EVALUAREA CARACTERISTICILOR MORTARELOR DE VAR ARMATE CU FIBRE DE CÂNEPĂ
EVALUATION OF THE CHARACTERISTICS OF LIME MORTARS REINFORCED WITH FIBERS OF HEMP

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The wooden churches painted in fresco, present exclusively in south zone of Romania, represents a limited category, very little explored and, additional, threaten with disappearance. The main problem of preservation is represented by remaking of the adherence of fresco at wood support.

This paper presents the results of the first researches regarding the obtaining of some materials which will serve in the process of consolidation of mural pictures on wood support. For this purpose were performed a series of mortars based on hydrated lime, river sand and fibers of hemp. For improvement of the adherence an acrylic additive was added. Different characteristics of mortars in hardened state were evaluated, such as: apparent density, water absorption, water vapor permeability, flexural and compressive strength, and resistance at the phenomenon of biodegradation. By using the fibers the flexural and compression strengths of the mortars were improved.

Bisericile de lemn pictate în frescă, prezente exclusiv în zona de sud a României, reprezintă o categorie restrânsă, prea puţin explorată şi, în plus, ameninţată cu dispariţia. Principala problemă de conservare o reprezintă refacerea aderenţei frescei la suportul de lemn.

Această lucrare prezintă rezultatele primelor cercetări privind obţinerea unor materiale care să servească în procesul de consolidare a picturilor murale pe suport de lemn. În acest scop au fost realizate o serie de mortare pe bază de var hidratat, nisip de râu şi fibre de cânepă. Pentru îmbunătăţirea aderenţei a fost adăugat un aditiv acrilic. Au fost evaluate diferite caracteristici ale mortarelor în stare întărită, cum ar fi: densitate aparentă, absorbţie de apă, permeabilitate la vapori de apă, rezistenţă la încovoiere şi compresiune, rezistenţa la fenomenul de biodegradare. Utilizarea fibrelor în compoziţia mortarelor a condus la imbunătăţirea rezistenţelor mecanice la încovoiere şi compresiune.

Keywords: *fresco, lime mortar, fiber, mechanical strength, water vapor permeability, biodegradation*

1. Introduction

Romanian churches from wood painted in fresco technique, both inside and outside, represent a unique patrimony, with a special preservation problematic. Using of such a technique, which is not retrieved in other ecclesiastic constructions from wood from European patrimony, is an expression of trying to approach of the appearance and the viability of the churches of masonry wall. However, the incompatibility between woody material of the church architecture and mineral materials that compose mural decoration in fresco generated specific damages, accentuated by the absence of a preservation program. This reality constituted the point of starting of a project for obtaining some materials and elaboration of some methodologies of preservation which to allow remaking of the adherence of the support for mural paintings at wooden walls of the churches. Chosen casuistry was two wooden churches with patron St. Nicholas, built in the centuries 18-19, situated in Vâlcea county, Ioneştii Govorii and Amărăşti localities. In the 19th century, both churches were painted in fresco inside altar, on walls and in lower register of the vault. Performed researches [1,2] showed that the mortar from which is performed the fresco is a mortar based on hydrated lime, with different proportions of sand and hemp tow. In order to solve the adherence problem, the painters used a cutting axe to roughen on the wooden surface. The technique of fresco on wood followed all phases of work characteristic to fresco on masonry wall. Fresco damaging is caused by the factors of microclimate, land destabilize through digging of graves nearly of church, earthquakes, lack of maintenance and, not last time, the incompatibility between the wooden support and fresco. At fresco

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level, the damages are of different sizes and are represented by: network of cracks, cracks/breaks at planks jointing, detachments of fresco of wooden walls and thelast level of damaging – lacunae. It has also distinguished the existence of complex biodeterioration of mural painting (massive deposits of wax in biodamaging process produced by microscopic fungi).

Using of the fibers (vegetal or animal) in composition of the mortars is an old technique, of Byzantine tradition. The scope was to diminish the contraction cracks, specific to the mortars rich in lime. Regarding the using of the fibers in the mortars and concretes the numerous researches were made, which put into evidence the benefits brought by these. Scientific studies showed that the reinforcement with natural or synthetic fibers is a method to improve the performance of the mortars from mechanical point of view, of contraction and dilatation (phenomena that lead to cracking), of durability [3-13].

