DEPARTMAN ZA GRAĐEVINARSTVO I GEODEZIJU

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15. međunarodna naučna konferencija

15th International Scientific Conference

iNDiS

Planiranje, projektovanje, građenje i obnova graditeljstva

Planning, Design, Construction and Building Renewal

2021

24-26 November 2021
Novi Sad, Serbia

Zbornik radova
Proceedings

Editors: V. Radonjanin, V. Vukobratović, I. Lukić

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Međunarodna naučna konferencija
International Scientific Conference

ZBORNIK RADOVA
Novi Sad, Srbija, 24-26. novembar 2021.

PROCEEDINGS
Novi Sad, Serbia, 24-26 November 2021

Organizaciju Konferencije i izdavanje Zbornika radova pomogli su suorganizatori i donatori Konferencije svojim prilozima

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Tehnička organizacija skupa: Departman za građevinarstvo i geodeziju, Fakultet tehničkih nauka, Novi Sad

Tehnički urednik zbornika radova: Ivan Lukić

Izdavač: Departman za građevinarstvo i geodeziju, Fakultet tehničkih nauka, Novi Sad

Štampa: Departman za grafičko inženjerstvo i dizajn, Fakultet tehničkih nauka, Novi Sad

CIP - Каталогизација у публикацији
Библиотеке Матице српске, Нови Сад

69.05(082)(0.034.4)
624(082)(0.034.4)
72:502.1(082)(0.034.4)

МЕЂУНАРОДНА научна конференција Планирање пројектовање, грађење и обнова градитељства ИНДИС (15 ; 2021 ; Нови Сад)
Zbornik radova [Elektronski izvor] = Proceedings / 15. međunarodna naučna konferencija Planiranje projektovanje, građenje i obnova graditeljstva iNDiS 2021, Novi Sad, 24-26. novembar 2021. = 15th International Scientific Conference Planning, Design, Construction and Building Renewal [iNDiS], Novi Sad, 24-26 November 2021 ; urednici V. Radonjanin, V. Vukobratović, I. Lukić. - Novi Sad : Fakultet tehničkih nauka, Departman za građevinarstvo i geodeziju, 2018. - 1 elektronski optički disk (CD-ROM) : tekst, ilustr. ; 12 cm

Sistemski zahtevi: Nisu navedeni. - Nasl. sa naslovnog ekrana. - Elektronska publikacija u formatu pdf opsega 1131 str. - Bibliografija uz svaki rad. - Rezime na engl. jeziku uz svaki rad.

ISBN 978-86-6022-253-6

а) Индустријска градња -- Зборници б) Грађевинске конструкције -- Зборници в) Архитектура -- Еколошка градња -- Зборници

COBISS.SR-ID 51562505

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PHYSICAL, MECHANICAL AND DURABILITY ASPECTS OF LIME-BASED COATINGS WITH ADDITION OF NATURAL ZEOLITE

Abstract: Lime-based renders were usually placed in several layers, each of them having specific role and composition. In this paper, physical and mechanical properties of lime mortars for the final layer (coating) at the age of 90 and 180 days were presented. Durability aspect of the tested mortars was considered through testing of their behavior in the presence of the soluble salts. Four mortar mixtures were tested (one reference mortar and three mortars with partial replacement of lime with natural zeolite). For all mortars tested it can be seen that there was no improvement in strength between two tested ages. Mortar with 30% of lime replaced with zeolite reached higher value of compressive strength and almost the same value of capillary water coefficient as reference mortar. Vapor permeability grew with the increase of the natural zeolite content. Mortars showed good resistivity to the presence of sodium-chloride and developed cracks and loss of compressive strength when exposed to the solution of sodium-sulfate.

