

Durability Properties of Innovative Plasters for Renovation of Historical Buildings

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ABSTRACT

The current practice of the solution of the problem of historical buildings surface layers damage is based more or less on the method of analogy. At a reconstruction, usually such material and method of its application is used which is according to the meaning of supervisory authorities compatible with the original treatments and which already was found to be suitable at an application on some other building before. The durability of new surface layers is mostly estimated on the basis of experience because too few parameters are known for a reliable durability estimate. The choice of a material for reconstruction is then often less suitable regarding to the moisture and salt content in the masonry which leads to low durability and short service life of surface layers. In this paper, main durability properties of innovative lime plasters with metakaolin admixture, namely water sorptivity, moisture diffusivity, water vapor diffusion coefficient, thermal conductivity and specific heat capacity are determined, together with the main mechanical parameters such as compressive and bending strengths. Comparative measurements with common lime plaster are done as well. On the basis of the experiments performed, it can be concluded that the analyzed lime-metakaolin plasters are suitable for an application in reconstruction of historical buildings. While their mechanical properties are significantly better compared to the reference lime plaster, their thermal and hygric properties are mostly similar or slightly improved.

KEYWORDS

Plasters, Historical buildings, Renovation

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1 INTRODUCTION

In many historical buildings parts of the original mortars, which have been deteriorated by natural weathering, need replacement. From the point of view of a historian, it is not acceptable to use lime-cement plasters in Romanesque, Gothic, Renaissance and Baroque buildings. The demands of conservators who take care of historical monuments are, that the materials for repair or innovation of plasters must have the most similar composition as the historical materials and they have to be applicable by the original methods [Hošek & Losos 2007]. This concerns especially the number and the structure of coated layers, the way of plaster surface treatment by striking, indentation or making it smooth. In most cases, inventions had employed cement and polymer based materials, which resulted in advancing the destruction, since harmful by-products have induced severe damage to the background stone blocks or bricks [Maravelaki-Kalaitzaki *et al.* 2005]. In addition, the polymer-based materials are incompatible to the existing materials of the original masonries, thus exhibiting different behaviour in the environmental conditions.

Plaster can play its function, ie architecturally and as a protection against negative environmental conditions, only if it creates a compact cover with surface treatment. Contemporary plasters meet these requirements due to their proper raw materials, technological processing, suitable storing and final application. Historical facade restoration brings not just new plaster creation but also protection of existing one. It is difficult and mainly unsuitable to produce plasters with the same composition and behaviour as historical plasters. The current solution of the problem of surface layers damage of historical building is based more or less on the improvement of technology and properties of each input raw material with preservation of visual and physico-chemical compatibility to original plaster.

As the chemical analyses of many plasters from historical buildings show, the past centuries external plasters that are preserved until today contain products formed by lime reaction with pozzolanic or hydraulic admixtures. Pozzolanic admixtures appeared to have positive effect on properties of lime binder in the past [Rojas and Cabrera, 2002]. According to the composition of the applied pozzolana, compounds similar to Portland cement products were formed but even compounds of zeolite character were found, such as phillipsite $3\text{CaO} \cdot 3\text{Al}_2\text{O}_3 \cdot 10\text{SiO}_2 \cdot 12\text{H}_2\text{O}$ and analcime $\text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 4\text{SiO}_2 \cdot 2\text{H}_2\text{O}$, in connection with microcrystalline calcite. These compounds are the cause of the plaster resistance against environmental conditions and in this way of the durability of these plasters [Cabrera & Rojas 2001].

The lime plasters are known to have high values of liquid water transport parameters. This is not a very convenient feature from the point of view of their exposure to the external environment as any intensive rain can lead to water penetration deep into the material. Therefore, an application of hydrophobization admixtures seems to be a logical solution for achievement of the increase of service life of lime-based plasters. In this paper, we used zinc stearate as the hydrophobization admixture for lime-pozzolana plaster and investigated its effect on mechanical and hygric properties.

