solution. This indicates the presence of carbonate salts in its composition.

Table 2. Comparative data on the technological properties of some local loams

Properties	Local soil of the Khirmontepa mine [6, 7]	Local soil of the Karauzak mine [6, 7]	Local soil of the Yarmish mine [6, 7]
According to the amount of alumina after firing	Sour	Semi-sour	Sour
Type by the amount of finely dispersed fraction	Coarse dispersion	Coarse dispersion	Coarse dispersion
Type according to the mineralogical composition of the clayey part	Hydrolyzed	Hydrolyzed	Hydrolyzed
By plasticity	Less plastic	Standardized plastic	Less plastic
Sensitivity to drying (Chijskiy method)	Low sensitivity	Low sensitivity	Low sensitivity

Judging by the amount of finely dispersed particles, this type of raw material belongs to the type of coarsely dispersed clay raw materials. According to the results obtained, depending on the amount of Al₂O₃ in the raw material, the sample belongs to the group of sour clay raw materials, and according to the amount of TiO₂ and Fe₂O₃, to the group of coloring raw materials.

standards. The average content of Al₂O₃ in the raw materials used in the experiments is 12.5%.

This amount is not enough to produce quality building bricks. The amount of CaO is also significantly higher than the established standards, which may not allow for the production of quality bricks.

The results of the study of the granulometric composition of raw materials based on the data provided in GOST 9169-2021, GOST 21216. (0-12) - 2014, GOST 2642.0-2014 and GOST 21-78-88-2012 are presented in Table 3.

According to the experimental results, the amount of particles with a size of 0.063–0.01 mm in the raw material is predominant (43.88%), the share of particles in the range of 0.01–0.001 mm is 35.19%, and the amount of particles smaller than 0.001 mm is 19.34%.

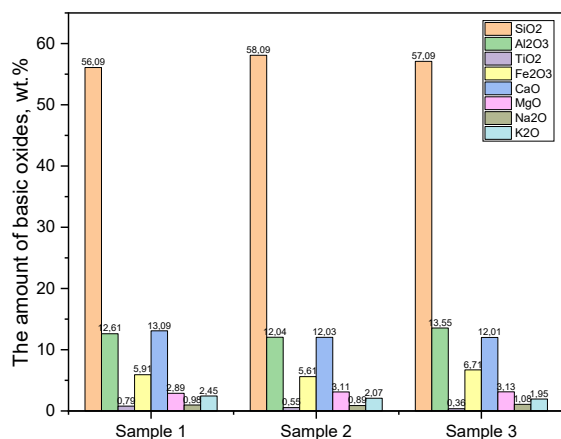


Figure 1: Chemical composition of local easily liquefied sandy loam soil

The determination of the chemical composition of raw materials was carried out in accordance with the standard method GOST 9169-2021, GOST 21216. (0-12) -2014, GOST 2642.0-2014 and GOST 21-78-88-2012 and on the basis of state standards introduced in the CIS countries and using previously known traditional methods [8-11].

It is known from the chemical analysis of the raw material (Figure 1) that the average SiO₂ content in it is 57.08 mass %. According to sources [12, 13], to obtain high-quality building bricks, the amount of SiO₂ in the raw material must be limited to certain

Table 3. Granulometric composition of the local easily liquefied sandy loam soil

Disperse particle size, mm	Percentage of raw material content, mass. %
1,0-0,063	1,59
0,063-0,01	43,88
0,01-0,005	16,23
0,005-0,001	18,96
Less than 0.001	19,34
Total:	100

The mineralogical composition of the raw material samples determined in the research work is presented in Figure 2. (GOST 9169-2021, GOST 21216.(0-12) -2014, GOST 2642.0-2014 va OST 21-78-88-2012).

According to the results obtained, the content of quartz mineral in the raw material is relatively

dominant, up to 29 wt.%. It was noted that the content of hydrous clay is up to 26 wt.%, the content of kaolinite and montmorillonite is small, and the content of feldspar minerals is up to 15 wt.%.