Key words: lime putty, durability, rendering mortars, natural zeolite, restoration

FIZIČKO-MEHANIČKI I ASPEKTI TRAJNOSTI KREČNIH MALTERA ZA MALTERISANJE SA DODATKOM PRIRODNOG ZEOLITA

Rezime: Krečni malteri za malterisanje su obično nanošeni u više slojeva, od kojih je svaki imao specifičnu ulogu i sastav. U ovom radu prikazani su rezultati ispitivanja fizičkih i mehaničkih svojstava za poslednji (završni) sloj maltera pri starosti od 90 i 180 dana. Aspekt trajnosti je sagledavan kroz ispitivanje ponašanja uzoraka u prisustvu rastvorljivih soli. Četiri malterske mešavine su ispitivane (jedna referentna i tri maltera sa delimičnom zamenom kreča prirodnim zeolitom). Kod svih maltera je primećeno da nije bilo porasta vrednosti čvrstoće pri pritisku pri dve ispitivane starosti. Malter sa 30% zamene kreča zeolitom, dostigao je više vrednosti čvrstoće pri pritisku i skoro iste vrednosti koeficijenta kapilarnog upijanja, u odnosu na vrednosti izmerene na referentnom malteru. Paropropustljivost je rasla sa povećanjem procenta učešća zeolita. Malteri su pokazali dobru otpornost na dejstvo rastvora NaCl, a razvili su oštećenja u vidu prslina i pad vrednosti čvrstoće pri pritisku kada su bili izloženi dejstvu rastvora Na_2SO_4.

Ključne reči: krečno testo, trajnost, malteri za malterisanje, prirodni zeolit, restauracija

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1. INTRODUCTION

Lime-based mortars have been used throughout centuries for bedding and rendering of masonry buildings. During the nineteenth and twentieth century they were neglected and reduced to use in special cases, while the most of the mortars were prepared with hydraulic binders, especially cement, that created a revolution in the construction sector. Nevertheless, in the last forty years lime-based mortars are finding their way back, through application in the restauration and preservation of architectural cultural heritage. They also have lower energy consumption and lower contribution to the global warming potential when compared to cement [1].

Historically, lime-based renders were placed always in several layers, each of them having a specific composition and properties. Inner layers served as a link between substrate and upper render layers. They also served to improve irregularities of the substrate. Maximum grain size in this layer was usually 4 mm, while binder to aggregate ratio was 1:4 of 1:3 (by volume). Middle layer served as a link between inner and outer layer of renders. Its composition was similar to the inner layer, sometimes with increase in the binder content. Outer or final layer (coating) was the thinnest, with maximum grain size of 0.5 mm and binder to aggregate ratio of 1:1 or 1:0.5. Apart from good drying ability, and lower capillary water absorption, this layer had an aesthetical role. At the same time, this layer was the most exposed part of the system to the environmental influences [2].

Although during the last forty years investigations regarding lime-based mortars have been numerous, most of them were considering mixtures with binder to aggregate ratio of 1:3 (both by mass and volume). The number of studies investigating the properties of lime-based coatings with higher binder content has been much lower.

Veiga et al. reviewed the boundaries for most important physical and mechanical properties based on the experiments performed on lime mortars with different binder to aggregate ratio. For mixtures where this ratio is 1:1, boundaries for flexural strength are 0,4 and 0,5 MPa, for compressive strength 0.5 and 1.2 MPa, and for open porosity 25% and 50% [3].

This paper presents the contribution to the information system of lime-based mortars for the outer render layer (coating). Apart from reference pure lime mortars, mortars with partial replacement of lime with natural zeolite, as the only natural pozzolanic material found in Serbia, have also been discussed. Basic physical, mechanical and durability properties have been investigated at the ages of 90 and 180 days.

2. MATERIALS AND METHODS

Lime putty produced by “Javor”, Veternik (Serbia) was used as a binder in all of the mixtures. At the time of mixing, lime putty was 18 months old (aged for 6 months by the producer, and then 12 months in sealed plastic containers). The water content in the putty was around 50% by mass. Exact amount of water was measured through drying of lime-putty sample for 24 hours before mixing. Zeolitic rock (further referred to as natural zeolite) excavated in Igroš, near Brus (Serbia) was used in this study as a partial replacement for lime. Before application, zeolite was ground to a fineness of 10% residue on 45 μm sieve. Natural river aggregate from the Danube river (Serbia) was used and graded 0/0.5 mm.

Reference mortar contained only lime putty, additional water and sand as component materials, and 3 more mixtures contained natural zeolite as a partial replacement of lime in amounts of 10%, 20% and 30% (by mass). Proportions of mortar mixtures are presented in Table 1.

