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PHYSICAL, MECHANICAL AND AESTHETIC CHARACTERISTICS OF SOME MORTARS BASED ON THE LIME–LIMESTONE–META-ARGILITE SYSTEM

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Lucrarea furnizează informații privind caracreristicile unor tipuri de mortar cu o structură pe bază de nisip de râu-var-piatră de var-meta-argilit, proiectate pentru păstrarea şi restaurarea lucrărilor în ghips din monumentele istorice. Investigația s-a făcut cu precădere asupra proprietăților chimice, fizice şi cromatice ale materialelor brute. Variatele compoziții ale tipurilor de mortar folosite pentru analiza lucrării au fost caracterizate din punct de vdere al proprietăților lor fizice, mecanice şi estetice în termen de 28 şi 56 de zile. Au fost realizate corelări între caracteristicile materialelor brute şi ale tipurilor de mortar, şi arătat efectul acestor caracteristici şi proporțiile materialelor brute asupra proprietăților fizice, mecanice şi cromatice ale tipurilor de mortar

The paper brings information regarding the characteristics of some coloured mortars based on lime–limestone–meta-argilite–river sand, designed for preservation and restoration of the plasterwork in historical monuments. The investigation focused on the chemical, physical and chromatic properties of the raw materials. The various compositions of mortars designed for the purpose of the work were characterized in terms of their physical, mechanical and aesthetic properties at 28 and 56 days. Correlations have been made between the characteristics of the raw materials and the mortars; and the effect of these characteristics and the ratios of raw materials on the physical, mechanical and chromatic properties of the mortars was inferred.

Keywords: Lime mortar, Limestone, Pozzolana, Mechanical properties, Colour

1. Introduction

When using binders in the work of preservation and restoration, the physical and mechanical properties of the work of art which is intervened upon must be maintained and its aspect should remain untainted. Both the binders employed in the work of preservation and restoration of historical monuments, as

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well as their quality depend primarily on the materials in the monument. In this respect, lime mortars feature mechanical and physical properties similar to those of the mortars in vintage masonry, and so they are desirable for historical monument restoration. In literature there are studies regarding the influence of the nature and the ratio of the raw materials on the characteristics of lime mortars, as well as ways to improve them. The factors which can influence the characteristics of the mortars include the nature of the binder and aggregate, the ratio binder/aggregate, the ratio water/binder, the presence of additions and the porosity of the mortar. Thorough control of these will help model the characteristics of future materials to be employed in restoration [1–8].

The paper presents the investigations carried out on the physical, mechanical and chromatic properties of some mortars obtained using hydrated lime, fine limestone, meta-argilite and river sand. Focus was placed on the way in which the type and ratio of the raw materials—various limestone and meta-argilite sorts, in this case—influence the quality of the mortars.

2. Experimental

2.1 Materials

The raw materials used in developing the binders included *hydrated calcium lime, meta-argilite*[5] and *limestone*. Two sorts of meta-argilite were employed, which differed mostly in colour: red and lilac. The raw materials were chemically characterized in terms of chemical composition (according to SR EN 196–2 [9]) and, in the case of limestone, in terms of clay content (according to SR EN 933–9 [10]) and total organic carbon or TOC (according to SR EN 13639 [11]) (Table 1).

Table 1

Chemical composition of the raw materials

Characteristics, %	**Raw materials**				
	Hydrated calcium lime V	**Meta-argilite**		**Limestone**	
		Red (P)	**Lilac (P2)**	**C1 white**	**C2 ochre**
L.O.I.	29.74	2.95	1.38	43.58	24.54
SiO_2	0.13	54.30	56.17	0.30	41.59
Al_2O_3	0.43	21.56	23.99	0.41	2.14
Fe_2O_3	0.39	7.31	7.28	0.12	0.41
CaO	68.04	4.99	3.59	54.43	29.66
MgO	0.77	2.35	2.17	0.49	0.59
SO_3	0.04	1.94	0.43	0.03	0.06
Na_2O	0.23	1.26	1.19	0.16	0.26

[5] *Meta-argilite* is clay which has undergone important changes as a result of spontaneous ignition in coal deposits.

