MODIFICATIONS OF LIME PLASTERS FOR THE APPLICATION IN HISTORICAL BUILDINGS

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Abstract

Lime-pozzolana plaster mixtures with metakaolin, grinded brick and grinded enamel glass as the pozzolana materials are analyzed in the paper. Both the basic plasters and those with the hydrophobization admixtures are studied. Two of the analyzed lime-pozzolana plasters are found to be 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. The hydrophobization is observed to have the most pronounced positive effect for the lime plaster with metakaolin.

Key words: lime plasters, pozzolana, properties

1 Introduction

The short lifetime of lime plasters follows generally from the fact that calcium carbonate, the product of lime carbonation, is easily decomposed by acid gases of the surrounding atmosphere. In the period of Ancient Rome, for the mortar manufacture mixtures composed of quicklime and pozzolana fillers especially volcanic ash, tuff, spongilite etc. were used. During the reaction of pozzolana with lime, in water medium stable hydrated calcium silicates were formed. In other parts of the world crushed or ground burnt clays were used. The reaction of these materials with lime resulted in the formation of hydrated calcium silicates and calcium aluminates. In the 16th century hydraulic lime was manufactured purposively, which substituted the mixtures of quicklime with hydraulically or pozzolanically reacting admixtures. Considering the higher resistance of these materials towards the environment, some original plasters or plaster fragments were conserved even up to now.

In this paper, lime-pozzolana plaster mixtures with metakaolin, grinded brick and grinded enamel glass as the pozzolana materials are analyzed. The experimental studies are performed both with the basic plaster mixtures and with the hydrophobized mixtures.

2 Materials and samples

The reference lime plaster consisted of hydrated lime – 200 g, natural quartz sand with continuous granulometry 0 to 4 mm – 600 g and water – 200 g (we will denote it S in what follows). The composition of the lime-pozzolana plasters was as follows: hydrated lime – 200 g (CL 90 Czech-Moravien Cement Mokrá), pozzolanic admixture - 200 g, natural quartz sand with continuous granulometry 0 to 4 mm – 600 g and water – 200 g. Metakaolin – Imerys (the plaster denoted as P1), metakaolin – Božíčany (the plaster denoted as P1*), grinded brick pottery – Hodonín (plaster P2) and grinded enamel glass (plaster P3) were used as pozzolana materials in lime-pozzolana plaster mixtures. Zinc stearate in the amount of 0.4% by mass was used as the hydrophobization admixture for three lime-pozzolana plasters, namely with metakaolin – Božíčany (plaster P1y*), grinded brick pottery – Dolní Jirčany (plaster P2y*) and grinded enamel glass (plaster P3y).

The following type and number of specimens were used for measurements of basic mechanical, thermal and hygric properties: bending and compressive strength - 9 specimens 40 x 40 x 160 mm, thermal conductivity – 10 specimens 71 x 71 x 71 mm, water sorptivity and apparent moisture diffusivity – 3 specimens 50 x 50 x 20 mm, moisture diffusivity from the moisture profiles – 3 specimens 20 x 40 x 296 mm, water vapor diffusion resistance factor – 3 cylinders with the diameter 105 mm and thickness 20 mm, linear hygric expansion coefficient – 5 specimens 40 x 40 x 120 mm. The samples for determination of moisture diffusivity and water vapor diffusion coefficient were provided on all lateral sides by water- and vapor-proof insulation.

3 Experimental methods

Compressive and bending strength were determined in a common way using a 100 kN testing device. First, three-point bending test was performed. Then, compressive strength was determined on the halves of the specimens left over after the bending tests. A cup method was employed in the measurements of water vapor diffusion resistance factor. The sealed cup containing silica gel was placed in a controlled climate chamber with near 100% relative humidity and weighed periodically until the steady state conditions were achieved. The apparent moisture diffusivity was determined on the basis of a common water sorption experiment (see [1] for details). The moisture dependent moisture diffusivity was determined using the measured moisture profiles in a solution of the inverse problem to the diffusion equation of moisture transport. The moisture profiles were determined using a common capillary suction experiment in the vertical position. The capacitance method [2] was employed for measuring the moisture content. The transient integral method [3], which is based on double integration by spatial and temporal variables, was employed for the inverse analysis of moisture profiles. The linear hygric expansion coefficients were determined in a common way using the measured length changes. The thermal conductivity was measured in laboratory conditions using the commercial device ISOMET 2104 (Applied Precision, Ltd.).