Reference mortar specimens were kept in molds under humid conditions (relative humidity of 100%) for the first five days after mixing, according to EN 1015-11. After this period, they were cured in laboratory conditions (temperature of 20±2˚C, relative humidity of 50±10%). Samples containing zeolite as a partial replacement of lime were kept in molds under humid conditions (relative humidity of 100%) for the first 48 hours. Afterwards, they were demolded and placed inside plastic containers (relative humidity 100% – RH100) until the time of testing. More detailed information about component materials and composition, preparation and curing of the specimens can be found in the paper [4].

Table 1 – Composition of the tested mixtures [4]

Mixture	Lime (kg/m^3)	Zeolite (kg/m^3)	Fine sand (kg/m^3)	Water (kg/m^3)	Partial replacement of lime (%)	W/B ratio (by mass)
1/1	393	-	916	491	-	1.25
1/1-10	354	39	916	491	10	1.25
1/1-20	314	79	916	491	20	1.25
1/1-30	275	118	916	491	30	1.25

2.1. Testing methods

Results of the most important physical and mechanical properties and chemical/mineralogical analysis of the presented mortars, at the ages of 28, 60 and 90 days are shown in the paper [4]. In this paper some of the results at the age of 90 days were repeated for easier understanding, and the results at the age of 180 days were added. This was performed for the compressive strength test (according to SRPS EN 1015-11), open porosity (according to EN 1936), capillary water absorption coefficient and water absorption (according to SRPS EN 1015-18). Drying curves, according to Italian Norm at the age of 90 days were also presented. Water vapor permeability according to wet cup method was tested (according to SRPS EN 1015-19). At the end, testing of the resistivity to soluble salts action was performed, according to the method presented in the dissertation [5].

For the durability test, two types of the soluble salts were used: sodium-chloride and sodium-sulfate. Both salts were delivered in the specimens using solution concentration of 10% and through capillary water action. Three prismatic specimens were broken into two halves. One of each half was used for test in the presence of sodium-chloride, and the other part of each prism was used for the test in the presence of sodium-sulfate. After the exposure to the salt solution in the duration of 90 minutes, specimens were dried through cyclic changes in temperature and relative humidity, as shown in Fig. 1. The salts were introduced to the specimens only in the first cycle, and in the consequent four cycles deionized water was used. Changes in the specimens' appearance were followed visually. At the end of the test, specimens were dried to constant mass and then tested on compressive strength.

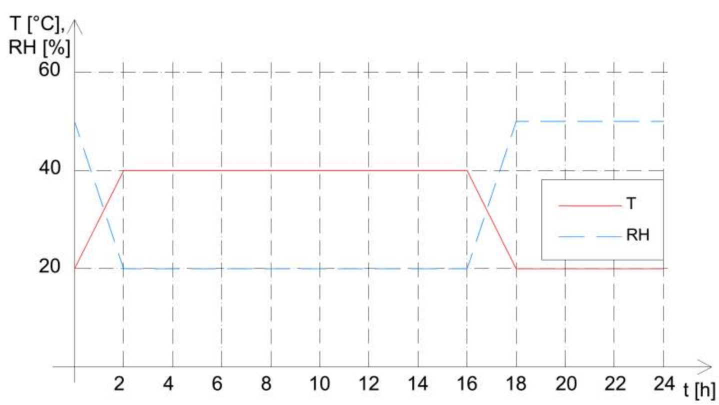

Figure 1 – Daily cycle of drying during the testing of the resistance to the soluble salts [6]

3. TESTING RESULTS

Compressive strength (with standard deviation values) and open porosity of tested mortars were presented in Table 2, while capillary water absorption coefficient and water absorption were presented in Table 3, at the age of 90 and 180 days. There is no significant changes between the values of compressive strength at the two tested ages. The differences between the values are within one standard deviation value. Capillary water absorption coefficient increased only for mortar with 10% of lime replaced with natural zeolite. For mortar with 20% replacement level coefficient was reduced for almost 40%. Water absorption and open porosity values showed similar trend and were reduced for 1-3 percent after the age of 90 days.