The main reason was construction materials deterioration are salt crystalization, water and salt solutions movement through the walls by capillarity and harsh environmental conditions. Therefore, in this paper, we are focused on the basic material characteristics and water vapour and liquid water transport parameters of basic lime plaster in the comparison with innovative plasters.

2 EXPERIMENTAL

Several different types of innovative lime plasters for renovation of historical buildings were tested to compare their durability properties to pure lime plaster (denoted as VO) with the same composition. Metakaolin as a pozzolanic admixture was used in the case of mixture denoted as VOM as binder increment, in the case of other two mixtures, denoted as VOM II and VOM H as replacement of lime. To improve high values of liquid water transport parameters we used zinc stearate as the

hydrophobization admixture for the lime-pozzolana plaster VOM H. The water/binder ratio was modified according to mixture workability. The composition of mixtures for sample preparation is presented in Table 1.

Table 1. Composition of tested plaster mixtures.

Type of mixture	Amount [kg]				
	Lime	Sand 0/2mm	Metakaolin	Hydrophobization admixture	Water
VO	4.80	14.40	-	-	4.80
VOM	4.80	14.40	0.80	-	5.50
VOM II	4.00	14.40	0.80	-	4.80
VOM H	4.00	14.40	0.80	0.02	4.20

2.1 Materials

Plaster mixtures were prepared using laboratory mixing machine with forced rotation for 3 minutes and then compacted using vibrating machine. Each mixture was cast into a standard prism form, after two days all prisms were taken out of forms and then cured for 28 days in high relative humidity environment.

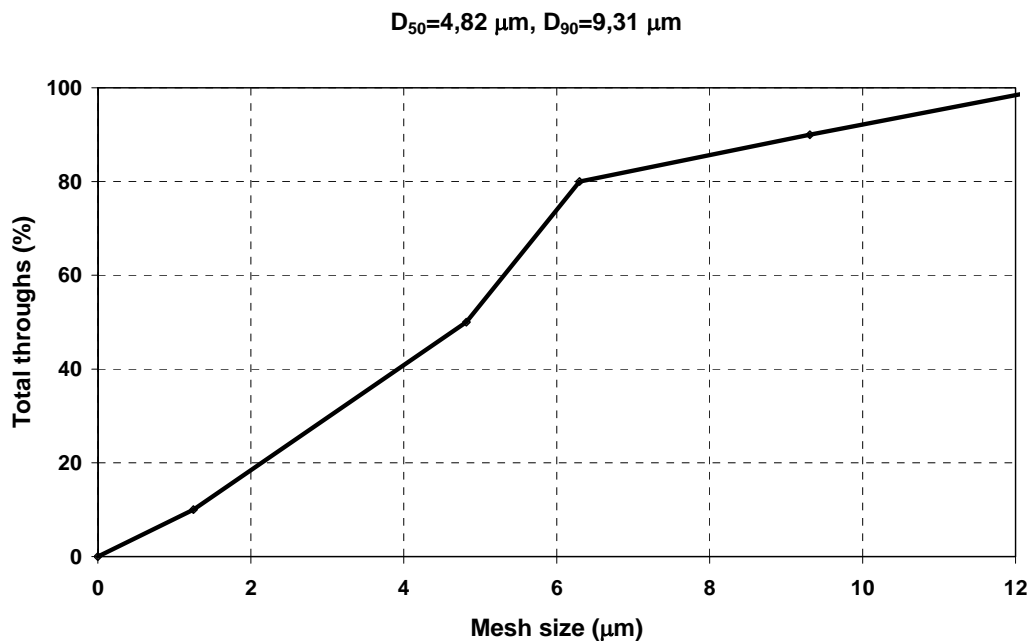


Figure 1. Granularity of used metakaolin.

