MORTARS FOR THE RESTORATION OF ARCHITECTURAL MONUMENTS OF BUKHARA IX-XVI CENTURIES

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ABSTARCT--*In this article, mortars used in the construction of unique architectural monuments of Bukhara were studied. As a result of the studies, modified solutions were obtained for the restoration and restoration of architectural monuments of Bukhara.*

Key words-- *Mortars, monuments, masouleum, minaret Kalyan, ASTM.*

I. INTRODUCTION

It is known that Uzbekistan is rich in its famous ancient cities such as Bukhara, Samarkand, Khiva, Tashkent, Shakhrisabz and others with monumental architectural monuments located on the tourist routes of the Republic. In the territory of these ancient cities.

At present, a huge number of unique architectural monuments are preserved - masterpieces of not only national, but also world architecture, built from the IX th century [1,2].

Preservation of the technical condition of the architectural heritage is unthinkable without their restoration and restoration. Restoration and restoration work of historical monuments in their original form requires the creation of building materials that are identical in the construction of these architectural masterpieces. Therefore, the study of building technology, the development and study of modified materials for the restoration and restoration of architectural monuments is an urgent problem.

The aim of this work is to study mainly mortars (partially and masonry bricks) used in the construction of unique architectural monuments of Bukhara, which primarily include the Ismoil Somoniy mausoleum, the Kalon minaret and the Abdulazizkhon madrasah. These architectural monuments represent the millennial history of Central Asian architecture. These national monuments capture materials and techniques of construction, which determine the quality and value of unique architecture.

A deep and comprehensive study of the construction industry as a whole and the building materials used in their construction, in particular, allows us to develop identical modified materials to preserve the value of restoration of architectural monuments.

Many historical monuments of Bukhara built using sulfate binders, i.e. gypsum-based (including "*gancha*"), despite a long time of existence, they also have a good condition under certain conditions of their

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presence, which indicates the use of a modified gypsum-based solution with satisfactory conditions in relation to the natural conditions of operation of structures [3] .

Therefore, to preserve the value of historical monuments during the restoration and restoration of architectural buildings and structures from brick (generally masonry) masonry, it is advisable to use modified materials, in particular, modified mortars, identical or similar to historical materials.

To study the physicochemical and mineralogical compositions and properties of the historical solution of architectural monuments of Bukhara and to develop the technology for their modification, we carried out the corresponding theoretician - experimental studies, the results of which are given below in the text of the article.

II. RAW MATERIALS AND RESEARCH METHODS

At the stage of the experiments, we studied samples of historical materials, i.e. brick masonry - mortars and bricks of the mausoleum of Ismail Samaniy, the Kalyan minaret and the Abdulazizkhan madrasah [1-3], which are unique and inimitable architectural monuments built in the IX, XII and XVII centuries, respectively. As it was established by us, in the process of conducting experimental studies, in the laboratory of the Institute of Inorganic Chemistry of the Academy of Sciences of the Republic of Uzbekistan together with Professor Z.R. Kadirova, in the construction of these monuments, binders based on gypsum, lime and clay or loess were used at one time.

In studies of historical masonry mortars and bricks, samples were used of masonry walls and coatings of the mausoleum of Ismoil Samani, the Kalyan minaret, the Abdulazizkhan madrasah and the monument to A. Gizhduvaniy. When developing the composition of a modified - identical (similar) mortar as a mineral additive, we used local lime obtained in the workshops of the Kagan gypsum plant in the Bukhara region, natural clay (loesslike loam), and honeysuckle, vegetable ash of local reeds. It may be noted that loess-like loam consists mainly of quartz (SiO_2) and kaolinite $Al_2Si_2O_5(OH)_4$.

The properties of modified mortars were studied according to the requirements of current regulatory documents, standards and techniques. Based on the classical technology of building materials, it was established [4-6] that all the basic physical, mechanical and physico-chemical properties of building materials, in particular mortars, masonry cements, fired bricks, are also directly dependent on chemical, mineralogical, and fractional compositions used initial components, the ratio of the main oxides contained in them and the amount of minor oxides, and, therefore, from the chemical compositions of the raw materials from which echny product. From the foregoing, it follows that operational control of the chemical composition of the raw materials is one of the main conditions for obtaining high-quality building material [7-12], in particular, masonry mortar that meets the specified requirements for physico-mechanical and physico-chemical properties.