Table 2 – Compressive strength (f_c) and open porosity (p_o) of tested mixtures

Mortar type	**f_c (MPa)**		**p_o (%)**	
	90 d	***180 d***	***90 d***	***180 d***
1/1	2.48±0.24	2.46±0.07	38.6	38.4
1/1-10	1.16±0.04	1.01±0.06	44.0	45.2
1/1-20	2.10±0.14	1.82±0.21	47.9	46.9
1/1-30	3.23±0.13	3.27±0.10	46.6	44.9

Table 3 – Capillary water absorption coefficient (A) and water absorption (W) of tested mixtures

Mortar type	**A (kg/m$^2\sqrt{s}$)**		**W (%)**	
	90 d	***180 d***	***90 d***	***180 d***
1/1	0.27	0.28	19.4	18.9
1/1-10	0.75	0.82	29.2	28.2
1/1-20	0.57	0.35	31.0	31.6
1/1-30	0.28	0.28	33.0	27.4

Reference mortars reached higher values of compressive strength than the boundaries found in literature for this property, while the open porosity values were closer to the stated lower limit. When the presented results are compared regarding the influence of natural zeolite replacement level it can be seen that with increase of natural zeolite quantity compressive strength was also increased, and capillary water absorption coefficient decreased. Nevertheless, only values for mortar designated as 1/1-30 were similar or higher than the values reached by reference mortar 1/1. Open porosity and water absorption showed increase with addition of natural zeolite, but the amount of zeolite did not influence the results.

Vapor permeability values measured at the age of 180 days for mortars 1/1, 1/1-20 and 1/1-30 are shown in Fig. 2. This parameter increased with addition of natural zeolite reaching 15% and 37% higher values than for the reference mortar. Since water vapor permeability is one of the crucial parameters for rendering systems, it was very important that the addition of pozzolanic material has a positive influence on its values.

Drying curves for all tested mortars at the age of 90 days are shown in Fig. 3. Drying period increased with addition of natural zeolite, but was not much influenced by the amount of zeolite in the mixture. Since the mixtures containing zeolite absorbed more water before the beginning of the drying these results were expected.

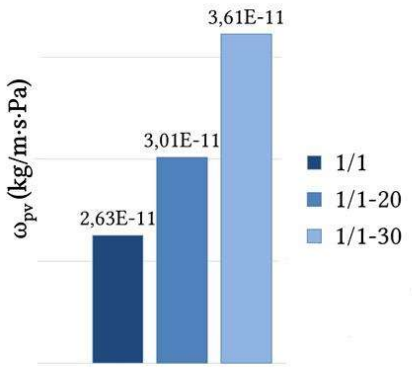

Figure 2 – Water vapor permeability of tested mortars

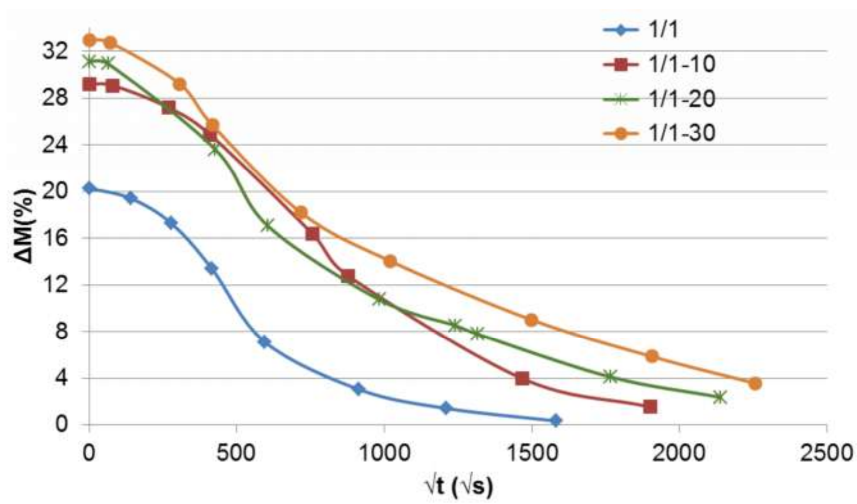

Figure 3 – Drying curves of tested samples at the age of 90 days

Since the samples having only 10% of lime replaced with natural zeolite showed very high values of capillary water absorption coefficient and relatively low values of compressive strength, it was decided not to test their behavior in the presence of the soluble salts. Samples exposed to the action of soluble salts were photographed at the beginning of the test and after each of the cycles. Fig. 4 and 5 present photographs of the selected samples at the beginning and at the end of the test.