K_2O	0.02	3.13	3.10	0.04	0.42
TiO_2	–	0.56	0.72	–	–
Clay content	–	–	–	nd	0.84
TOC	–	–	–	0.04	0.03
$CaCO_3$	–	–	–	97.20	52.96
Reactive SiO_2	–	34.82	34.02	–	–

The X-ray diffraction analysis showed that the powder of hydrated lime contained mostly $Ca(OH)_2$ along some $CaCO_3$.

The meta-argilite contained 34–35% reactive silica, which was determined by means of chemical analysis, and presented a mostly vitreous structure. The latter was indicated by a halo in the diffractograms in the small angle domain (i.e., $2\theta = 15\div35$), which lend the meta-argilite pozzolanic properties. The X-ray diffraction revealed, as crystalline phases and through specific interferences, the following mineralogical compounds:

- Quartz and hematite in the red meta-argilite, P1; and
- Indialite, quartz, calcite, hematite, opal and metacaolinite in the lilac meta-argilite, P2.

The hematite contained in the meta-argilite is probably the mineralogical phase which gives the mineral its colour (i.e., red and lilac).

The meta-argilite had a porosity, microscopically determined, of 10–15% in the case of meta-argilite P1 and below 1% in the case of the meta-argilite P2.

The limestone sorts differed in colour, being white or ochre, and also in their compositional characteristics, namely, the content of calcite ($CaCO_3$) and silica (SiO_2). Limestone C1 (white) contained the highest amount of calcite (97.20%), and limestone C2 (ochre) had the highest content in silica (41.59%). The ochre colour is given by iron oxides and hydroxides microscopically identified, which were present in a ratio of 0.5–1% in the micritic component of limestone C2.

From the physical point of view, the limestone sorts and the meta-argilite presented the following water absorption values, as determined on pieces of rock according to the method described at Chapter 2.3: limestone C1 = 0.15%; limestone C2 = 6.41%; meta-argilite P1 = 23.54% and meta-argilite P2 = 7.24%.

The mortars were prepared using *river sand*, namely, the sort of 0–2 mm. The grain size distribution of the river sand is shown in Table 2.

Table 2

The grain size distribution of the river sand

Grain size class	Passed on sieve (%)
< 2 mm	100
< 1.25 mm	87.76
< 630 μm	63.60
< 318 μm	17.04
< 160 μm	1.05

The sand employed contained traces of mica, but no clay lumps.

The chromatic characterization of the raw materials

The chromatic characterization of the raw materials was carried out both by visual perception and by using a GRETAG MACBETH spectrophotometer (with D65 light source and an incidence angle of 10°) for determining the chromatic parameters on the green–red (a*) and blue–yellow (b*) axes, the luminosity[6] (L*) and the saturation[7], the last being indicated by a ring of 100 unit and the centre at the intersection of axes a* and b*.

Under visual examination, the raw materials in powder presented the following main characteristics:

- In chromatic terms, the lime (V) and the white limestone (C1) belong to the non-colours category, and are situated at the superior pole of white in the Runge *chromatic sphere* [12]. Together with black, which is situated at the inferior pole, they serve to break the colours and obtain infinitely varied hues straight to the (neutral) grey axis.
- The ochre limestone (C2) is situated in the bright yellow zone, qualifying for the warm colour group.
- The red meta-argilite (P1) belongs to the warm colours, and, according to the *colours star* conceived by Johannes Itten [13], is situated in the red-luminous tonality zone.
- The lilac meta-argilite (P2) belongs to the warm colour border-zone, with a red-lilac tonality.

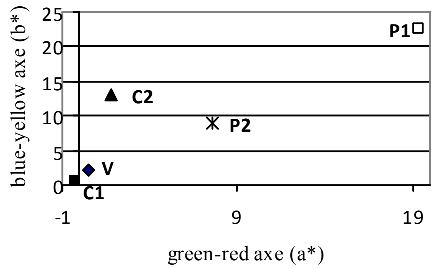
The colorimetric analysis highlighted the belonging of almost all the raw materials to the red-yellow area, close to the intersection of the blue-yellow and green-red axes (Fig. 1a). The white limestone (C1) is an exception being situated in the green-yellow area, right next to the intersection of the two axes.