The purpose of the research presented in this paper was to obtain and characterize of some compositions of mortars based on lime, river sand, hemp tow, in proportions closed to the original ones, and the adherence of original fresco at wooden walls of the churches to be remade. The compositions of the mortars varied from ratio lime/sand point of view, sand grain size and the length of hemp tow. In the paper are presented the physical-mechanical characteristics and the resistance at bio-deterioration action of these mortars, following that their properties of durability to be completed and presented in a subsequent paper.

2. Experimental

The researches [1,2] made on samples of fresco taken from above mentioned wooden churches put into evidence a varied composition of the mortars such as 60-90 % hydrated lime, 10-40 % river sand and vegetal fibers (hemp tow). Used sand was fine sand, below 0.500 mm and below 0.710 mm. Sometimes, in very small proportions, they were found in the composition of mortars fine fragments of limestone that could result from used sand source [1].

2.1. Used materials

Raw materials used for obtaining of the mortars were: hydrated calcium lime type CL 80 S in quality of binder, river sand in quality of mineral aggregate and hemp tow as vegetal aggregate, having role of reinforcement. The lime and the sand are characterized through low content of sulphate, chlorine and alkali (determined according SR EN 196-2 [14]:

- hydrated calcium lime: 0.00% SO_3, 0,66% Na_2O, 0.11% K_2O;
- river sand: 0.00% SO_3, 0.00% Na_2O, 0.00% K_2O, 0.034% Cl^-.

In the composition of mortars were used river sand having the following grain sizes: 0.01-0.500 mm and 0.01-0.710 mm. Hemp tow were immersed, according to traditional technique, in whitewash for a period of 24 hours. Subsequently, the tow was dried in oven at 60°C and then was cut at two dimensions: 4-5 mm and 12-15 mm. For the improvement of the adherence at the wooden support the Acril 33 additive was used. This additive, sometimes used in the works of fresco consolidation, is an aqueous dispersion of acrylic copolymer, of white color, with a viscosity at 20°C of 2500-5000 MPa•s.

2.2. Experimental conditions

Taking into consideration that the obtained mortars must adhere to wooden walls of churches, the experiments were initiated through testing at adherence of some mortars without additive, through their application on plates of oak wood. After hardening, through easy knocking with finger, it was stated that all tested mortars have a weak adherence at the small wooden plates. Same compositions of mortars, but in which were added the Acril 33 additive, tested again from adherence point of view at the wooden plates. Mortars compositions which had the best behavior are represented in the Table 1. Also, in order to evaluate the influence of the additive and tow on mortars characteristics, were prepared three standard mortars with/without additive/tow (M1, M2, M3), in which the lime/sand ratio was 1/0.5. The mortars were obtained through homogenization of the lime and the sand, in dry environment, in rotation mill, for a period of 2 hours. To the mixtures the water, additive and tow was added, the homogenization being manually made, with aid of a trowel, in a vessel of plastic. Because the water from fresh mortar is not easily absorbed of the wooden support on which is applied, was chosen a consistency, expressed through values of spreading, of 125±10 mm, determined with spreading mass according SR EN 1015-3 [15].

2.3. Testing methods

Obtained mortars were characterized from physical point of view (apparent density, water absorption, water vapor permeability) and mechanical (flexural and compressive strength). Also, the mortars were tested from the resistance at bio-deterioration point of view. Physical-mechanical characteristics were determined at the terms of 28 and 56 days, on prisms of 4x4x16 cm, carried out and kept according to the conditions from SR EN 1015-11, art. 7.2.3. and the table 1 for mortars of air lime [16]. The water vapor permeability and the resistance at biodeterioration were determined on hardened specimens at 28 days.

Table 1

Compositions of the mortars / *Compoziţia mortarelor*

Mortar code *Cod mortar*	Dry powder, gravimetric parts / *Pulbere uscată, părţi gravimetrice*			Hemp tow / *Câlţi de cânepă, %*		Acril 33, %
	Hydrated calcium lime / *Var calcic hidratat*	River sand/ *Nisip de râu*				
		<0.710 mm	<0.500 mm	4-5 mm	12-15 mm	
M1	1	0.5	-	-	-	-
M2	1	0.5	-	-	1	-
M3	1	0.5	-	-	-	2
M4-A	1	0.5	-	-	1	2
M5-A	1	1	-	-	1	2
M6-A	1	2	-	-	1	2
M7-A	1	-	0.5	-	1	2
M4-B	1	0.5	-	1	-	2
M5-B	1	1	-	1	-	2
M7-B	1	-	0.5	1	-	2