In the chemical analysis of various building materials, in particular mortar, as well as hydrated materials, it is important to determine the content of oxides of silicon (SiO_2), aluminum (Al_2O_3), iron ($FeO + Fe_2O_3$), calcium (CaO), magnesium (MgO), sodium (Na_2O), potassium (K_2O), sulfur (SO_3) and loss on ignition. The content of other oxides present in small amounts, for example, oxides of titanium (TiO_2), phosphorus (P_2O_5), manganese (MnO_2), chromium (Cr_2O_3), etc., is much less frequently required. Scheme of the chemical, i.e. The silicate analysis is as follows: after the decomposition of the sample, determine by the weight method of the content of silicic acid, with the obligatory subsequent removal of it in the form of silicon tetrafluoride - SiF_4. In the filtrate, after separation of silicic acid, the oxides of iron, aluminum, calcium and magnesium were complexon metrically determined, and the content of titanium, phosphorus, manganese and sometimes chromium oxides was determined by photocolorimetric. From individual weights, the loss on ignition of the content of sodium, potassium, and sulfur oxides was determined.

Phase transformations and stability regions or changes in solution samples using differential thermal studies,i.e. thermographic and thermogravimetric analysis together with Professor Z.R. Kadyrova performed the F.Paulik I.Paulik L.Erdey system on the Hungarian derivatograph, which simultaneously recorded synchronously the differential thermal analysis curve with the curves of linear dimensions (shrinkage) and weight loss. Sensitivity of a galvanometer, DTA – 1/3, DTG – 1/5, TG –200, T –900ºC, at a heating rate of 10 deg./min in platinum crucibles. Sample holder corundum crucible with a diameter of 10 mm from the standard (Al_2O_3). Dynamic mode. Differential and temperature recordings were carried out with a P_t–P_t/R_h thermocouple. The heating curves were recorded with an average weight of 2 g. At the same time, on other samples from the material under study, changes in linear dimensions were recorded using a torsion balance with a mirror reading.

The radiographs were deciphered by the well-known method. In the analysis, the crystals of each individual compound give a specific, only inherent x-ray with characteristic values of interplanar distances and a certain intensity of the corresponding reflections.

According to the above, the diffraction patterns of the mortar and clay mortar samples were obtained by the powder method on a DRON-4.0 X-ray MoKα-radiation device, Zr-filter. The radiograph was taken at a counter disk speed of 2 deg/min. Single crystal quartz was used as an internal standard. The wavelength of cobalt radiation is 1.78529 A^0, the tube voltage is 25 kV, and the filament current is 20 kV.

When identifying the phases, tables and handbooks compiled by the authors of [13–15], as well as an ASTM card index using ASTM X-ray powder diffraction patterns [16], were used.

Thus, the physicochemical analysis of the compositions of historical masonry materials of architectural monuments and the compositions of modified mortars based on calcium sulphates was studied by the currently used methods in existing devices.

III. THE RESULTS OBTAINED AND THEIR DISCUSSION

An analysis of world literature showed that in practice, in ancient times, various organic additives were used to improve the physicomechanical properties of mortars during their preparation [17, 18], in particular (“sheres”) [17-23], camel milk (“syuzma”) [18-23], wood glue [24], decoction of glutinous rice [25,26], egg white [27], dextrin, citric acid, wine [19] and others. To increase water resistance, i.e. To reduce the solubility of calcium sulfate in water and create the conditions for the formation of insoluble compounds protecting calcium sulfate dihydrate, in combination with a gypsum binder, mineral fillers, additives with pozzolanic properties, were used [17, 18]. The results of our research on the chemical composition of historical building solutions of architectural monuments of Bukhara and modified solutions using the above methods are shown in table №. 1 and №. 2, respectively.

Table 1: The chemical composition of the mortar the mausoleum of Ismail Samaniy, the Kalyan minaret and the more mediocre Abdulazizkhan

Sample	The content of oxides on air-dry matter, mass %										
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	P_2O_5	Cl^-	
1B*)	24,63	4,04	2,40	39,92	3,00	0,68	0,48	0,50	0,01	0,02	23,9
1C	21,83	4,09	2,72	38,56	2,00	0,59	0,46	0,56	-	-	24,1
2B	15,89	3,22	2,70	40,30	2,50	0,71	0,49	0,61	-	0,02	33,1
3B	55,89	9,78	3,99	10,45	2,70	1,28	1,91	1,89	0,04	0,03	12,3

Notes: 1B- samples of the upper part of the wall of the mausoleum of Ismail Samoniy;
1C- samples of the lower part of the wall of the mausoleum of Ismail Samoniy;
2B- design samples of the Minaret Kalyan
3B- samples of the construction of the eastern wall of the Abdulaziz Khan Madrasah