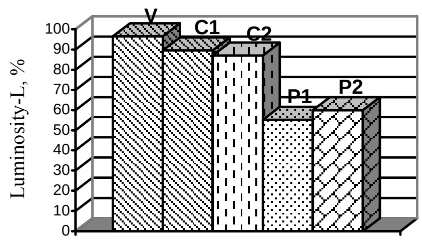
It is worth making some remarks regarding the *chromatic quality* of the raw materials used for the mixtures; a quality which was appreciated by the degree of purity/saturation of the colours.

By their intrinsic nature, none of the raw materials employed in the present research was able to offer anything more than a limited degree of purity, with them being situated in the vicinity of the saturation ring centre (the intersection of the green-red and blue-yellow axes). In terms of luminosity, the lime and the limestone brought the highest values (Fig. 1b).

[6] Colour luminosity is measured on a scale (from 0 to 100) from white to black, where white represents the maximum degree of luminosity, and black the minimum degree.

[7] Colour saturation or colour purity (named also chrome) is determined by the quantitative ratio between the spectral colour and the white colour. Spectral colours, being pure colours, present a maximum saturation. By adding different quantities of white to the spectral colours, different tones of unsaturated colours are obtained.





a. b.

Fig. 1 Colorimetric analysis of the raw materials: a–chromatic parameters on the green-red axes (a*), blue-yellow axes (a*); b – luminosity, L

It must be mentioned that the sand was a permanent presence in the mortar mixtures albeit it brought no significant chromatic quality change to them.

2.2 Experimental conditions

Five binder mixtures were developed in the lime–limestone–meta-argilite system (Table 3), with a constant ratio lime/meta-argilite of 1/0.6 gravimetric parts. Mixtures 1, 3, 4 and 5 maintained the same ratio of limestone related to the amount of lime and meta-argilite. Mixtures 1 and 2 were designed with a varied ratio of limestone but keeping the same sort of limestone and ratio lime/meta-argilite. Table 3 shows the compositions of the mixtures in gravimetric parts.

Table 3

The binder compositions in the lime–limestone–meta-argilite system

Components in the binder	**Symbol**				
	1	**2**	**3**	**4**	**5**
Lime (V)	1	1	1	1	1
White limestone (C1)	0.9	0.3	0.9		
Ochre limestone (C2)				0.9	0.9
Red meta-argilite (P1)	0.6	0.6		0.6	
Lilac meta-argilite (P2)			0.6		0.6

The limestone sorts were ground up to a fineness corresponding to a residue of about 6% on the sieve with a 90 μm aperture. The meta-argilite sorts were ground up to the same fineness in order to increase their reactivity. The laser grain size distribution of the above, as determined with a CILAS 715 laser granulometer in an aqueous suspension, is presented in Table 4.

Table 4

The laser grain size distribution of the limestone sorts

Raw materials	Grain size distribution (%)				D_{50} (µm)
	< 3 µm	< 6 µm	< 16 µm	< 32 µm	
Limestone C1	53.1	68.7	79.5	85.0	2.8
Limestone C2	47.0	61.8	71.6	79.0	3.6
Meta-argilite P1	28.6	42.3	62.1	76.6	9.0
Meta-argilite P2	12.5	23.4	40.4	62.3	21.9

The data in the Table shows large amounts of fine granular material in the limestone sorts—the cumulative passing reaches 50% at an average particle diameter (D_{50}) of 2.8 µm for the white limestone and 3.6 µm for the ochre limestone. Another remark is that the red meta-argilite, P1, is finer (D_{50} = 9.0 µm) than the lilac meta-argilite, P2 (D_{50} = 21.9 µm).

Each binder mixture was mixed with river sand in a ratio of 1 to 1.17 binder-to-sand gravimetric parts, with obtaining of the corresponding mortars: M1, M2, M3, M4 and M5.

2.3 Testing methods

The mortars were characterized in terms of physical characteristics (consistency determined by the spreading method, apparent density, water absorption, adherence to support, permeability at water vapours) and mechanical characteristics (mechanical resistance at bending and compressive strength) by using the standards and the methods below.