The lime CL 90 was produced by limekiln Morká, Czech Republic. Metakaolin MEFISTO K05 was a product of České lupkové závody Inc., Nové Strašecí. It is a highly active pozzolanic material on metakaolinite basis. MEFISTO is supposed to be used first of all as an alternative silicate binder. It can replace 5-15% of cement by weight at concrete production where it can be used instead of microsilica. It can also be utilized in the production of geopolymers. The reason for using MEFISTO in the mentioned applications is the supposed increase of compressive and flexural strength and frost resistance, decrease of water absorption and reduction of the occurrence of efflorescence. Dominant compounds of metakaolin MEFISTO represent SiO_2 (55%) and Al_2O_3 (41%). Fe_2O_3 , TiO_2 , CaO ,

MgO, and Na₂O are present in minor amounts. Average particle size of metakaolin is in the interval of 3 to 5 μm, see Fig. 1.

Hydrophobization admixtures have to reduce pore walls wettability and replace capillary suction by capillary depression. Addition of hydrophobization admixture to lime plaster leads to lower sorptivity and better resistance to water and aggressive solution penetration. Fatty acid salts are often used as a hydrophobizer, namely calcium or zinc stearate. One end of the carbon chain is hydrophilous and it is connected to mineral structure while the other end which is formed of hydrophobic group is oriented outside the structure and can repulse water.

Sand 0/2 mm fraction was delivered by Heidelberg Cement Group, Brněnské písky Inc., affiliate Bratčice, normalized according to EN 196-1. The grain-size distribution curve of applied sand is shown in Fig. 2.

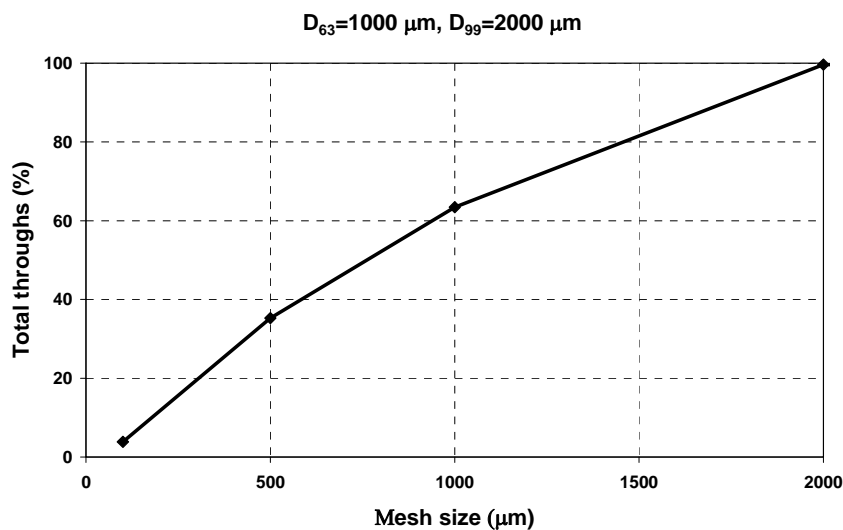


Figure 2. Granularity of used sand.

2.2 Experimental Methods

At first, basic material properties of all tested lime plasters were determined. As fundamental physical material characteristics, bulk density ρ_b [kg m⁻³], matrix density ρ_m [kg m⁻³], and open porosity ψ [%] were determined. Bulk density was measured using gravimetric methods. Matrix density was obtained using Pycnomatic ATC, automatic helium pycnometer with fully integrated temperature control with precision of ± 0.01 °C and real multi volume density analyzer. The samples for the basic material parameters determination were cut from cubic prisms with the size of 40 x 40 x 40 mm and their dimensions were 40 x 40 x 20 mm.

Investigation of mechanical parameters was carried out according to the norm [ČSN EN 196-1, 2005]. The compressive and flexural strengths were determined as the most important mechanical parameters for lime-based plasters. For each measurement standard prisms 40 x 40 x 160 mm were tested with DSM 2500 hydraulic testing device, Inova Praha. The flexural strength was measured using standard three-point bending test. The compressive strength was determined using the same test device on the remainder of the specimens after bending test. The measurements were done after 7, 14, 28, 90 and 180 days of hardening period.