From the above table1 it can be seen that the chemical composition of the studied samples of the samples of the mausoleum of Ismoil Samaniy, Minaret Kalyan and Madrassah Abdulazizkhan consists of the following oxides: SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, SO_3, Na_2O, K_2O. Consequently, the main chemical composition of the samples of the solutions of the Ismail Samaniy Mausoleum (1B - 1C) consists of calcium oxides and silicon. The main chemical composition of samples of solutions of the Kalyan minaret (2B) also consists of calcium and silicon oxides. In the studied mortar, the SPP content was 23.9 and 33.14%, respectively. The obtained composition of the modified solution is similar (table №. 2).

Table 2: The results of chemical analysis of modified solutions

Sample	The content of oxides on air-dry matter, mass %										
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	P_2O_5	Cl^-	
1M	24,02	4,34	2,7	40,422	3,5	0,6	0,56	0,6	0,02	0,01	23,3
2M	16,05	3,32	2,45	40,22	2,58	0,71	0,5	0,65	-	0,03	33,54
3M	53,79	10,88	4,49	10,95	2,5	1,48	1,51	1,99	0,03	0,04	12,77

A comparative analysis of the studied compositions of the building mortars of the mausoleum of Ismoil Samaniy and Minaret Kalyan with the data of literary sources showed that while in the masonry of architectural monuments of the 9th-12th centuries the main content of the solutions was calcium oxide and silicon, then the monument of Shokhi-Zinda and the monument built several centuries later in Samarkand The solution composition is composed not only of these oxides, but also of aluminum oxide [17.30]. Our studies of the mortar of the brickwork of the Abdulazizkhan madrasah (sample №.3B), built in Bukhara in the middle of the XVII century, the results of which are presented in the same table №.1 confirmed this fact.

The composition of the mortar of the brickwork of the mausoleum of Ismail Samaniy and Minaret Kalyan differs from the architectural monuments of the later period in the lower content of aluminum oxide. On the basis of this provision, one can come to a preliminary opinion that clay mortars were added to mortar in mortars of late times. This is confirmed by the material of the Abdulazizkhan madrasah (table №. 1, sample 3B).

For a more reliable conclusion or conviction on this issue, it was advisable to conduct a DTA analysis. The results of studies of the DTA analysis of architectural monuments are presented in Fig.1a-3a. It can be seen from the obtained curves that the mineralogical composition of the samples consists of the following thermal effects. At temperatures of 246 and 627 0C, exothermic effects were observed, and at temperatures of 162, 187, 220, 331, 376, 416, 489, 728 0C, endothermic effects were observed.

In fig. Figure. 1-3 presents the results of X-ray irradiation of samples of a mortar of brickwork of architectural monuments-the mausoleum of Ismail Samaniy, Minaret Kalyan and the madrasah of Abdulazizkhan.

The results of the study of the mortar of the brickwork of these architectural monuments showed that the diffraction maxima appeared at d = 0.756; 0.422; 0.306 and 0.208 [3]. These sizes indicate the presence of gypsum in the solution. In addition, the mixture contains quartz (d = 0.334; 0.245; 0.228 nm), albite (d = 0.310; 0.402 nm) and dolomite (d = 0.290; 0.241; 0.219; 0.202 nm).

In the sample samples of the lower part of the walls of the Ismail Samaniy mausoleum, diffraction maxima occurred at d = 0.756; 0.427; 0.306 and 0.208 nm. These sizes indicate the presence of gypsum in the mortar. In addition, the composition of the mixture contains quartz (d = 0.334; 0.245; 0.228 nm), basanite (d = 0.606; 0.281 nm), albite (d = 0.310; 0.402 nm), KPSh (d = 0.324 nm), clinoenititis (d = 0.893 nm) and calcite (d = 0.187 nm).

The difference in the sizes of the diffraction maxima of the solutions of the upper and lower parts of the brick cladding of the walls can be explained by the operating environments of the structure. At one time, the lower part of the wall was in a buried state for a long period of time, as a result of which aggressive factors of the filled soil were acting on it. As a result of this, additional minerals KPSh, clinoeenititis and calcite formed in the composition of the solution of the lower part of the wall.