4 Experimental results

The mechanical properties of the studied plasters are given in Figs. 1a,b, 2a,b. As for the non-hydrophobized plasters, the 7-days values of mechanical parameters were not yet very convincing concerning the expected improvement due to the pozzolanic admixtures (except for the compressive strengths of P1 and P1*). However, the situation after 28 days was already much more promising. For the material P1*, an increase of the 28-days bending strength about four times compared to the reference lime plaster was observed, for the material P2 almost two times. For the 28-days compressive strength the results were even better, the increase compared to the reference lime plaster was about six times for P1* and four times for P2. Concerning the material P3, there was not observed any significant improvement of mechanical properties. Among the 7-days and 28-days values of bending strength and compressive strength of lime-pozzolana plasters with 0.4% of zinc stearate, the most favorable values were achieved for the lime-metakaolin plaster. The decrease of mechanical properties compared to the reference plaster without hydrophobization was here typically only in the range of several tens of percent. The results obtained for grinded brick and grinded enamel glass were much worse. The 28-days strengths decreased several times compared to the non-hydrophobized materials. This does not seem to be an acceptable result.

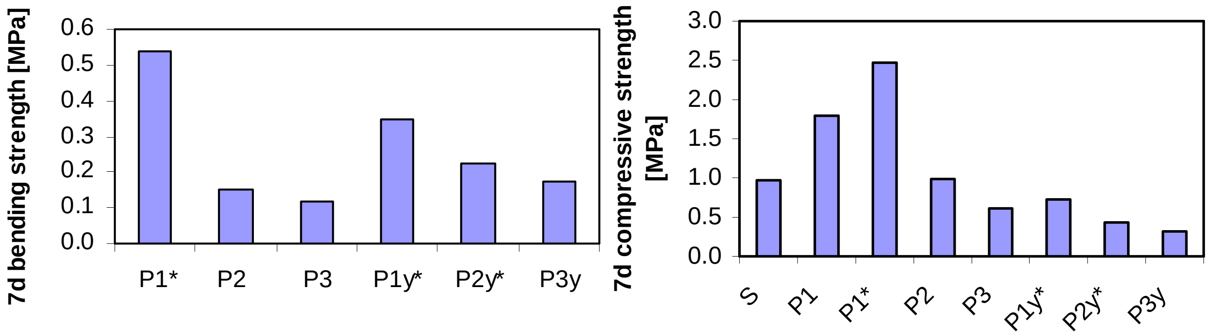

Fig. 1a,b 7-days bending strength and compressive strength of lime-pozzolana plasters

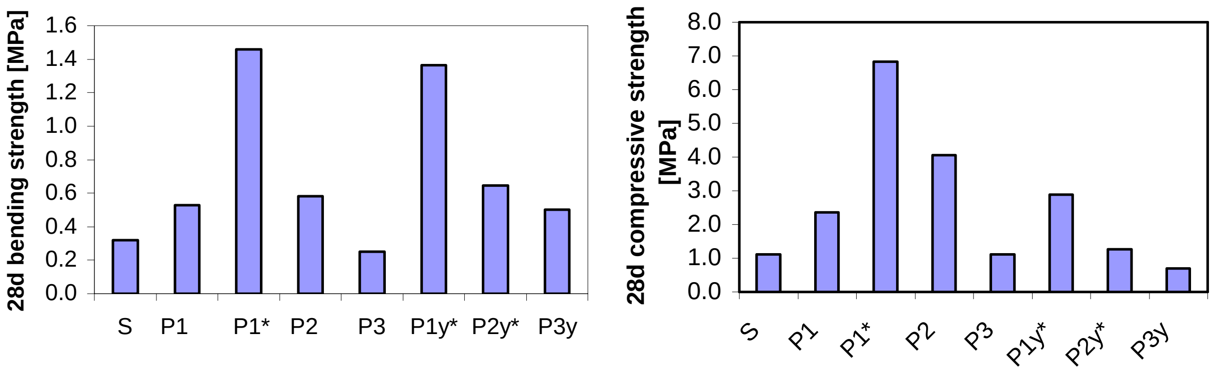

Fig. 2a,b 28-days bending strength and compressive strength of lime-pozzolana plasters

The basic hygric properties of non-hydrophobized plasters are shown in Table 1a. The water vapor diffusion resistance factor μ of the lime-pozzolana plaster P1 was found to be about 20% higher than for the reference lime plaster S but μ factors of P2 and P3 were almost two times lower than for S. The water absorption coefficient of all lime-pozzolana plasters was significantly lower than for the reference lime plaster. A 20-30% decrease was observed for P2 and P3, more than 50% decrease for P1. Similar results were achieved for the apparent moisture diffusivity calculated on the basis of water absorption coefficients. On the other hand, the linear hygric expansion coefficients of all lime-pozzolana plasters increased about two times compared to the reference lime plaster. This is not a very favorable feature.