The *consistency* of the mortars was determined with the spreading mass according to SR EN 1015–3 [14].

The *apparent density* was determined according to STAS 2634–80 [15] at the terms of 28 and 56 days.

The *water absorption,* determined on specimens of 4 cm x 4 cm x 16 cm, was carried out by weighing the dry sample followed first by gradual and then by total immersion in distilled water. Wet sample weighing was carried out within 24 hours of the total immersion, with the weighing being repeated every two hours until the difference between two consecutive weights was 0.2% at the most.

The water absorption (abs) was determined at the terms of 28 and 56 days and was expressed as percentage based on the formula:

$$abs = \frac{(m_1 - m_0)}{m_0} x100 \quad (\%) \tag{1}$$

where: m_o is the dry mass of the specimen, in g, and
m_1 is the wet mass of specimen, in g.

The *adherence to support* was determined according to SR EN 1015:12 [16], with the mention that mortar application was done on a previously wetted, solid brick and the thickness of the layer was of about 6 mm. The testing was performed using a DYNA Z16 apparatus at the term of 28 days. The values of the adherence are expressed in N/mm^2. The adherence to support was also evaluated by means of breaking. This can occur in the mortar, at the interface mortar–support, or in the support on which the mortar is applied for testing.

The *mechanical strength at bending and compression* was determined according to SR EN 1015–11 [17]. The specimens were tested at the terms of 28 and 56 days.

Permeability at water vapours is a characteristic which must be taken into consideration in the case of mortars designed for the work of preservation–restoration of historical monuments. The permeability at water vapours was determined at the term of 28 days according to standard SR EN 1015–19 [18], on cylindrical specimens kept in the conditions specified in the standard. The determination was carried out using a saturated aqueous solution of KNO_3.

The mortars were also analysed from the *chromatic* point of view both by visual examination and by using a GRETAG MACBETH spectro-photocolourimeter for determining the chromatic parameters L*, a* and b*.

The consistency of the fresh mortars was 140±10 mm.

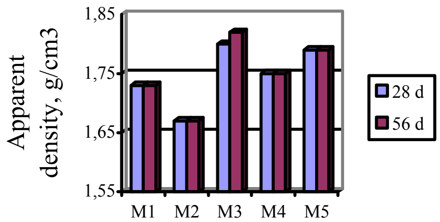
3. Results and discussions

Physical and mechanical characteristics

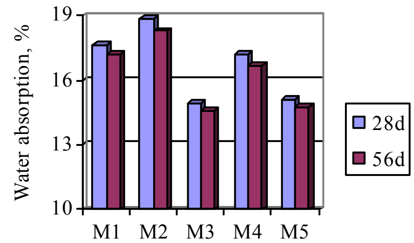
At 28 days, the mortars presented values of *apparent density* between 1.67 g/cm^3 (M2) and 1.80 g/cm^3 (M3). At the term of 56 days, no increases of the apparent density were noticed (Fig. 2a).

The values of *water absorption* were situated between 14.96% (M3) and 18.84% (M2) at the term of 28 days (Fig. 2b). At the term of 56 days, a decrease in the water absorption was noticed by 2.45–3.37% as compared to that at the term of 28 days. The values obtained for the mortars having been investigated in this study were close to the values determined on some mortar samples taken from historical monuments, with the latter being generally high enough, that is, 16–20%.

As far as the *compressive strength* was concerned, it was found that there was a variation of these values at the term of 28 days, i.e., between 1.5 MPa (M5) and 4.2 MPa (M2) (Fig. 3). The values increased slightly at the term of 56 days, generally by 0.2–0.3 MPa, with the exception of M1 with an increase in strength of 1.4 MPa. It was found that the mortars had low-to-moderate mechanical strengths, which was deemed optimal in the preservation–restoration work as well as in treating the existing lacuna in the mural picture support and the rendering of historical monuments. According to SR EN 998–1 [19], the mortars were type CSII, with strengths between 1.5 and 5 MPa.



a.



b.