The samples of the central part of the eastern part of the destroyed wall of the Abdulaziz Khan madrasah contain quartz (diffraction appeared at d = 0.335; 0.246; 0.228 nm)-34.4%, albite (d = 0.406; 0.320 nm)-19.5%, mica (19 5%), calcite 0.1875 nm -11.9%, dolomite d = 0.304, 0.29 and 0.24 nm -7%, ferrite-magnesium-chlorite-6.1% and gypsum d = 0.427; 0.306 and 0.209 nm -1.6%. These sizes show the content in the masonry mortar of mainly loess and lime [3.33].

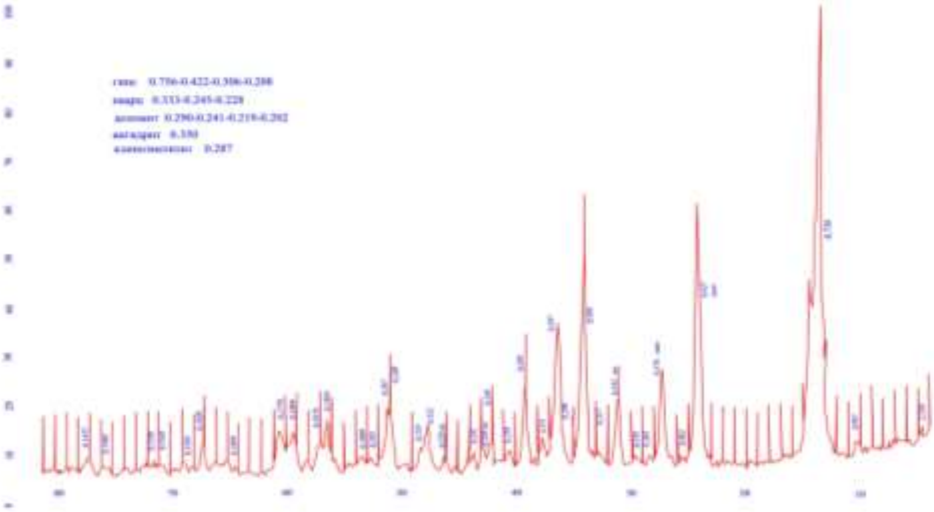

Figure 1: Results of the X-ray diffraction pattern of the sample mausoleum of Ismoil Samonius №1B

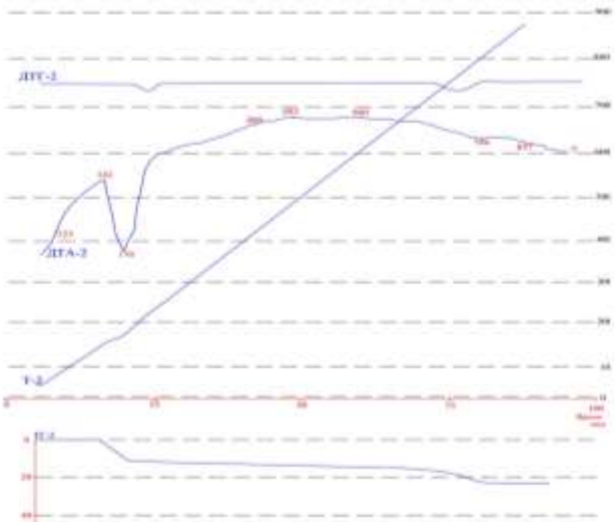

Figure 1a: DTA Sample Results the mausoleum of Ismail Samaniy No. 1B (the upper part of the wall)

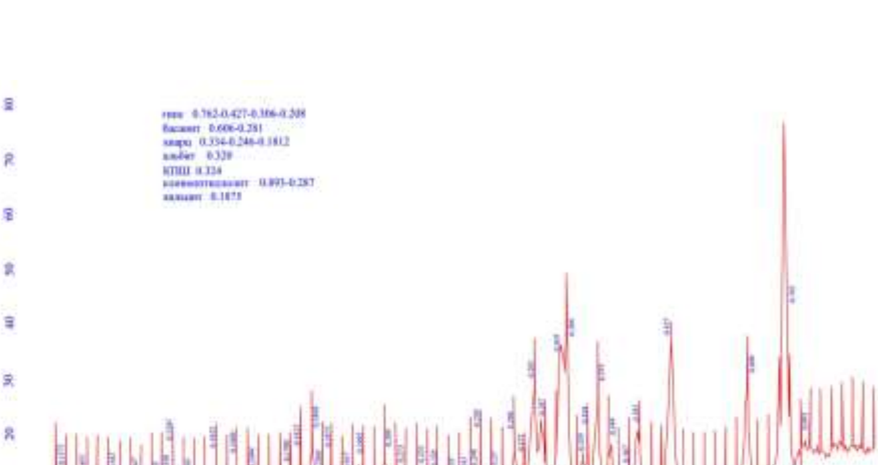

Figure 2: Results of the X-ray diffraction pattern of the samplethe mausoleum of Ismoil Samonius №. 1C