Table 1b shows basic hygric properties of the studied lime-pozzolana plasters with 0.4% of zinc stearate. We can see that for the plasters with grinded brick and grinded enamel glass the water vapor diffusion resistance factors are significantly higher than for the respective plasters without hydrophobization but for the lime-metakaolin plaster it is about 10% lower. This can

be considered as a positive factor because the high water vapor permeability of lime plasters should be preserved after their modification.
The liquid water transport properties expressed by the water absorption coefficient and the related value of apparent moisture diffusivity decreased very significantly for all three studied plasters, the water absorption coefficient being 3 to 10 times lower and the apparent moisture diffusivity one to two orders of magnitude lower. The linear hygric expansion coefficients were also improved in a significant way due to the hydrophobization. Their values decreased in the range of 20% for P1 to seven times for P3. So, from the point of view of hygric properties the hydrophobization was very successful for all three studied materials.

Table 1a Basic hygric properties of non-hydrophobized plasters

Material	Water vapor diffusion resistance factor (-)	Water absorption coefficient [$kgm^{-2}s^{-1/2}$]	Apparent moisture diffusivity [m^2s^{-1}]	Linear hygric expansion coefficient 10^{-5} [%kg/kg]$^{-1}$
Lime plaster S	15	0.241	6.86E-7	3.3
Lime-pozzolana plaster P1	18	0.108	7.64E-8	6.1
Lime-pozzolana plaster P2	8.3	0.183	3.60E-7	7.2
Lime-pozzolana plaster P3	9.4	0.161	3.69E-7	7.6

Table 1b Basic hygric properties of the lime-pozzolana plasters with 0.4% of zinc stearate

Material	Water vapor diffusion resistance factor [-]	Water absorption coefficient [$kgm^{-2}s^{-1/2}$]	Apparent moisture diffusivity [m^2s^{-1}]	Linear hygric expansion coefficient 10^{-5} [%kg/kg]$^{-1}$
Lime-pozzolana plaster P1y*	15.6	0.039	1.19E-08	4.7
Lime-pozzolana plaster P2y*	13.9	0.015	1.06E-08	1.4
Lime-pozzolana plaster P3y	12	0.012	9.00E-09	1.1

Fig. 3 presents the dependence of the moisture diffusivity of lime-pozzolana plasters on the moisture content calculated on the basis of moisture profiles. The lime-pozzolana plaster P1* exhibited significantly lower values of moisture diffusivity compared to the other plasters, the differences being between one half and one order of magnitude. The differences between moisture diffusivities of the two other studied materials were much lower, within the range of tens of percent. As for the hydrophobized plasters, their moisture diffusivity was observed to decrease in a significant way, typically by about one order of magnitude compared to the basic plasters without hydrophobization. A comparison of the moisture dependent moisture diffusivities in Fig. 3 with the apparent moisture diffusivities calculated from the water absorption coefficients in Tables 1a,b shows that the apparent values of moisture diffusivity corresponded to the moisture profile-based moisture diffusivities at higher moisture content, typically about two thirds of the water saturation values.

