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Hygric properties of lime-cement plasters with the addition of a pozzolana

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Abstract

There are more than seven billion people currently living on the Earth and the demands of population are rising. Lime and cement are parts of most building materials, so their global consumption grows. Therefore, it is necessary to think both economically and ecologically, and search for a suitable alternatives and replacements. This study is aimed at an investigation of the influence of pozzolana as the third binder component on basic physical characteristics and hygric properties of lime-cement plasters. Results show that with the increasing amount of pozzolana in the mixture the open porosity goes down. This is accompanied by a liquid water absorption decrease. Also diffusion parameters are somehow worsened, as the water vapour diffusion resistance factor increases.

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Keywords: Lime; cement; pozzolana; plaster; hydric properties; basic physical properties

1. Indtroduction

In these days, there is a wide variety of plasters, which are used either for external or internal walls. The binder material can be clay, gypsum, gypsum-lime, magnesium, quicklime, hydraulic lime, lime-pozzolana, lime-cement or cement [1]. Cement, which started to be utilized in plasters in 1920s, gives the material higher hardness and

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strength, on the other hand the diffusion properties are somehow worsened, which is next to its less original appearance the reason why they are not recommended for use on historical buildings [2]. Lime plasters are commonly the most popular form of surface finishing. They have good diffusion properties [3], but they are less resistant to weathering and other external harmful influences.

Pozzolanic materials have been used as a part of binder since ancient times. Their presence in a mixture is beneficial in many ways, which was known already in the era of Roman Empire. The Romans used natural pozzolanas such as volcanic ash, tuff, spongolite or burnt clays. Nowadays, many natural pozzolanic materials and even pozzolanas of technogenic origin are frequently utilized. Investigation attempts are mainly focused on ternary systems; which means binder consists of three different components. The problematic issue is an appropriate ratio to reach the desired properties of a certain plaster, which request a well elaborated design.

This study is aimed at an investigation of water transport properties in connection with its open porosity and other basic physical properties of lime-cement plasters with the gradual substitution of the binder by a pozzolana – namely by ceramic powder.

2. Materials

The composition of studied plasters is given in Table 1. The main binary binder system is composed of lime and cement, where cement represents 10 % of their weight. The used lime hydrate comes from Vápenka Čertovy schody a. s. and cement CEM I 42.5 R [4] was supplied by Lafarge cement, a.s., Čížkovice. Except of the reference mixture the binary binder was substituted by a pozzolana, in amount of 10, 30 and 50 % of weight. The used pozzolana was fine ceramic powder, which originates during the manufacture of precise ceramic blocks, supplied by Heluz, v.o.s. [5]. The siliceous fine aggregate was dosed in three fractions, each of them in the same amount. Water to solid ratio was determined for each mixture separately in order to gain the flow of the fresh plaster of 160 mm [6].

Table 1. Studied plasters.

Mixture	Pozzolana (*kg*)	Lime hydrate (*kg*)	Cement (*kg*)	Aggregate (*kg*)			water/solid ratio
				0.3–0.8	0.6–1.2	1.0–4.0	
LCPP_R	0	5.63	0.63	6.25	6.25	6.25	0.220
LCPP_10	0.625	5.06	0.56	6.25	6.25	6.25	0.248
LCPP_30	1.875	3.94	0.44	6.25	6.25	6.25	0.224
LCPP_50	3.125	2.81	0.31	6.25	6.25	6.25	0.200

3. Experimental methods

The tested basic physical properties were the bulk density ρ ($kg \cdot m^{-3}$), matrix density ρ_{mat} ($kg \cdot m^{-3}$) and open porosity ψ_0 (-). These properties were measured using the water vacuum saturation method [7] and helium pycnometry [8]. Samples were dried at 80 °C and weighed. Afterwards samples were vacuum saturated by water. They were given to the vacuum desiccator for not less than 24 hours, and weighed again in the saturated state and in the Archimedes weight under water. The matrix density was determined also by helium pycnometry. This experiment was carried out by the device “Pascal 140 + 440”. This device has analogous principle as classic porosimetry.

Water absorption coefficient ($kg \cdot m^{-2} \cdot s^{-1/2}$) and apparent moisture diffusivity ($m^2 \cdot s^{-1}$) were determined to characterize the liquid water transport. The absorption experiment was performed on samples insulated on lateral sides to ensure the one-directional absorption of water through the material. Samples were immersed in water 1 – 2 mm deep and continuously weighed by an automatic balance. From the dependence of weight increases on the square root of time, the water absorption coefficient was determined as the constant of proportionality and knowing the capillary moisture content the apparent moisture diffusivity was then calculated [9,10].