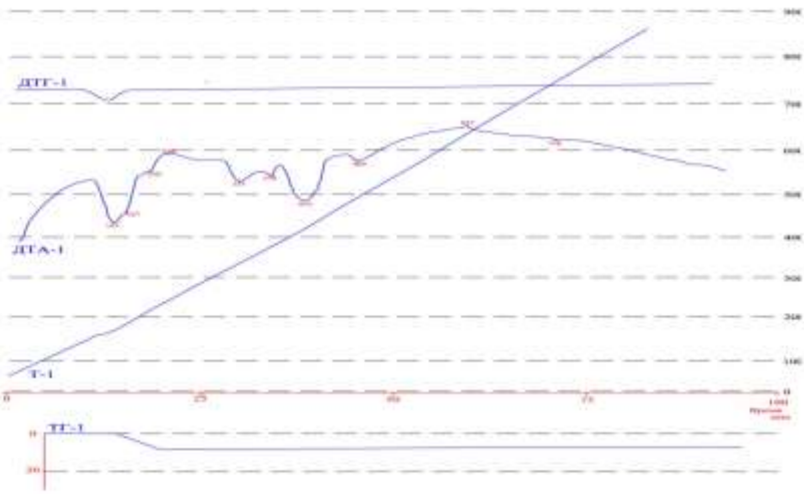

Figure 2a: DTA Sample Resultsmausoleum of Ismail Samaniy №. 1C (lower part of the wall)

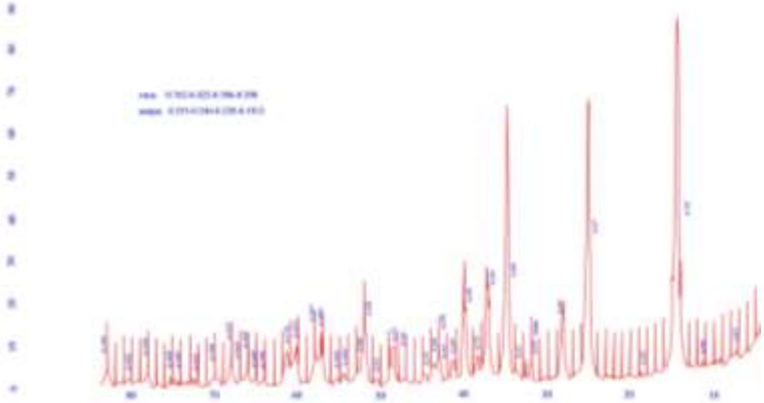

Figure 3: The results of the X-ray diffraction pattern of the sample sample Minaret Kalyan No. 2B