Fig. 2 Graphic representation of the apparent density (a) and the water absorption (b) at 28 and 56 days

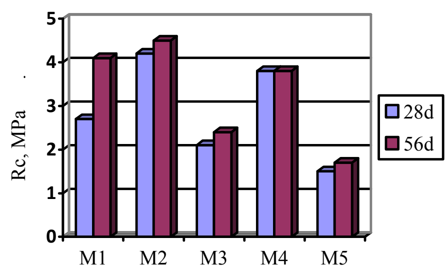
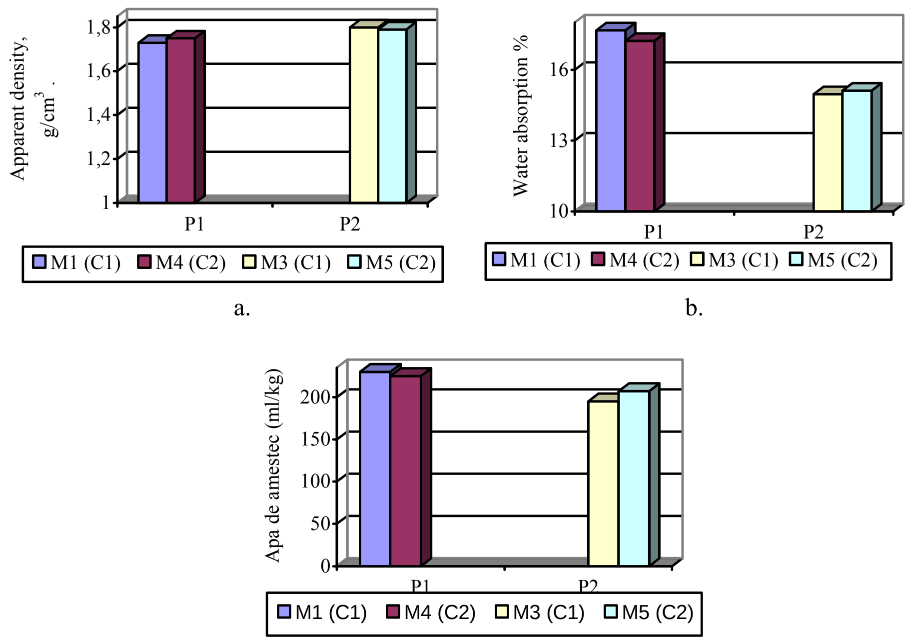


Fig. 3 Compressive strengths (Rc) of the mortars at the terms of 28 and 56 days

The influence of the sort of limestone

The sort of limestone had no significant effect on the values of the apparent density. At the term of 28 days, the density difference was of 0.02 g/cm^3 in the case of mortars M1 (with limestone C1) and M4 (with limestone C2) containing meta-argilite P1 and of 0.01 g/cm^3 in the case of mortars M3 (with limestone C1) and M5 (with limestone C2) containing meta-argilite P2 (Fig. 4.a). The same slight influence of the sort of limestone was found on the water absorption. At the term of 28 days, the water absorption difference was of 0.44% in the case of mortars M1 and M4 with meta-argilite P1 and of 0.16% in the case of mortars M3 and M5 with meta-argilite P2 (Fig. 4.b). These variations of the values of apparent density and water absorption are given rather of the different quantity of mixing water (Fig. 4.c), wich is necessary to obtain the same consistency of the mortars (a scattered of the 145-146 mm); smaller quantities of mixing water have resulted in obtaining of somewhat more dense and less absorbent mortars.



c.

Fig. 4 The influence of the sort of limestone on the apparent density (a), the water absorption (b) at 28 days and mixing water (c)

Also, concerning the compressive strenght there is no significant influence of type of limestone (Fig. 5). At the term of 56 days, the difference is small - 0.3 MPa - for the mortars M1 and M4 (with meta-argilite P1) and slightly higher - 0.7 MPa - for the mortars M3 and M5 (with meta-argilite P2).