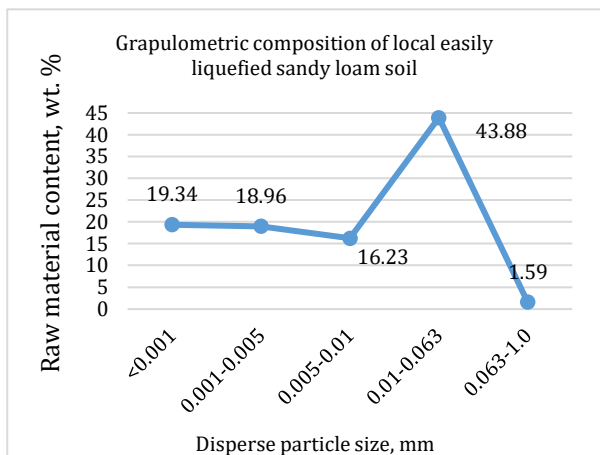


Figure 2: Mineralogical composition of local easily liquefied sandy loam soil

X-ray phase analysis of the raw material confirmed these results, indicating the presence of these minerals, as diffraction line values corresponding to quartz ($d/n=0.181; 0.197; 0.211; 0.240; 0.334; 0.423$ nm), gypsum ($d/n=0.185$ nm), hydromica ($d/n=0.202; 0.225; 0.287; 0.317; 0.353; 0.367$ nm), kaolinite ($d/n=0.238; 0.420$ nm), and montmorillonite ($d/n=0.308$ nm) were recorded (Figure 3).

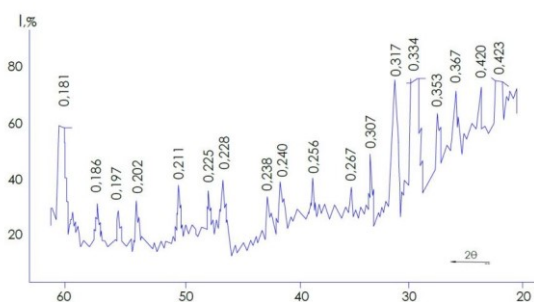


Figure 3: Diffractogram of the local loamy soil of easily liquefied sandy loam

Differential thermal analysis of local soil showed the presence of a number of endo- and exo-effects [14]. In this case, the endothermic effect at a temperature of 90 °C corresponds to the evaporation of hygroscopic moisture in the sample, while the exothermic effect at a temperature of 325 °C occurs as a result of the combustion of organic compounds in the sample. The small endothermic effect that appears in the thermal curve at a temperature of 560 °C is due to the evaporation of crystallization water in the sample, while the exothermic effect that

appears at temperatures of 840–890 °C is due to the decomposition of calcium carbonate salt. It is known that the low plasticity index of the mass based on easily liquefied local clay in the production of high-quality building bricks leads to a number of difficulties and defects in the molding process [12]. The occurrence of a large number of defects during the molding process is due to the fact that the mass composition consists of coarsely dispersed systems and the low plasticity of the initial raw material, and its prevention directly implies the importance of increasing the dispersion level of the mass and ensuring the uniformity of its fractional composition, as well as increasing its plasticity [7,15-17]. The essence of using colloidal chemical technologies in the production of high-quality building bricks is that when the particle size of the mass increases and the mass has the same granulometric composition when molded, the arrangement of the clay grains in it relative to each other is optimized, the speed of the physicochemical processes occurring during the firing process is the same, and the chemical interaction of the components and the formation of new compounds are accelerated [16].

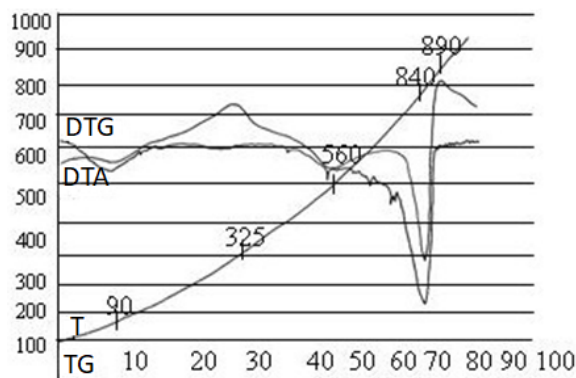


Figure 4: Derivatogram of local (Kushkupir district, Khorezm region) easily liquefied sandy loam soil