Figure3a: DTA Sample Results Minaret Kalyan

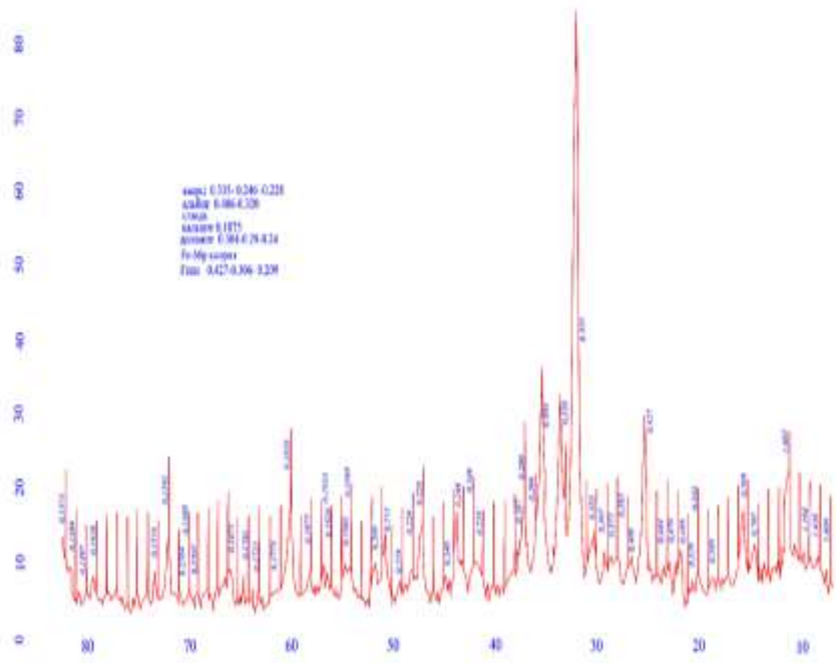

Figure 4*: Sample X-ray Results*
Madrasah of Abdulazizkhan №. 3B

Figure 4a*: DTA Sample Results*
Madrasah of Abdulaziz Khan № 3B

In complex studies, the results of an electron microscope of the structure of samples of mortar for masonry of architectural monuments - the mausoleum of Ismail Samaniy, Minaret Kalyan, the Abdulazizkhan madrasah in the city of Bukhara and the monument A. Gizhduvaniy in the Bukhara region in 100 times magnification were studied. The results of studies of the material structure of architectural monuments using an electron microscope are presented in Fig.5-9. It can be seen from these photographs that the composition and structure of the samples is characterized by the presence of mostly uniformly distributed crystals and pores.

The results of studies of model samples of the upper part of the mausoleum of Ismail Samaniy is a confirmation of this opinion. You can gloss over the presence of gypsum in the solution. The composition of the solution of the Abdulaziz Khan madrasah is also characterized by a normal structure. In this composition, the presence of gypsum in the solution can be observed. In addition, the mixture contains quartz and other minerals.

Some difference in the state of the structures of the solutions of the mausoleum of Ismail Samaniy of the upper and lower parts of the brick cladding of the walls can be explained by the operating environments of the structure. At one time, the lower part of the wall was in a buried state for a long period of time, as a result of which aggressive factors of the filled soil were acting on it. As a result of this, additional KPSh minerals, clinoenetitite and calcite, were formed in the solution of the lower part of the wall, which is clearly seen from photo 5a.

The results of studies using a V-150 brand electron microscope with a 100x magnification are shown in the following figures 5–9.

Figure 5a shows a photo of the structure of the sample sample of the masonry mortar of the upper part of the brick wall of the Ismail Samaniy mausoleum in 100x magnification. From the photographs you can see that their structure is almost identical (see photos 6a and 6b). Crystallics of minerals and pores in the structure are evenly distributed, there are no cracks, large voids and other damages in it.

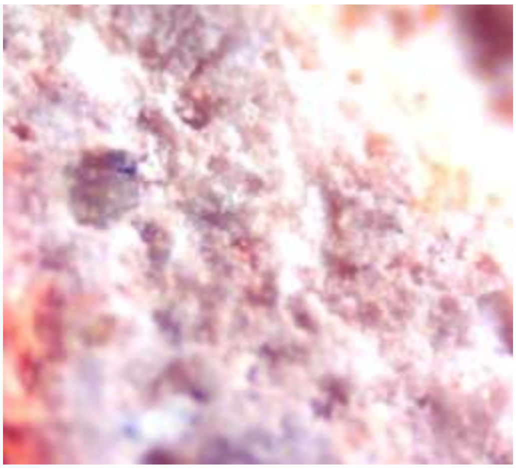

Figure 5a: The structure (x100) of the sample of the historical masonry mortar of the upper part of the brick wall of the mausoleum of Ismail Samaniy

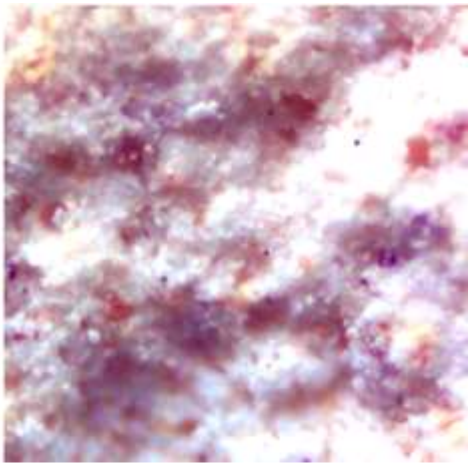

Figure 5b: The structure (x100) of the sample sample of the recommended modified masonry mortar (for restoration of the wall of the mausoleum of Ismail Samaniy)

From the picture taken by the above electron microscope at a 100-fold increase (Fig.-5b) it follows that the recommended composition of the modified masonry gypsum mortar consists of gypsum, sand, cement, reed ash and milk of lime.

Figure 6a below shows the state of the sample structure — a sample of the historical masonry mortar of the wall of the Kalyan minaret (x100).