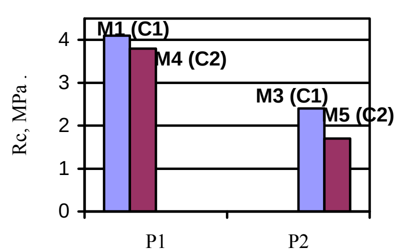
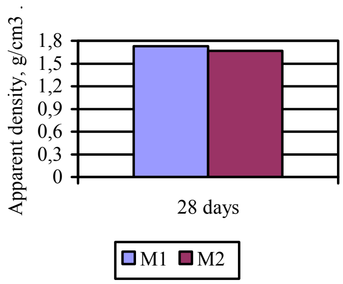


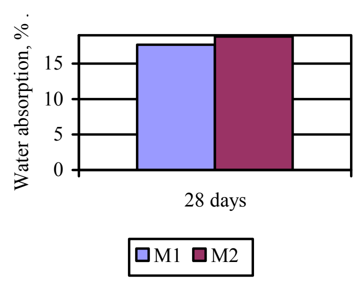
Fig. 5 The variation of the mechanical strengths against the sort of limestone when maintaining the same sort of meta-argilite

The influence of the limestone proportion

At the term of 28 days and for mortars M1 and M2 in which the sort of meta-argilite and the ratio lime/meta-argilite were the same and the ratio of limestone (C1) was different, it was found that the density was higher for the mortar with a higher content in limestone (M1 with 0.9 limestone gravimetric parts as compared to M2 with 0.3 limestone gravimetric parts). Consequently, the absorption was lower (Fig. 6a,b). This is correlated with the fact that the limestone rock is more compact in structure than the hardened binder, for which it is a substitute in the composition of the mortar. Mortar M2, with a smaller content in limestone, developed better mechanical strengths especially at the term of 28 days. To this, the pozzolanic reaction with formation of silicate hydrates CSH may contribute to a greater extent because of its higher content in lime and meta-argilite as compared to M1. (Fig. 6c).



a.



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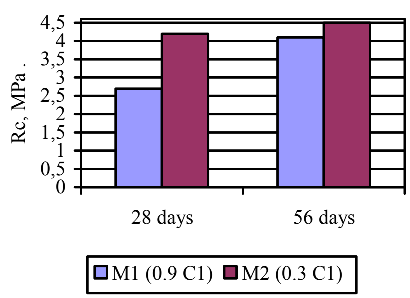
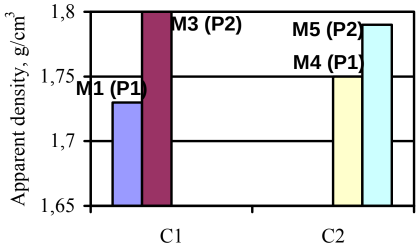


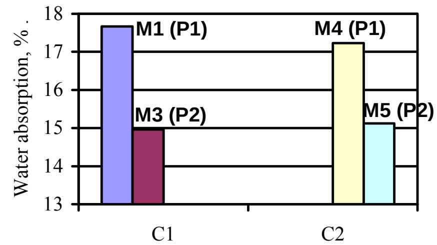
c.

Fig. 6 Graphical representation of the physical and mechanical characteristics of the mortars with variable content of limestone C1 and the same lime/meta-argilite P1 ratio: a – apparent density; b – water absorbtion; c – compressive strenght

The influence of the sort of meta-argilite

When the same sort of limestone and the same compositions were kept and the sort of meta-argilite (M1, M3 and M4, M5) differed, it was found, in terms of physical characteristics, that the mortars with meta-argilite P2 (M3, M5) were more dense and the absorption was lower (Fig. 7) as compared to those with meta-argilite P1 (M1, M4). This may be due to the different grinding fineness of the two meta-argilites—P1 is finer (D_{50}=9.0 μm) than P2 (D_{50}=21.9 μm).

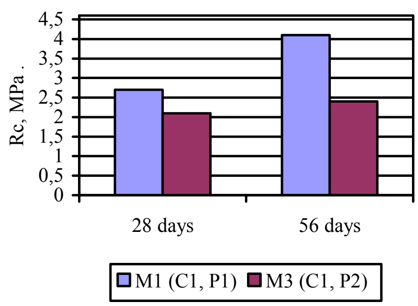


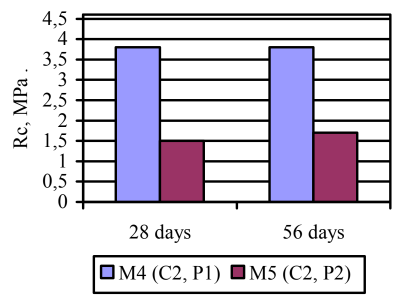


a. b.