For the samples treated with sodium-chloride solution there were no signs of damage at the surface of the samples. Reference mortar had pronounced signs of efflorescence during all cycles, and at the end of the test the efflorescence was intermixed with the surface layer of the mortar. On the surfaces of the mortars 1/1-20 and 1/1-30 there were almost no signs of efflorescence during the whole testing procedure.

Samples treated with sodium-sulfate solution showed different behavior. Already at the beginning of the second cycle deep cracks occurred on the surface of the reference mortar, and on the sides of the mortars containing zeolite (Fig. 6). These damages were only pronounced during other cycles of rewetting and drying. By the end of the test reference mortar also suffered from bulging and detachment of parts of the surface layer of the mortar. On the samples containing zeolite, partial efflorescence was noticeable at the end of the test. The cracks are probably connected with formation of gypsum in reference mortar and ettringite in mortars containing zeolite, but these findings have to be confirmed through mineralogical analysis.

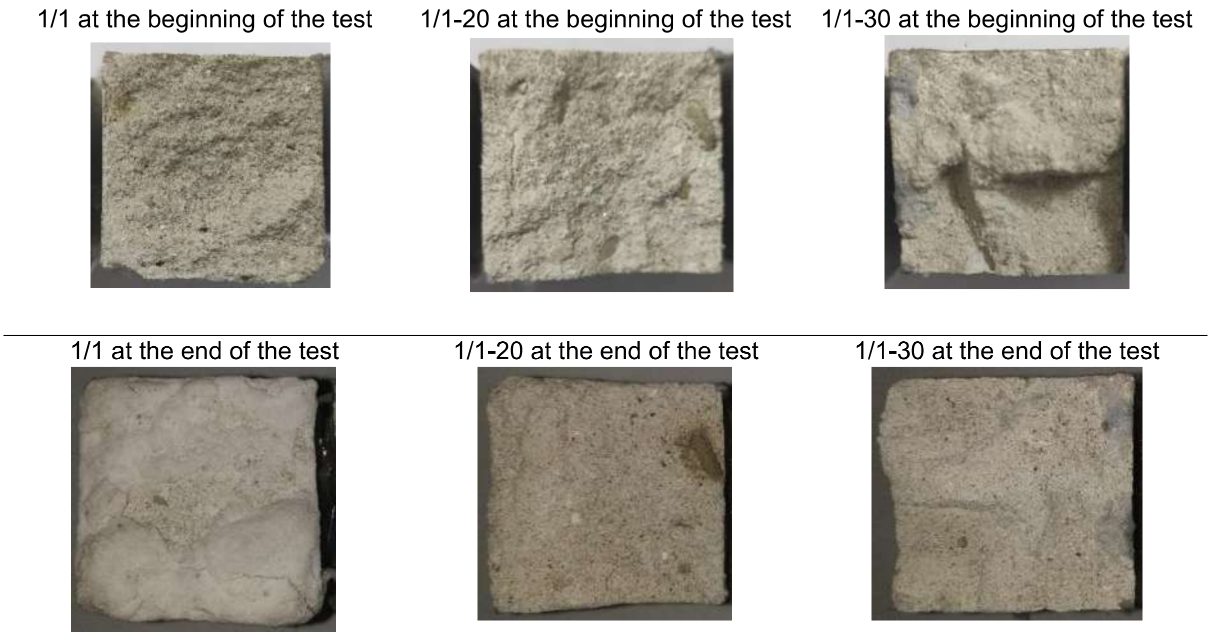

Figure 4 – Samples exposed to solution of sodium-chloride before and after the test