Table 2

The fungal growth assessment / Evaluarea creşterii fungilor (SR EN ISO 846)

Method *Metoda*	Fungal growth *Creşterea fungilor*	Assessment of mortars resistance / *Evaluarea rezistenţei mortarelor*
A	0	Mortar is not used as nutrient by fungi; it is inert and has fungitoxic effect *Mortarul nu constituie un mediu nutritiv pentru fungi; este inert sau are efect fungitoxic*
	1	Mortar has low content of organic compounds; it is used as nutrient by fungi and has fungitoxic effect / *Mortarul conţine cantităţi reduse de compuşi organici; este utilizat ca nutrient de către fungi şi are efect fungistatic*
	2-3	Mortar contain organic compound used as nutrient by fungi assuring colonization / *Mortarul conţine compuşi organici; este utilizat ca nutrient de către fungi asigurând colonizarea*
	4-5	Mortar contain organic compound used as nutrient by fungi assuring an intense colonization *Mortarul conţine compuşi organici; este utilizat ca nutrient de către fungi asigurând colonizarea intensă*
B	0	Intense fungitoxic effect / *Efect fungitoxic intens*
	1	Partial fungitoxic effect / *Efect fungitoxic parţial*
	2-5	Fungitoxic effect descending / *Efect fungitoxic descrescător*

Apparent density – the determination consisted of measuring of specimen and its weighing. Apparent density is calculated with the formula:

$$\rho_a = m/V \ (kg/m^3) \quad (1)$$

in which: m = speciment mass in dry state, in kg; V = volume, in m^3.

Water absorption – the determination consisted of sample drying at 60°C, weighing of dried sample, the immersion on distilled water, weighing of wet sample. The weighing in wet state was made after 24 hours from immersion, the weighing being repeated at interval of 2 hours up to the difference of weight between 2 weighings not exceed 0.2%.

Water absorption (abs) was expressed by percent, based on formula:

$$abs = (m_1 - m_0)/m_0 \times 100 \ (\%) \quad (2)$$

where: m_0 – dry mass of the specimen, in g; m_1 – wet mass of the specimen, in g.

Flexural and compressive strength was determined according to SR EN 1015-11 [16]. Testing speed at flexural was of 15 N/s and at compression of 100 N/s.

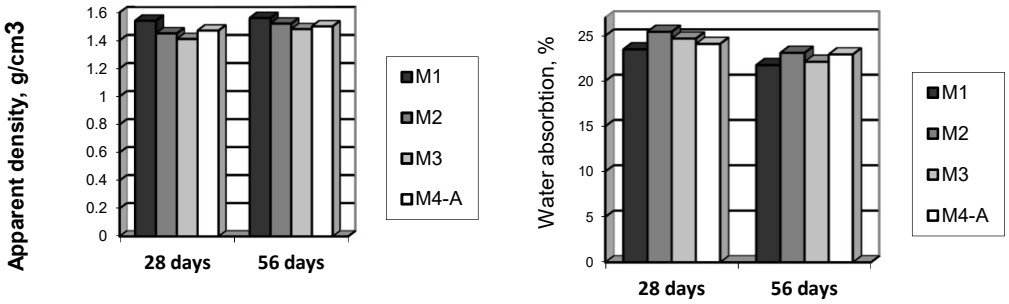
Water vapor permeability was determined according to the standard SR EN 1015-19 [17] on cylindrical specimens, kept in the conditions specified by the standard. The determination was made with saturated solutions of KNO_3 in order to assure a relative humidity of 93.2%, at a temperature of 20°C.

Mortars resistance to biodeterioration had been tested according to SR EN ISI 846 [18]. The test is based on visual and microscopic examination of type and size of deteriorated area after inoculation of mixed suspension of fungal spores on different mortars. The total amount of inoculum (2ml) containing spores of *Aspergillus niger*, *Cladosporium herbarum*, *Ulocladium chartarum* and *Penicilliump* sp) had been placed on the surface of mortars like they were (method A) and after adding of glucose (1%) as carbon supplementary sources (method B). All inoculated mortars have been placed in humid chamber for incubation at 25°C. Assessment of size colonised areas as well as fungitoxic effect has been evaluated and expressed as figures (0-5) after one month of incubation (Table 2).