The results of the study show that the composition of the local, widely distributed, easily liquefied sandy loam soil is significantly different from the composition of the soil used to build ancient monuments (Figure 4). Building bricks produced on the basis of such soil are not considered suitable for the repair of historical monuments. The literature does not contain much information on the preparation of a hydromechanically activated plasticized binder (HAPB) based on local soil to bring the composition of building bricks into line with the composition used in ancient historical monuments and its use in technological processes. It is known that water is usually used as a wetting agent in brick molding. However, some sources [7, 18] have reported that the use of a clay-based suspension in brick molding leads to positive results, which necessitated the study of the possibility of preparing GAPB based on local clay and using its

suspension as a wetting agent in the brick molding process.

In the research work, using the decantation method, local loam soil was immersed in water in a ratio of 1:5 and left to settle for 2 days. The water in the upper part of the aqueous solution, which was divided into three parts, was first separated using

pumps, and then the hydromechanically activated plastic mass was separated. A series of physicochemical analyses was carried out to study the changes in the properties of building bricks when a certain amount of GAPB was added to the ceramic mass. The results of the obtained chemical analyses are presented in Table 4.

Table 4. Chemical composition of hydromechanically activated plasticized binder

Composition, mass. %									
Nº	SiO ₂	Fe ₂ O ₃	TiO ₂	Al ₂ O ₃	CaO	MgO	K ₂ O	Na ₂ O	the remaining
1	50,06	4,17	0,42	19,02	11,30	2,83	1,12	0,59	10,49
2	49,87	4,36	0,36	19,08	11,36	2,77	1,10	0,61	10,49
3	50,07	4,16	0,39	19,05	11,48	2,65	0,96	0,75	10,49
Aver.	50,01	4,22	0,39	19,05	11,38	2,75	1,06	0,65	10,49

The data presented in Table 5 on the analysis of the mineralogical composition of the samples, compared with the data presented in Table 3, showed that the amount of clay minerals - montmorillonite, hydromica, illite - in its mineralogical composition increased relatively, and

the amount of minerals such as quartz, calcite, and feldspar decreased. It was found that the amount of mineral salts in the raw material also decreased slightly under the influence of hydromechanical activation [19-20].

Table 5. Mineralogical composition of hydromechanically activated plasticized binder

Nº	Mineral content, mas. %					
	Clay minerals	Feldspar	Quartz	Dolomite	Calcite	Chloride
1	58,10	7,5	24,4	4,5	4,0	1,5
2	57,01	6,2	23,1	5,7	5,1	0,9
3	56,23	5,8	26,0	4,2	3,5	1,2

Granulometric analysis of samples activated by the hydromechanical method showed that this type of raw material belongs to the finely dispersed group of materials (table 6). According to the data obtained as a result of analyzing the electron microscope images of the samples and comparing them with the

images of the main raw material, the electron microscope image of the binder obtained based on the local clay soil presented in Figure 5(b) shows a relatively increased number of particles in the form of a layer, an island, which is associated with an increased amount of clay minerals in it [21-24].

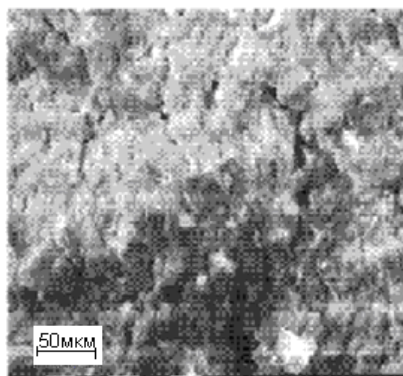
Table 6. Granulometric composition of hydromechanically activated plasticized binder

Nº	Amount of fractions, mm (%)							Clayey part, %	Dispersion level, %
	Clayey part			Dust		Sand			
	< 0,01	0,005-1,0	<0,001	0,1-0,05	0,05-0,01	0,5-0,25	0,25-0,1		
1	26,12	12,21	30,73	0,20	32,54	0,05	0,05	67,16	45,7
2	31,15	13,86	27,65	0,04	27,26	0,02	0,02	72,66	38,0
Avr.	28,63	13,03	29,19	0,24	29,90	0,035	0,035	69,91	41,85