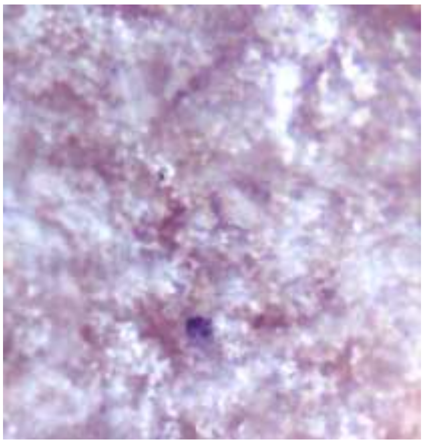

Fig ure 6a: The structure (x100) of the sample **-** samples of the masonry mortar of the brick wall of the Kalyan minaret

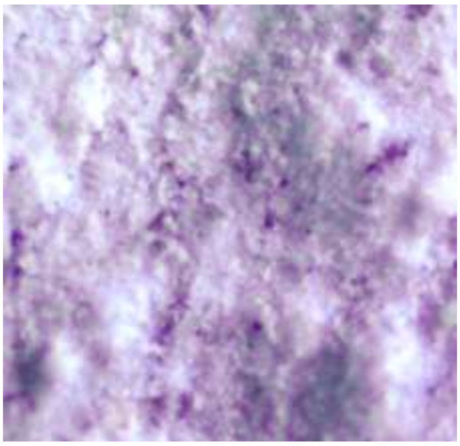

Figure 6b: The structure (x100) of the sample sample of the recommended modified masonry mortar (for restoration of the wall of the mausoleum of Minaret Kalyan)

From photographs 6a and 6b, you can see that the structure is similar to each other and almost identical. The recommended composition of the modified masonry gypsum mortar contains gypsum, quartz sand, cane ash and milk of lime.

Figure-7a. The state of the structure of the masonry mortar sample taken from the collapsed part of the eastern brick wall of the Abdulazizkhan madrasah (x100) is presented.

Figure 7a: The structure (x100) of the sample **-** samples of the historic masonry mortar wall of the madrasah of Abdulazizkhan

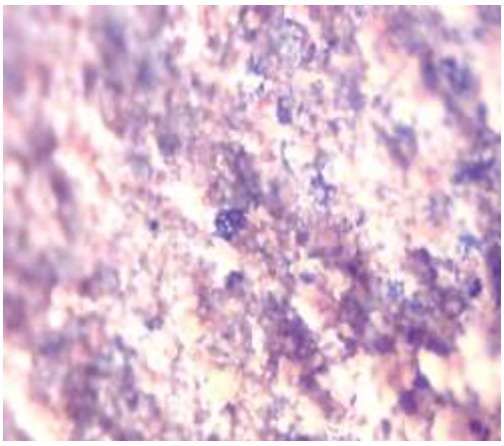

Figure 7b: The structure (x100) of the sample sample of the recommended modified masonry mortar (for restoration of the wall of the Abdulazizkhan madrasah)

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From photographs 7a and 7b you can see that the state of their structure is almost identical, similar to each other. The recommended composition of the modified masonry clay mortar consists of quartz sand, clay (mica and albite), cane ash, gypsum and milk of lime. Thus, this composition of the recommended masonry glazed mortar is similar to the composition of the historical masonry mortar of the Abdulazizkhan madrasah.

Figures 8a and 8b show a photo of the structure of samples of samples of masonry mortar taken during the opening of the brick foundation of the monument of Abdukhalik Gizhduvaniy (Gizhduvan) in 100x magnification.

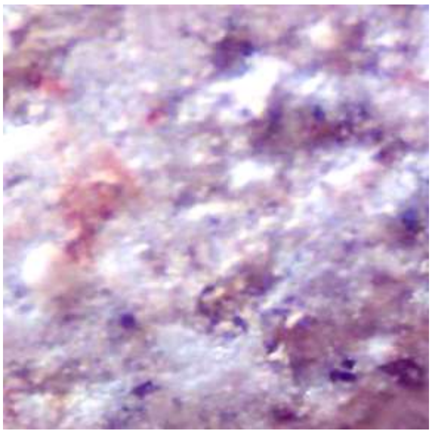

Figure 8a: Structure x100) of the sample - samples of masonry mortar of the wall of the monument A. Gijduvoniy (Gijduvan, Bukhara region)