The thermal conductivity as the main parameter of heat transport and the specific heat capacity as the main parameter of heat storage were determined using the commercial device ISOMET 104 (Applied Precision, Ltd.). ISOMET 104 is a multifunctional instrument for measuring thermal conductivity, thermal diffusivity, and volumetric heat capacity. It is equipped with various types of optional probes, needle probes are for porous, fibrous or soft materials, and surface probes are suitable for hard

materials. The measurement is based on the analysis of the temperature response of the analyzed material to heat flow impulses. The heat flow is induced by electrical heating using a resistor heater having a direct thermal contact with the surface of the sample.

The cup method was used for determination of water vapour transmission properties. The measurement performed in this work was based on the standard [ČSN 72 7031]. The measurement is carried out in steady state under isothermal conditions. It is based on one-dimensional water vapour diffusion and measuring the water vapour flux through the specimen and partial water vapour pressure in the air under and above specific specimen surface. Water vapour transmission properties of a material are obtained by placing a specimen of the material on the top of a cup and sealing it. Two versions of the common cup method were employed in the measurements of the water vapour diffusion coefficient. In the first one, the sealed cup containing burnt CaCl_2 (0% relative humidity) was placed in a controlled climatic chamber at $25 \pm 0.5^\circ\text{C}$ and 45% relative humidity and it was weighed periodically. In the second one, the cup containing saturated K_2SO_4 solution (97% relative humidity) was placed at $25 \pm 0.5^\circ\text{C}$ and 45% relative humidity environment. Firstly, samples sizes of 95 mm in diameter x 20 mm were cut from the standard prism 100 x 100 x 100 mm and water vapour-proof insulated with epoxy resin. Then, the sealed cups with samples were weighed periodically. The steady state values of mass gain or mass loss were utilized for the determination of the water vapour transfer properties. In the practical calculations of water vapour transport parameters in porous buildings materials, the diffusion coefficient of water vapour D [m^2s^{-1}] and water vapour diffusion resistance factor μ [-] were determined.

The simplest way, how to describe liquid water transport through a porous material is realization of a one-dimensional free imbibition experiment [Roels *et al.* 2004]. Specimens sizes of 40 x 40 x 20 mm were cut from the original prisms and then water and vapour-proof insulated with epoxy resin on four lateral sides, and after that dried in an oven. The face side of each sample was immersed 1-2 mm into water on top of a saturated sponge. The sample mass was measured continuously. The water absorption coefficient, A [$\text{kgm}^{-2}\text{s}^{-1/2}$], was calculated from the linear part of the dependence of the increase of tested sample's mass on the square root of time. Then, the apparent moisture diffusivity κ [m^2s^{-1}] was calculated using the vacuum saturation moisture content w_{sat} [kg m^{-3}] and water absorption coefficient [Kumaran 1994].

3 RESULTS AND DISCUSSION

Basic properties of all materials are summarized in Table 2. Each result represents the average of five measured values. The open porosity was found not to be distinctly affected by the metakaolin and zinc stearate addition. The observed differences were between 3-5 % in the case of lime-metakaolin plasters, and 8% in the case of hydrophobized plaster which is clearly due to the lower water/binder ratio. So, the addition of fine grained metakaolin MEFISTO did not change the basic material properties as bulk density, matrix density and total open porosity in a significant way. The observed differences were within the range of the accuracy of applied measuring methods. All studied materials have proven high porosity, which is a very positive factor from the point of view for application on historical buildings. The high porosity of plaster guarantees fast water vapour transport, and so its fast removal from the load bearing structures of reconstructed historical buildings.

Table 2. Basic properties of studied mixtures.