2.4. Results and discussions

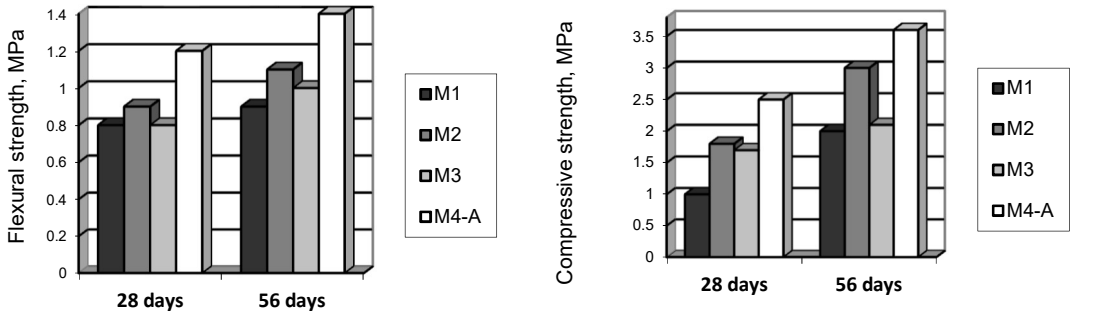
Based on the obtained results, it was stated that all the mortars have low apparent density, higher water absorption and moderate mechanical strength at compression, specific to mortars based on lime. Nevertheless, there are differences between them depending on their composition.

Influence of the tow and the additive on the mortars characteristics were evaluated in the case of the mortar with 0.5 gravimetric parts sand with grain size smaller than 0.710 mm. It was stated the presence of the tow (M2), the additive (M3), respectively of the tow and the additive (M4-A), in



a. b.

Fig.1 - Apparent density (a) and water absorption (b) versus the composition of the mortars with/without tow or additive, at the terms of 28 and 56 days / *Densitatea aparentă (a) şi absorbţia de apă (b) vs. compoziţia mortarelor cu/fără câlţi sau aditiv, la termenele de 28 şi 56 zile*



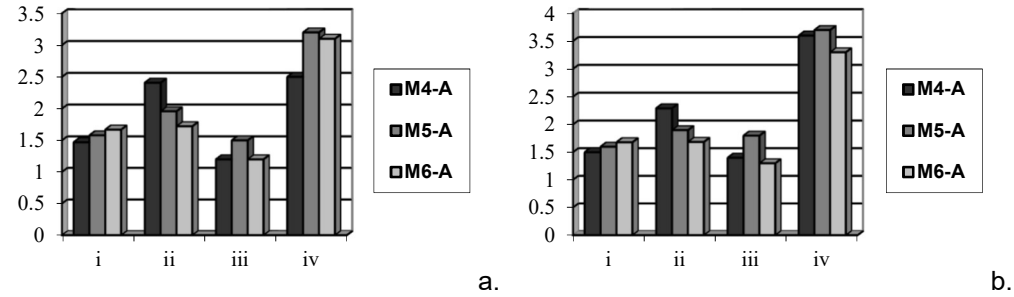
a. b.

Fig.2 - Flexural (a) and compressive (b) strength at 56 days versus composition with/without tow or additive
Rezistenţa mecanică la încovoiere (a) şi compresiune (b) la 56 zile vs. compoziţie cu/fără câlţi sau aditiv

Table 3

Water vapor permeability / *Permeabilitatea la vapori de apă*

Mortar code *Cod mortar*	Conductance at water vapors *Conductanţa la vapori de apă* (kg/m^{2}sPa)	Permeability at water vapors *Permeabilitatea la vaporii de apă/* (kg/m.s.Pa)	Coefficient of water vapor permeability *Coeficientul de permeabilitate la vapori de apă*
M2	5.27x10^{-9}	1.32x10^{-10}	1.47
M3	6.89x10^{-9}	1.38x10^{-10}	1.41



a. b.