Fig.7 The variation of the physical characteristics against the sort of meta-argilite: a – apparent density; b – water absorption

The mechanical strengths at compression were lower in the case of the mortars with meta-argilite P2 (M3, Fig. 8a and M5, Fig. 8b).





a. b.

Fig. 8 The variation of the mechanical strengths against the sort of meta-argilite when maintaining the same sort of limestone: a – C1; b – C2

It was found that, at the term of 56 days, for the mortars with limestone C1 (M1 and M3), the compressive strength of the mortar containing meta-argilite P1 was about 70% higher than that containing meta-argilite P2. In the case of the mortars with limestone C2, mortar M4 with meta-argilite P1 had also at the term of 56 days a higher compressive strength (by about 123%) than that of mortar M5 with meta-argilite P2. The difference in strength may be due to the higher grinding fineness of meta-argilite P1 (D_{50}=9.0 μm) as opposed to meta-argilite P2 (D_{50}=21.9 μm). This contributed to an increasing of the reactivity of meta-argilite P1, which had resulting in the end the higher mechanical strengths in the case of the mortars with meta-argilite P1.

The values of the *adherence to support* and the mode of breaking are presented in Table 5.

Table 5

The adherence of the mortars in the lime–limestone–meta-argilite–river sand system

Mortars	Adherence at 28 days	
	Adherence, N/mm²	Mode of breaking
M1	0.25	80% in mortar +20% at interface
M2	0.30	50% in mortar +50% at interface
M3	0.20	95% in mortar +5% at interface
M4	0.24	50% in mortar +50% at interface
M5	0.15	40% in mortar +60% at interface

The standard SR EN 998–1 [19] lays down no specific value for the adhesion. Instead, it lays down an imposition of maintaining the declared value. The values of the adherence were below 0.3 N/mm^2, which is a moderated value for lime mortars used in preservation and restoration of monuments. The breaking takes place mainly in the mass of the mortar, which confirms both a good adherence to support and an assurance that there is no risk of ruining the support on which the mortar is applied, by stripping out material from the support.

The values of *permeability at water vapours* are presented in Table 6.

From the data in the Table it is found that the values of the water vapour permeance are generally between 3.56×10^{-10} and 3.91×10^{-10} kg/m^2sPa. Exception makes mortar M1, which has a slowly lower value (1.41×10^{-10} kg/m^2sPa) and M5 with a value one order lower (3.77×10^{-11} kg/m^2sPa). The literature [20, 21] makes reference at the basic requirements of a coating material (plastering), among which the permeance at water vapours is one. This is recommended to be between 2×10^{-10} and 6×10^{-10} kg/m^2sPa. According to these data, mortars M2, M3 and M4 had a good permeability at water vapours. Furthermore, in order that a material be more permeable, the permeability coefficient must be as small as possible. The standard SR EN 998–1:2004: “Specification of the mortars for masonry. Part 1: Mortars for plastering and cement rendering” [19] lays down a value of the permeability coefficient for water vapours lower than 15 in the case of “mortars for redecoration (R)”. From this point of view, all mortars had good permeability at water vapours. Some specifications of restoration products stipulate a coefficient of 0.01 up to 6 [22, 23].