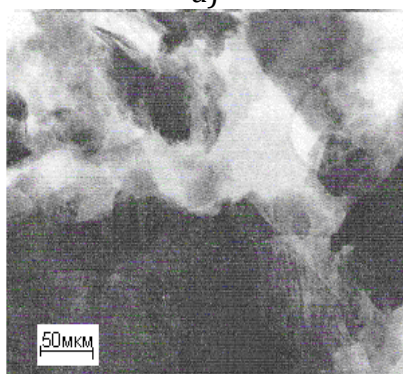
It is reported in [12] that hydromechanical activation of a binder obtained from local clay soil, when carried out by means of pulsating mixing in a strong flow, can yield significant positive results. We also used this method in our research, conducting experiments using a mixer with a rotation frequency of 1500 rpm. To create a strong flow pulsation, we carried out the mixing in a continuous cycle of "mixing-stop-mixing", "5 min-3 min-5 min".

As a result, the mass was crushed to a very fine powder due to the impact of the walls of the container and the blades of the mixer.

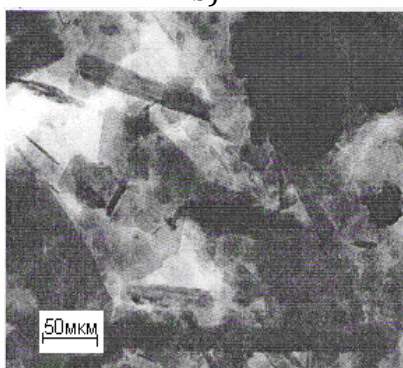
According to the electron microscopic analysis of the obtained sample, shown in Figure 5, the sample contains a significantly increased amount of needle-shaped, rhombic particles.



a)



b)



c)

Figure 5: Electron microscope image of a hydromechanically activated plasticized binder. a – image of the original raw material, b – image of a hydraulically separated sample; v– Image of the sample after hydromechanical activation

According to the results of a study conducted on the technological properties of the samples, the fire resistance of this raw material is 1100 °C, plasticity is 7.4, the coefficient of sensitivity to drying is 180 s, the mechanical strength in compression is 2.11 MPa, and the average density is 1425 kg/m³.

The main technological idea of mechanically activating local clay is to achieve a change in its properties and improve the macrostructure of the mass by using the binder obtained from it in the process of molding the product (Figure 6). Improving the rheological properties of the molding mass requires increasing the amount of colloidal compounds in its composition. For this purpose, a

suspension was prepared based on local sod soil. For this purpose, local sod soil was dissolved in water in a laboratory with a "solid:liquid phase" ratio of 1:5. To do this, local sod soil was dissolved in water in a 100-liter container in a ratio of 1:5 and mixed thoroughly. Mixing was carried out in a mixer with a rotation speed of 1500 rpm. Mixing time was 30 min. The liquid in the container was poured back into the container through a special nozzle sprayer using a centrifugal pump. In this process, analysis of the composition of the suspension showed that some of the salts in it dissolved, changing the alkalinity of the aqueous medium. This situation, in particular, can change proportionally with increasing temperature of the dissolution process, according to experimental research results. The liquid suspension treated in this way was settled, and using the decantation method, a fine-particle mass was separated from the settled mass, from which a suspension with a moisture content of 45% was prepared. The use of activated suspension instead of a wetting agent in the molding process of local compacted soil mass reduces the coefficient of internal friction of the mass and increases the bonding forces of coarse particles in the mass, that is, it acts as a binder [24-27].