Fig.3 - Variation of characteristics values of the mortars versus the proportion of aggregate at 28 days (a) and 56 days (b):
i – apparent density (g/cm^3); ii – water absorption (% x 10); iii – flexural strength (MPa); iv – compressive strength (MPa)
Variaţia valorilor caracteristicilor mortarelor funcţie de proporţia de agregat la 28 zile (a) şi 56 zile (b):
i – densitatea aparentă (g/cm^3); ii – absorbţia de apă (% x 10); iii – rezistenţa la încovoiere (MPa);
iv – rezistenţa la compresiune (MPa)

comparison with the mortar without tow and additive (M1), had as effect the decreasing of apparent density (with 0.09-0.13 g/cm^3 at 28 days, respectively with 0.4-0.8 g/cm^3 at 56 days) and, implicitly, increasing of water absorption (with 0.6-1.94% at 28 days, respectively 0.37-1.36% at 56 days) (Fig.1). Generally, the tow determined a higher increasing of water absorption, in both mortars without/with additive (M2, M4-A).

From mechanical strengths point of view, when was used tow in the mortars without/with additive (M2, M4-A) a insignificant increase (with maximum 0.2 MPa) of the values of flexural strength and a higher increase of the values for compressive strength (with about 1-1.8 MPa) in comparison with those of the mortars based on lime-sand (M1) was remarked, at both terms (Fig.2). Increasing of the mechanical strengths, especially at compression, in the case of using the fibers is also signalized by

Cardoso et al. in [19]. In case of using just of the additive (mortar M3), it is stated an insignificant increase (0.1 MPa) both of the flexural strength, and at compression in comparison with those of the mortar M1. It is remarked that the mortar that contain tow and additive (M4-A) has higher mechanical strengths.

Measurements of water vapor permeability made for the mortars M2 and M3, in hygroscopic range 50±5%/93.2%, show that the addition of tow, respectively acrylic additive not influence negatively this parameter (Table 3). In literature of specialty it is mentioned that a material is more permeable so as the coefficient of permeability (μ) is smaller [20]. In the technical data sheet of some products of restoration this coefficient is from 0.01 up to 6 [21,22], and the standard of mortars SR EN 998-1 [23] specify in the case of repair mortars a value of the permeability coefficient at water vapors of maximum 15.

Influence of the proportion of aggregate on characteristics of the mortars with tow and additive was analyzed in the case of the mortars with sand of granulation lower than 0.710 mm (Fig.3). It is remarked at both terms that the mortar mass become more dense (with about 0.2 g/cm^3) on measure that the proportion of aggregate increase, fact that lead to a decreasing of water absorption (with about 0.7 g/cm^3). The values of flexural and compressive strengths present small variations at both terms. Nevertheless, it is stated a maximum of these for the mortar with ratio binder/aggregate of 1/1 (M5-A).

The influence of the dimensions for hemp tow on the characteristics of mortars was evaluated in the case of the mortars type M4, M5 and M7 (Fig.4). It was stated that, indifferent of mortars composition, the decreasing of the tow dimension from 12-15 mm at about 5 mm has as effect an aeration of the structure for hardened mortar identified by decreasing of mortars density with about 0.08-0.11 g/cm^3 at 28 days, respectively 0.06-0.13 g/cm^3 at 56 days. Implicitly, occur an increasing of water absorption with 2.05-4.67% at 28 days, respectively 0.64-3.97% at 56 days. In good correlation with these variations, the values of mechanical strengths present a slight decrease.

Thus, at the term of 28 days, the flexural strength decreases with maximum 0.4 MPa, and compressive strength decreases with maximum 0.8 MPa. At the term of 56 days, the decreasing of the values for mechanical strength is lower significant.

The assess of the *fungitoxic effect* is shown in Table 4.

After one month of incubation results were as follows:

- Inoculum was developed on the surface of mortars as well as in microcracks (due to carbonation process); biodeterioration was in progress;
- Atypical growth of hyphae had been noticed with intensive branching.