<i>Type of mixture</i>	ρ_b	ρ_{mat}	Ψ
	[kg m^{-3}]	[kg m^{-3}]	[%]
VO	1 650	2 575	36.0
VOM	1 670	2 570	35.0
VOM II	1 695	2 580	34.0
VOM H	1 745	2 625	33.0

The survey of mechanical properties of studied plasters is presented in Figs. 3 and 4. Each result represents the average value of six or three values in the case of compressive and flexural strength measurement, respectively.

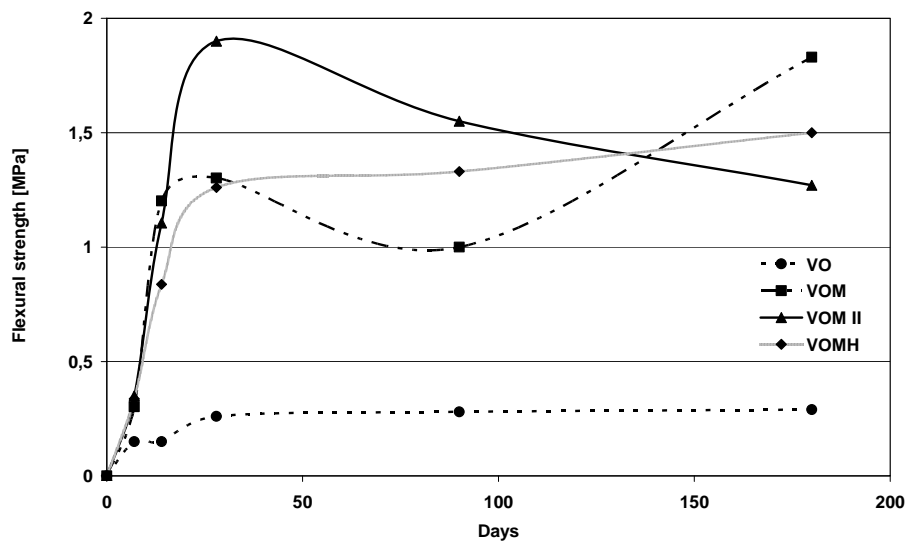


Figure 3. Flexural Strength of Tested Plasters.

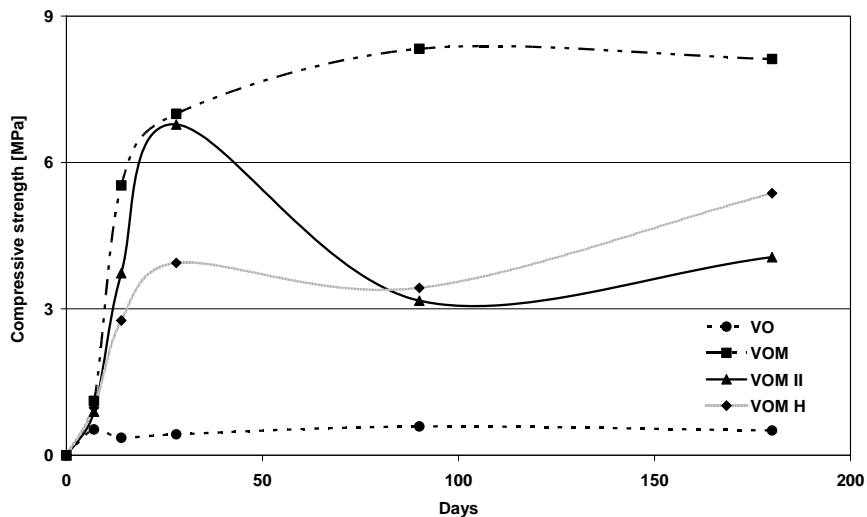


Figure 4. Compressive strength of tested plasters.