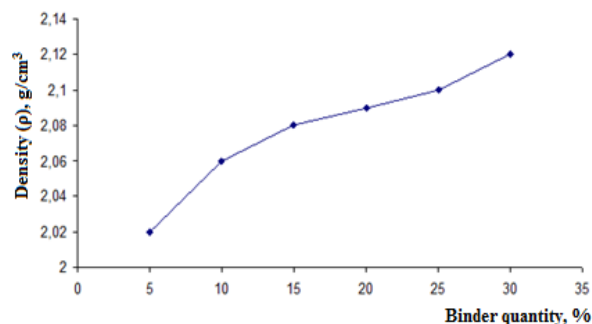


Figure 6: Change in the density of the product obtained by adding a binder to the composition of local soil. $T_{heat} = 950\text{ }^{\circ}\text{C}$, isothermal holding time - 8 hours

In the next stage of the research, this local clay-based binder was added to the composition of the building brick mass and its effect on the molding process was studied. For this purpose, mixtures were prepared by adding 10; 20; 30% of the binder to the mixture and their technological parameters were studied, and the results obtained are presented in Table 7. Analysis of the results presented in the table showed that the Atterberg plasticity index increased in the samples obtained due to the introduction of an activated suspension binder into the mass composition. At the same time, it was shown that increasing the amount of suspension-binder in the mass composition increased the air permeability of the samples by 30% compared to the initial sample, the mechanical strength limit value in compression by 92%, and in bending by 11%, and

contributed to a positive shift in quality indicators. The main reason for this is that the colloidal-

chemical properties of the mass change due to the presence of a binder included in its composition.

Table 7. Changes in the mass of building bricks due to changes in the amount of local soil and its binder

№	Indicators	Quantity, %			
		MS 100	MS90+B10	MS80+B20	MS70+B30
1.	Airborne, %	4,0	4,6	4,9	5,2
2.	Condition of the surface after drying	there are cracks	few cracks	cracks have decreased	without cracks
3.	Mechanical strength limit, MPa: -compression, -bending,	7,5 1,8	12,5 3,4	13,0 3,6	14,4 3,8

The results of this scientific research were compared with the scientific results of scientists

from a number of foreign countries and are presented in the following table 8.

Table 8. Table of comparison of scientific results based on specific experimental indicators

№	Research works	Material type	Main composition	Compressive strength, MPa	Water absorption, %	The novelty of the scientific article
1	Masharipova, S.M. (2024)[13]	Ceramic brick	Lyoss+defekat	12-15	14-16	strength is higher, water absorption is lower
2	Misiewicz, J. (2025)[6]	Mortars	Calcite marble	3-5	18-22	A new ceramic composition has been developed
3	Khan, M.S. (2025)[9]	Brick	Traditional raw materials	8-12	16-20	a degradation resistant composition is created
4	Grănescu, A.M. (2025)[7]	Wall materials	Classic minerals	10-13	15-18	Aimed at creating a new composition based on waste
5	Current research results	Ceramic brick (for restoration)	Local clay + mineral and industrial waste	18-22	10-12	A new scientific result

For the first time, a ceramic composition suitable for the renovation of historical and architectural buildings has been developed comprehensively, that is, mineralogical compatibility, mechanical stability, and resistance to climatic influences were simultaneously ensured.

While scientific research has been limited mainly to the analysis of existing historical materials, in this work a new ceramic composition was created based on the results of the analysis, which determines the fundamental difference of the work. According to the results of the research work, the compressive strength of ceramic bricks was increased by 18-22 MPa and water absorption was reduced to 10-12%, which fully meets the requirements of historical bricks and determines their superiority over other works. The development of ceramic compositions based on local raw materials allows reducing the dependence of restoration materials on imports. By implementing the results of the research in practice

at enterprises producing building materials, economic efficiency can be achieved.

4. Conclusions

The research work focused on improving the molding process based on local clay. It is known that local clay is a system that is divided into coarse and fine particles, and the ceramic mass obtained from this type of raw material is distinguished from other types of raw materials by its low plasticity and poor bonding properties. The research has shown that the inclusion of components such as bentonite and kaolin in the composition of ceramic mass obtained from local clays leads to positive results. However, in regions where the above raw materials are in short supply, using them to produce products is considered economically inefficient due to the high costs associated with transporting them from abroad and Therefore, it is an urgent issue to develop scientific and practical foundations for the

production of bricks with improved technological properties using various processing methods for this type of raw material available in the republic. By adding various percentages of binder obtained by hydromechanical method based on local clay soil to the main composition, it is possible to obtain a building brick composition similar to the composition of ancient building bricks used in the reconstruction of historical monuments.

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