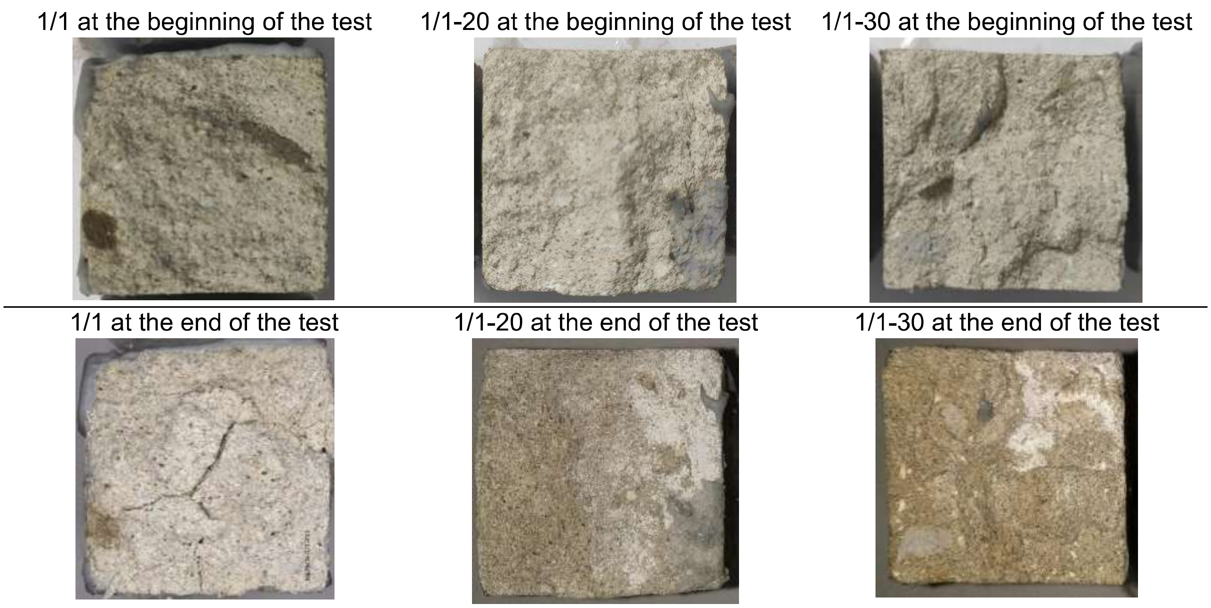

Figure 5 – Samples exposed to solution of sodium-sulfate before and after the test

After the complete drying of the samples, one of the samples from each type of mortar and each exposure group was tested on compressive strength. The values are presented in Table 4 and compared with the values measured on the untreated samples, presented in Table 2.

It can be seen that after the exposure of the mortars to the NaCl solution, there have been very small changes (less than 10%) in the compressive strength value, when compared to the values measured on untreated samples (Table 2). In the case of treatment with Na_2SO_4 solution, results are in accordance to the developing damage within the samples. All mortars had decrease in compressive strength, that was the highest for the reference mortar 1/1 and mortar 1/1-30 (38% and 39%).

Figure 6 – Cracks on the sides of the 1/1-30 mortar samples

Table 4 – Compressive strength of mortar samples after their exposure to the soluble salt solutions

Mortar type	**Compressive strength (MPa)**	
	After exposure to NaCl	***After exposure to Na_2SO_4***
1/1	2.25	1.53
1/1-20	1.81	1.72
1/1-30	3.00	1.92

4. CONCLUSIONS

Basic physical, mechanical properties and durability aspects of lime-based coatings with addition of natural zeolite were presented in this paper. Following conclusions can be drawn:

- Mortars containing natural zeolite used as a partial replacement of lime had higher open porosity, water absorption, capillary water coefficient and water vapor permeability than the reference (pure lime mortars).
- Increase in amount of zeolite lead to increase in the compressive strength of the mortars, and decrease in capillary water coefficient, but only mortar containing 30% of lime replaced with zeolite reached higher strength values, and similar values of capillary water coefficient when compared to reference mortar.
- Basic physical and mechanical properties did not change much between 90 and 180 days of curing, which approves durability testing of these mortars already after the age of 90 days.
- Exposure of the samples to the solution of NaCl lead to very little damage and small decrease of compressive strength in almost all of the samples (less than 10%). Visually, reference mortars showed highest level of efflorescence.
- Exposure of the samples to the solution of Na_2SO_4 lead to damage on all samples already at the beginning of the second cycle of rewetting. Still, the detachment of upper layer of mortar was noticed only on the reference samples, while mortars containing zeolite showed cracks on the sides of the samples. The highest decrease in the compressive strength after the test was detected on the reference samples and the sample 1/1-30.
- Since these mortars were designed as the final layer of the lime-based mortar system, their properties measured in laboratory should be compared with results gained on the composite multilayered samples and in the field.

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