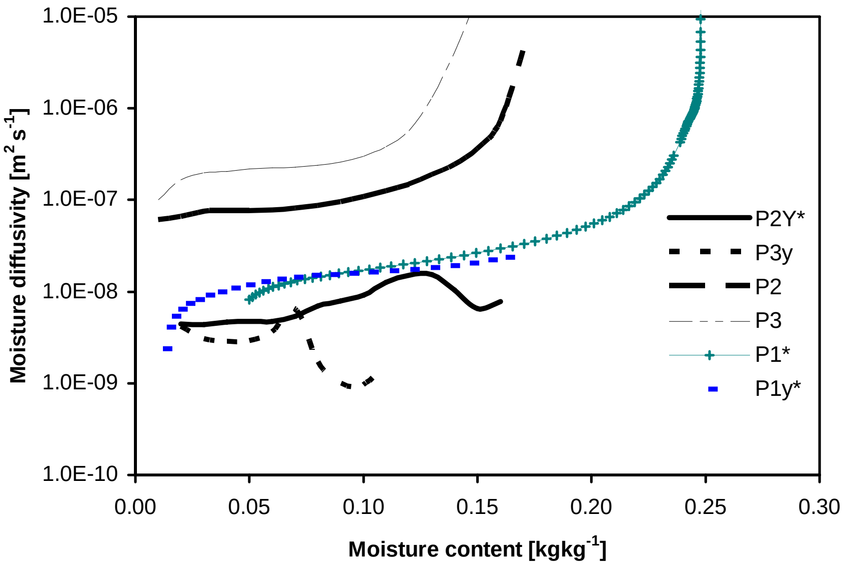

Fig. 3 Moisture-dependent moisture diffusivity of lime-pozzolana plasters

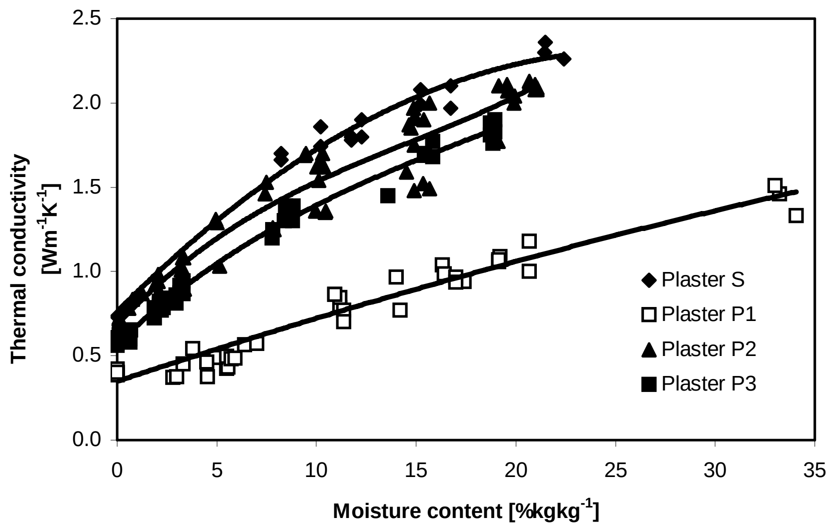

Fig. 4a Thermal conductivity of non-hydrophobized plasters as a function of moisture content

Fig. 4a shows the dependence of the thermal conductivity of the non-hydrophobized lime-pozzolana plasters and the reference lime plaster on the moisture content. The differences between the thermal conductivity of the lime-pozzolana plaster P1 and the other three plasters were even higher than in the dry state. The increase of thermal conductivity of the plasters S, P2 and P3 was faster in the range of hygroscopic moisture than in the range of overhygroscopic moisture, for P1 a single linear relation was found in the whole moisture range. Fig. 4b presenting the thermal conductivity of hydrophobized plasters gives evidence that in the range of lower moistures, there was not found any significant decrease of thermal conductivity due to the hydrophobization. However, as the porosity of hydrophobized plasters decreased in a remarkable way, the highest values of thermal conductivity measured for the non-hydrophobized plasters were not achieved any more.

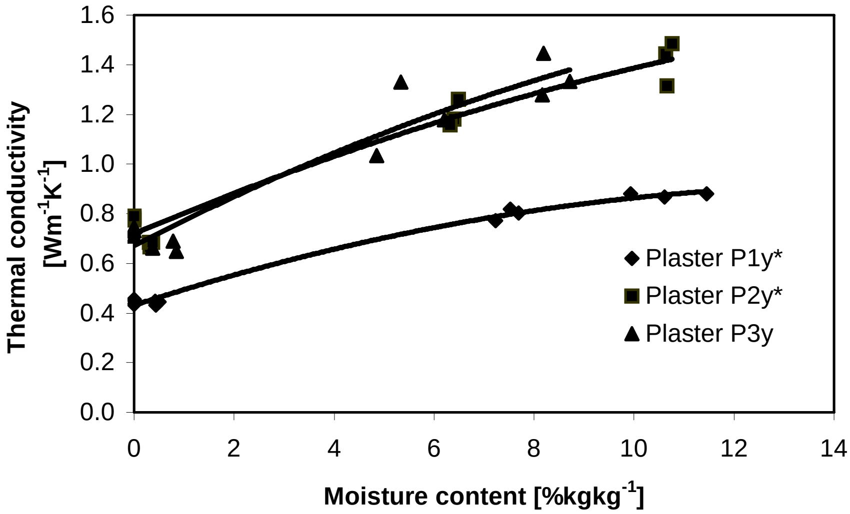

Fig. 4b Thermal conductivity of hydrophobized plasters as a function of moisture content

5 Conclusions

The measurements of mechanical, thermal and hygric properties in this paper make it possible to conclude that two of the three designed lime-pozzolana plasters, namely those with metakaolin and grinded brick, could be possibly applied in historical buildings instead of the classical lime plaster even without hydrophobization. Among the lime-pozzolana plasters with hydrophobization using zinc stearate, the most favorable properties exhibited the lime-metakaolin plaster. The hydrophobization of this plaster has led to a significant decrease of liquid water transport properties while the mechanical properties preserved their high values. This makes great prerequisites for its application in the renovation of historical buildings instead of the common lime plasters.

Acknowledgement

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