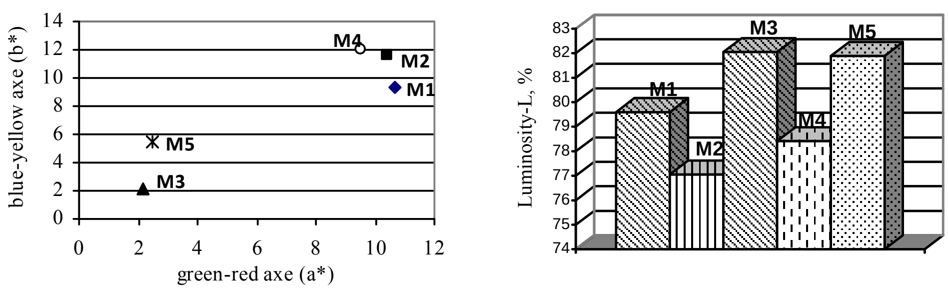
Table 6

The permeability at water vapours of the mortars

Mortars	**Permeability at water vapours**		
	Permeance, (kg/m^2sPa)	**Flow of water vapours, (kg/s)**	**Coefficient at permeability at water vapours**
M1	1.41×10^{-10}	2.22×10^{-9}	1.38
M2	3.67×10^{-10}	5.66×10^{-9}	0.53
M3	3.56×10^{-10}	5.49×10^{-9}	0.55
M4	3.91×10^{-10}	6.09×10^{-9}	0.495
M5	3.77×10^{-11}	5.92×10^{-9}	5.16

➔ ***Evaluation of the aesthetical characteristics: the chromatic and aesthetic characterization of the mortars***

The mixtures made with the raw materials presented above led to coloured mortars making a succession of luminous, pastel hues from warm to cold. Luminous grey tonalities situated mostly in the yellow-red area of the warm colour group, close to the intersection of the green-red and blue-yellow axes (fig. 9a), were dominant.



a. b.

Fig. 9 Colorimetric analysis of the mortars: a – chromatic parameters on the green-red (a*) and blue-yellow (b*) axes; b – luminosity, L

The mortars containing meta-argilite P2 (M3 and M5) had a higher luminosity than those containing meta-argilite P1 (M1 and M4) due to the higher value of the luminosity of meta-argilite P2 (59.87 units) as opposed to P1 (55.18 units). Decreasing the ratio of white limestone C1—which had a luminosity of 89.48 units—from 0.9 gravimetric parts (mortar M1) to 0.3 gravimetric parts (mortar M2) and its replacing with a corresponding content in lime and meta-argilite P1—in which the luminosity of meta-argilite P1 was of 55.18 units—determined a decreasing in the luminosity of mortar M2 (to 77.05) as opposed to M1 (79.60) (Fig. 9b).

From the visual standpoint, the mortars are in a warm–cold relation because of a simultaneous contrast. According to this, the presence of a warm(/cold) colour nearby the mortar may bring out the cold(/warm) tonality of the mortar.

4. Conclusions

The paper presented the characterization of a series of mortars developed from hydrated lime, fine limestone, meta-argilite and river sand. At the same time, the influence of the nature and the ratio of these components on the characteristics of the mortars was investigated.

Based on the results of the investigation, it may be stated that all investigated mortars presented—

- Low values of apparent density and water absorption values, close to those determined on samples taken from historical monuments;
- Values of compressive strength adequate for materials employed in preservation–restoration interventions upon historical monuments;
- Good adherence to support, with the breaking taking place in the mortar mass;
- Good permeability at water vapours.

The sort and ratio of limestone had an influence on the characteristics of the mortars to the effect that—

- The type of limestone no significantly affects physical and mechanical characteristics of mortars;
- By decreasing the ratio of limestone—
  - Mortars were less dense and became more absorbent as a consequence of a higher amount of hardened binder (lime and meta-argilite), which was less compact in structure as opposed to the limestone;
  - The compressive strengths had a slight increase. With the higher content in lime and meta-argilite, a possibly higher impact of the pozzolanic reaction may have contributed to this, with formation of silicate hydrates CSH.

The use of different sorts of meta-argilite revealed the following aspects:

- The physical characteristics (density and water absorption) of the mortars were influenced by the grinding fineness of the meta-argilite. That is to say that the more advanced fineness, the higher porosity and the higher absorption of meta-argilite P1 as opposed to P2 led to obtaining mortars with lower apparent density and higher water absorption.
- The compressive strength of the mortars with meta-argilite P1 was higher than those with meta-argilite P2 as a consequence of a more advanced grinding fineness of meta-argilite P1 as opposed to P2. This led to an intensification of the pozzolanic reaction between the lime and the reactive silica.

From the chromatic standpoint, both the ochre limestone (C2) and the two meta-argilite sorts imprinted luminous, pastel hues on the mortars developed in the study.

Aknowledgement

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