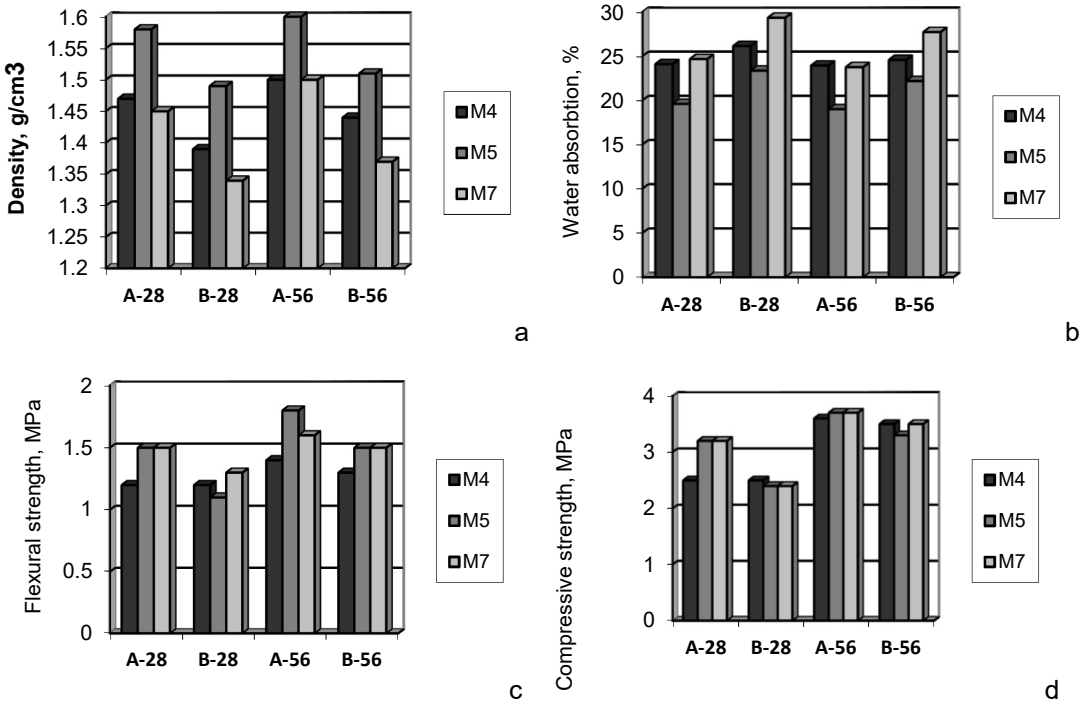


Fig.4 - Apparent density (a), water absorption (b), flexural strength (c) and compression strength (d) at 28 and 56 days versus tow dimension (A – 12 mm, B – 5 mm) / *Densitate aparentă (a), absorbţie de apă (b), rezistenţa la încovoiere (c) şi rezistenţă la compresiune (d) la 28 şi 56 zile vs dimensiune călţi (A – 12 mm, B – 5 mm)* .

Table 4

Assessment of fungitoxic effect of mortars / *Evaluarea efectului fungitoxic al mortarelor*

Mortar code ***Cod mortar***	**No inoculated** ***Neinoculat***	**Inoculated /** ***Inoculat***		**Inoculated + glucose** ***Inoculat + glucoză***	
			Fungistatic / *Efect fungitoxic* Fungistatic effect / *Fungitoxic*		Fungistatic effect *Fungitoxic*
M4-A	0	0*	Partial for germination *Parţial pentru germinare*	3	Total for germination *Total pentru germinare*
M5-A	0	3	Total for germination *Total pentru germinare*	5	Absent */ Inexistent*
M6-A	0	3	Total for germination *Total pentru germinare*	5	Absent */ Inexistent*
M7-A	0	0*	Partial for germination *Parţial pentru germinare*	0*	Partial for germination *Parţial pentru germinare*

*Monitoring the fungal growth in time, will explain if sporulated mycelium has as origin inoculum or is a result of spores germination

3. Conclusions

In paper were presented researches regarding obtaining of some materials which to serve in the process of consolidation of mural painting on wooden support. A series of mortars based on hydrated lime, river sand, fibers (hemp tow), and an acrylic additive were performed and characterized.

Based on the results of the performed determinations the following appreciation was made:

- using of acrylic additive lead to improvement of mortars adherence at small wooden plates;
- using either of tow, or of the additive lead to improvement of mechanical strengths of the mortars, the tow being more efficient; the water vapor permeability is not negative influenced;
- concomitant using of the tow and additive determine the obtaining of the best mechanical strengths of the mortars;
- diminishing of tow dimension determines the decreasing of mechanical strengths;
- by varying of aggregate proportion it was obtained a maximum of mechanical strengths in the case of the mortars with the binder/aggregate ratio of 1/1;
- mortars have a low resistance to biodeterioration so, its improvement could be performed by adding biocides.

The researches will continue with supplementary tests in order to evaluate the durability of these mortars (resistance at frost-thawing and salts action). From microbiological point of view adding a proper biocid in mortars could be a preventive solution in restoration and conservation of historical monuments.

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