The diffusion of water vapour through the material was determined by both wet-cup and dry-cup methods according to ČSN 72 7030 [11]. Both methods are based on the diffusion of water vapour caused by different partial relative pressures on the opposite sides of the samples, which were on lateral sides air-proof insulated. The climatic chamber presented the external environment with 25 °C and 50% relative humidity, while inside the cup was either 97% or 5% relative humidity created by water or silica gel placed in the cup for wet-cup and dry-cup method respectively. The increases/decreases of the sample´s weight were periodically recorded and from the last readings, after reaching a steady state, the transport parameters - water vapour diffusion coefficient ($m^2 \cdot s^{-1}$) and water vapour diffusion resistance factor (-) - could be calculated [12].

4. Results and discussion

Table 2. summarizes the results of vacuum saturation experiment and helium pycnometry. Variations of bulk density and matrix density are within 6% and 2% respectively for values obtained from both methods. The highest bulk density was found for mixture LCPP_50, followed by LCPP_30 and the decreasing trend continued with a low slope in the order of LCPP_R and LCPP_10. Values of open porosity showed a decreasing trend with the increasing amount of pozzolana, which was obtained from results of both used methods. However, helium pycnometry showed lower differences between reference mixture and mixtures with 10% and 30% substitutions of the binder with a jump in values between LCPP_30 and LCPP_50. Vacuum saturation method showed a bit more proportional trend, as there were, in comparison to the reference mixture, decreases in the values by 2%, 5% and 10% for mixtures LCPP_10, LCPP_30 and LCPP_50 respectively.

Table 2. Basic physical properties of studied plasters.

Mixture	Vacuum saturation			Helium pycnometry		
	ρ ($kg \cdot m^{-3}$)	ρ_{mat} ($kg \cdot m^{-3}$)	ψ_0 (%)	ρ ($kg \cdot m^{-3}$)	ρ_{mat} ($kg \cdot m^{-3}$)	ψ_0 (%)
LCPP_R	1697	2606	34.9	1669	2667	37.4
LCPP_10	1675	2551	34.3	1663	2649	37.2
LCPP_30	1722	2575	33.2	1678	2667	37.1
LCPP_50	1787	2597	31.5	1764	2659	33.7

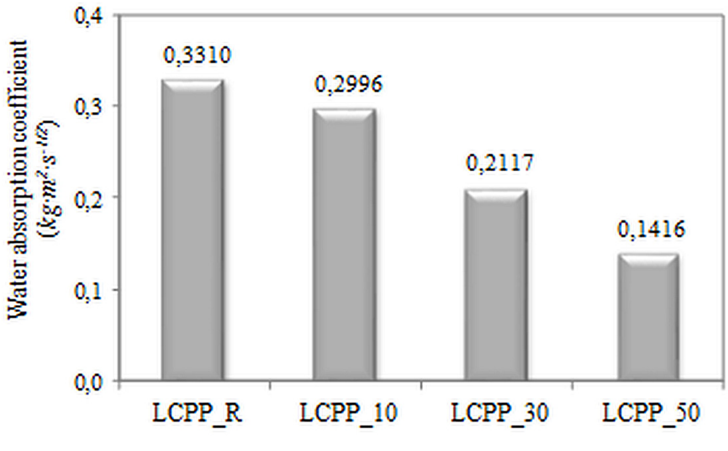

Fig. 1. Water absorption coefficient of studied plasters.

Results of the absorption test are presented in Fig. 1 and 2. Values of water absorption coefficient correlated with the decreasing trend of obtained values of open porosity from the vacuum saturation method. The highest water absorption coefficient was found for the reference mixture, while for the mixtures with 10%, 30% and 50% of pozzolana there were drops in the values by 10%, 36% and 57% respectively. The same trend but with higher differences was recorded for apparent moisture diffusivity with decreases in values by 34%, 64% and 80% compared to the reference mixture.