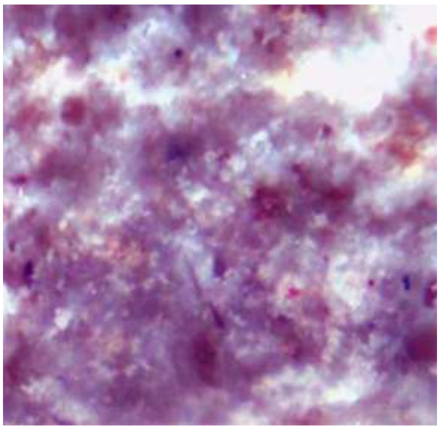

Figure 8b: The structure (x100) of the sample sample of the recommended modified masonry mortar (for the monument A. Gijduvanov)

The composition of the modified masonry clay mortar recommended for the A.Gizhduvani monument consists of gypsum, sand, cane ash and milk of lime. The composition and structure of the developed modified gypsum mortar is similar to the composition of the historical masonry mortar of the monument A. Gijduvoniy.

Figure-9 shows the structure of the sample - a brick sample of masonry walls of the mausoleum of Ismail Samaniy in a 100-fold increase. From the photo you can see the good structure of the brick, the absence of cracks and other damage in it.

Figure 9: The structure (x100) of a sample of a brick of the upper part of the wall

mausoleum of Ismail Samaniy

Thus, the results of studies using an electron microscope showed the identity of the structure of the studied modified compositions of masonry solutions with historical materials used in the construction of the studied architectural monuments.

Since Bukhara is located in a seismically active region with an intensity of at least 7 points, therefore, the requirements for the adhesion of bricks to the solution are imposed for the masonry mortar [31,32]. Therefore, in further studies, the adhesion strength of the brickwork of the monuments using the Onyx OS-2 device with a modified mortar of compounds №. 1b, №. 2b, №. 3b and №. 4b was studied (see photo №. 10).

Figure 10: Photo taken from the process of testing to determine the adhesion strength of the mortar to the masonry bricks.

In the experiments, modified mortar mixtures with a mobility of 18 cm were prepared. Then, a fragment of the wall was made of masonry bricks on the recommended compositions №.1b-4b. 7 days after hardening of the masonry mortar, a test for adhesion strength was carried out, the results of which are presented in the following table №. 3.

Table3: the results of which are presented

№	Name of mortar	Compres-sive strength $R_{s., kg/sm^2}$	Flexural Tensile Strength $R_{t., kg/sm^2}$	Grip strength $R_{g, kg/sm^2}$
1a	Masonry historical mortar (№1) of the upper part of the brick wall of the mausoleum of Ismail Samaniy *)	78		
1б	Modified solution identical to (similar) composition №1**)	94	10.5	1.5

2а	Masonry historical mortar (№2) of the brick wall of the Kalyan minaret *)	120		
2б	A modified solution similar to the composition №2**)	140	14.5	1.9
3а	Masonry historical mortar (№3) wall of the Abdulaziz Khan Madrasah *)	45		
3б	A modified solution similar to the composition №3**)	55	7	1.2
4а	Masonry historical mortar(№4) walls of the monument A. Gijduvoniy*)	72		
4б	A modified solution similar to the composition №4**)	86	9	1.4

*) compressive strength determined by Onyx -2.51

**) compressive strength determined on 5 ton hydraulic press

The test results showed that the compressive strength of the tested materials 1a and 1b, 2a and 2b, 3a and 3b, 4a and 4b ranges up to 20%. The difference in the strength characteristics of materials under compression and tensile strength during bending can be explained by some production times and long-term operation in natural conditions.

Studies have shown that the adhesion strength of the proposed compositions of the modified solutions ranges from 1,2 to 1,9 *MPa*, which corresponds to the strength of the solutions of the 1st and 2nd category of masonry according to the regulatory document - KMK 2-01-03-96 [31] and recommend in seismic areas for restoration of wall structures.

IV. CONCLUSIONS

According to the results of the physico-chemical analysis of the building mortar of the brick clutch of the mausoleum of Ismoil Samany, Minaret Kalyan, the monument to A. Gizhduvaniye and the Abdulazizkhan madrasah, it can be noted that these solutions are gypsum, gypsum-lime and clay with organic and mineral supplements. Therefore, when developing the modified mortar technology for restoration work of architectural monuments of an early period, we took these results into account, which was taken into account when conducting further research. As a result of the studies, modified solutions were obtained for the restoration and restoration of architectural monuments of Bukhara.

The test results showed that the compressive strength, bending and adhesion of the proposed compositions of the modified solutions is 1,2 ... 1,9 MPa, which corresponds to the strength of solutions of the 1st and 2nd category of masonry recommended in seismic areas for restoration of wall structures.

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