The flexural strength of pure lime plaster reached its maximum after 28 days and then it had almost the same value even after 180 days hardening period. Its compressive strength, on the other hand, had somewhat fluctuating character. Lime plasters with metakaolin addition have proved two times higher both flexural and compression strength than pure lime plaster already after 7 days of hardening. In the case of incremental metakaolin addition (VOM mixture) the flexural strength exhibited certain decrease after 28 days of hardening but after 180 days it was the highest among all tested plasters, six times higher than for the pure lime plaster. The compressive strength of the same mixture increased more continuously. Its maximum was achieved after 90 days of hardening, where it was eight times higher than after 7 days and even fourteen times higher than the compressive strength of pure lime plaster at the same time. In the case of metakaolin replacement mixture (VOM II) the flexural strength increased until 28 days of hardening then it slowly decreased. The maximum was nearly five times higher in the comparison with flexural strength of pure lime plaster. The VOM II mixture reached fourteen times higher value of compressive strength than pure lime plaster after 28 days but then a substantial decrease was observed. The hydrophobization admixture addition caused reduction of both flexural

and compressive strengths at the same time in comparison with other lime plasters with metakaolin addition, but both compressive and flexural strength development had ascending trend.

Thermal properties of the studied plasters are presented in Table 3. The lime-pozzolana plasters exhibited slightly higher thermal conductivity than the reference lime plaster. This is in accordance with their higher bulk density and lower porosity (Table 2). The values of specific heat capacity were very similar for all the studied mixtures, the differences being within the error range of the applied method.

Table 3. Thermal properties of studied mixtures.

<i>Type of mixture</i>	λ [W/mK]	c [J/kgK]
VO	0.67	580
VOM	0.71	590
VOM II	0.88	620
VOM H	0.85	610

The results of water vapour and liquid water transport parameters determination are presented in Table 4, each result represents the average value from five measurements.

Table 4. Water vapour and liquid water transport parameters.

<i>Type of mixture</i>	D [m ² s ⁻¹]		μ [-]		A [kg m ⁻² s ^{-1/2}]	w_{sat} [kgm ⁻³]	κ [m ² s ⁻¹]
	97-45% RH	0-45% RH	97-45% RH	0-45% RH			
	VO	2.90E-6	4.50E-6	9.0	5.0	2.20E-1	359.0
VOM	2.50E-6	5.10E-6	10.0	4.5	2.70E-1	350.0	5.70E-7
VOM II	1.80E-6	5.70E-6	13.0	4.0	2.20E-1	343.0	4.30E-7
VOM H	1.60E-6	4.40E-6	15.0	5.0	6.50E-2	332.0	3.90E-8

The water vapour transport parameters were not very different for all studied plasters. Lime-metakaolin plasters had higher water vapor diffusion resistance factor than the reference lime plaster but the differences were not very significant. From the quantitative point of view, the obtained values of water vapour diffusion parameters of innovative plasters are very promising for application in restoration of historical buildings and renewal of the old materials. The values of liquid water transport parameters were in case of lime-metakaolin plasters without hydrophobization similar or slightly higher than for pure lime plaster. This may be considered as a negative finding in general because the rain water could be transported either the same fast or even faster into the load bearing structure. However, from the quantitative point of view the differences were not very high so that this is only a minor flaw on otherwise significantly improved material. In the case of zinc stearate addition the liquid water transport parameters decreased in a significant way, the moisture diffusivity by about one order of magnitude, which is a very positive feature.

4 CONCLUSIONS

Main durability properties of innovative lime plasters with metakaolin admixture were determined in the paper and compared with the reference lime plaster. The modified plasters showed significant improvement of mechanical properties. Another good point with the studied lime-metakaolin plasters was that the hygric and thermal properties were basically unaffected by the metakaolin addition. The

material retained the good water vapour transmission properties which are characteristic for the lime plasters and exhibited also acceptable thermal properties. The application of hydrophobization admixtures in lime-pozzolana plasters was proved successful. It resulted in an order of magnitude decrease of moisture diffusivity which means a significant reduction of liquid water transport in the plaster.

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