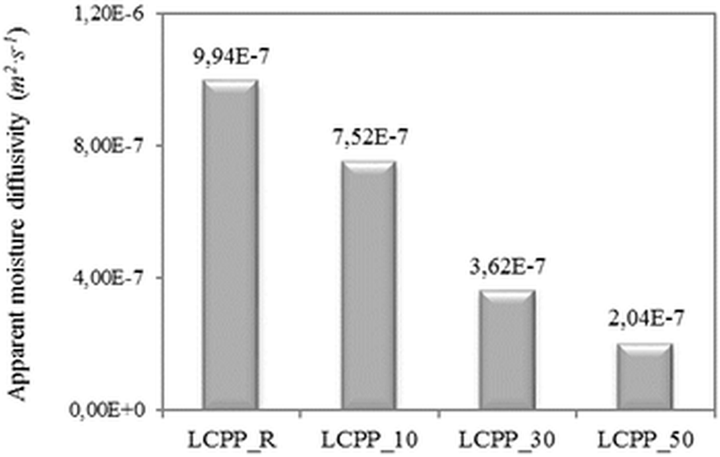

Fig. 2. Apparent moisture diffusivity of studied plasters.

Diffusion characteristics were also found in agreement to the trend of open porosity; results are given in Fig. 3 and Table 3 for wet-cup and dry-cup methods. With the increasing amount of pozzolana in the mixture, the values of water vapour diffusion coefficient went down. In the case of dry-cup methods, the differences were higher, showing drops in the values by 9%, 20% and 35% for LCPP_10, LCPP_30 and LCPP_50 respectively; while in wet-cup the decreases were by 13%, 17% and 20% in comparison to the reference mixture. Water vapour diffusion resistance factor showed similar proportional differences in the values, only with the opposite (i.e. increasing) trend.

Table 3. Water vapour diffusion coefficient of studied plasters.

Material	Water vapour diffusion coefficient ($m^2 \cdot s^{-1}$)	
	Dry - cup	Wet - cup
LCPP_R	1.72E-6	2.20E-6
LCPP_10	1.57E-6	1.92E-6
LCPP_30	1.37E-6	1.83E-6
LCPP_50	1.11E-6	1.77E-6

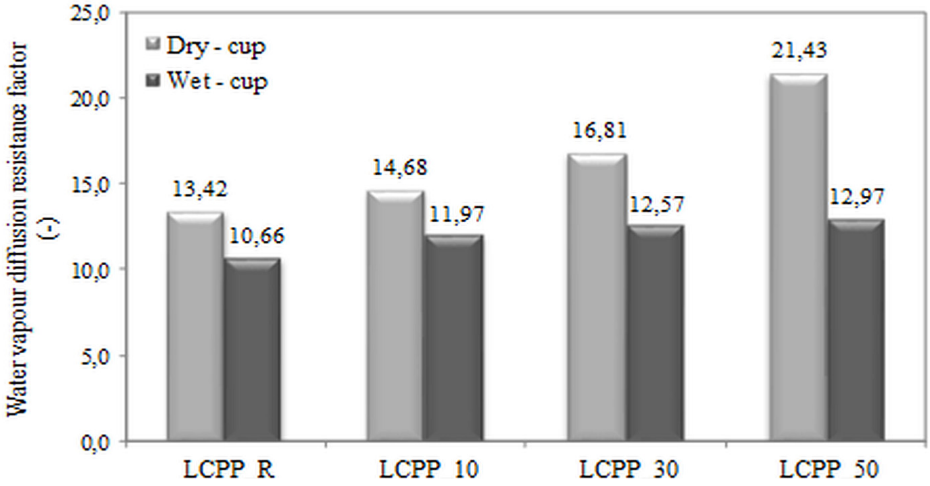

Fig. 3. Water vapour diffusion resistance factor of studied plasters.

5. Conclusions

This paper presented basic physical characteristics, liquid water and water vapour transport properties of four lime-cement plasters with gradual substitutions of the two-component binder system by a third binding material – technogenic pozzolana. Particularly fine ceramic powder in replacement levels of 10%, 30% and 50% of the binder weight was used. Obtained results can be summarized as follows:

- Matrix density variations of studied mixtures were within 2% and bulk density differed in maximum by 6%. Similar results were obtained from both used methods – vacuum saturation method and helium pycnometry.
- Open porosity showed a decreasing trend with increasing replacement levels in values determined by both methods, where vacuum saturation method gave slightly higher variations between the single values. The fall was by 10% in the case of the highest replacement level.
- Water absorption coefficient decreased with increasing amount of pozzolana and apparent moisture diffusivity as well. When 50% of pozzolana was used the water absorption coefficient went down by 57%, while apparent moisture diffusivity fell by 80%.
- Water vapour diffusion coefficient also went down with increasing substitution level. Utilisation of the highest amount of ceramic powder led to the drop by 35% in dry-cup arrangement and by 20% for wet-cup method. Water vapour diffusion resistance factor went up proportionally with similar but opposite trend.

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