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To cite this article: M áchová *et al* 2018 *IOP Conf. Ser.: Mater. Sci. Eng.* **379** 012004

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Hygric and mechanical parameters of ternary binder based plasters lightweighted by expanded perlite

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Abstract. This article is focused on modern plasters with improved thermal insulating ability. The studied plasters were composed of lime, cement, ceramic powder, expanded perlite and silica sand. Regarding the matrix, three kinds of binders were used. Lime was partially replaced by ceramic powder. These waste materials show good pozzolanic reactivity and thus bring economic and ecological benefits. Portland cement was added as a third component to the mixture for the purpose of improving mechanical performance of the studied plasters. In this article, mechanical properties of designed plasters are presented. It was proved that matrix strengthening brought positive effect and eliminated the deterioration of mechanical behaviour; the final values of compressive strength were over 3 MPa. Due to desired high porosity of the studied plasters, their durability can be strongly affected by presence of the water. Therefore, in this article, the hygric parameters were studied too. Namely, the water absorption coefficient, apparent moisture diffusivity, the water vapour diffusion resistance factor and sorption and desorption isotherms belong among studied hygric characteristics. In this article, pore size distribution curves, which affect the discussed parameters, are presented.

1. Introduction

Application of lightweighted plasters in civil engineering branch proposes many advantages. The most important is indisputably its contribution to better thermal performance of structure due to their improved thermal insulating ability. The most common way how to lighten plaster is in utilisation of lightweight aggregate. However, an application of those aggregates with higher porosity, but also usually lower mechanical strength, led to deterioration of mechanical performance of final plasters. For example Silva et al. [1] presented that utilisation of 10 wt. % of perlite in lime-cement mortar causes the significant decrease of compressive strength by almost 90% to the value of 0.37 MPa. Due to the 10 wt. % of vermiculite application, the compressive strength was decreased to 1.01 MPa, which means the descent by more than 70%, comparing with mortar with just siliceous aggregate. In the study performed by Palomer et al. [2], the negative effect of both lightweight aggregates was confirmed. The compressive strength of lime-cement mortars decreased due to the 50 vol. % of vermiculite application to final value of 3 MPa, by 51% lower in comparison with reference plaster. 50 vol. % of perlite had also deteriorating effect, however the decrease was just by 20% to the compressive strength of 4.89 MPa. Expanded polystyrene studied in Torres et al. [3] can be named as an example of another lightweighted aggregate. Its application in amount of 1.77 wt. % (of the whole composition) in cement mortar led to decrease by more than 82%. The lightweighted mortar showed compressive strength of



1.71 MPa. Granulated cork was studied by Bras et al. [4]. This material caused also the descent of compressive strength of plasters. When hydraulic lime and 50% of cork were used, the decrease was almost 77% and the compressive strength of this plaster was 0.70 MPa.

This deterioration can be somehow compensated by strengthening of matrix. From ancient time the natural pozzolana (such as example a pumice-stone, tuff, or clays, diatomaceous earth [5]) was used in combination with pure lime for the purpose of obtaining better mechanical performance of a final material. Nowadays, artificial materials are also frequently used, and the most often employed pozzolanic material is the waste material which proposes also the benefits from the ecological point of view. The application of industrial by-products such as ground granulated blast furnace slag or fly ash [6] have already been widely studied and its application in concrete production is common. Waste materials from kaolin production [7] were also studied in current research. Another representative of a clay material is a ceramic powder, which was the matter of the study in our previous work [8]. It also proved its sufficient pozzolanic properties, the kinetics of pozzolanic reaction of this waste material has already been described [9] but its wide application was not so much popularized yet. However, the ceramic powder proposes lower improvement of mechanical performance of studied plasters. Therefore, the combination of three kinds of binders were used in this study. Ternary binder based system have already been studied only in the case of a plaster production [10]. It seems to be a good opportunity applicable also in the case of a lightweight plaster.

Plasters create the exterior face of the majority of low-rise buildings, they does not fulfil only aesthetical role, but also serve as a protective layer. In this context, a plaster is always exposed to environmental deteriorative effects. There are many degradation processes, which can be divided according to the mechanisms of degradation into the physical, chemical and biological degradation. However, in the case of real building materials, degradation processes usually interact together and cannot be simply recognized. The main deteriorating mechanism affecting durability of all building materials is indisputably permeability of a material and presence of water. Water can cause primarily the physical degradation, especially in wintertime its presence causes severe damage due to the repeating freezing and thawing cycles [11, 12]. These conditions lead to the chemical degradation by dissolving or reacting with building materials. Another problem of moisture content is chemical composition of water. In real situations, water is never chemically pure, but brings along dissolved sulphates, chlorides, or gaseous pollutants. These particles can also react with components of building materials and evoke the degradation process; such as alkali-silica reaction, crystallization of salts, or carbonation [13, 14]. Therefore, hygric properties of the plaster are of a great importance and they should be appropriately investigated. Especially in the case of those materials with higher porosity such as lightweighted plasters.

In this article, two kinds of new plasters with improved thermal insulating ability are investigated and a lime-cement plaster as a reference plaster. The pore structure, mechanical properties and hygric properties are the matter of the performed research. Namely, water vapour transport parameters, water liquid properties and moisture storage ability were experimentally determined, compressive strength and achieved results are discussed herein.

2. Studied materials

Ternary binder based plasters with improved thermal insulating ability were studied in this article. Designed plasters differ in used aggregates (Table 1). The first material LP III is composed just of expanded perlite, while in the second plaster LP IV is the half of the expanded perlite replaced by the silica sand. The expanded perlite is commercially labelled as EP 180 and it is produced in temperature range 850–1,150°C. This material has low bulk density, specifically about $95 \text{ kg}\cdot\text{m}^{-3}$, and therefore it has also low thermal conductivity about $0.049 \text{ W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$ and its compressive strength shows value of 320 kPa. The silica sand was taken from the sand pit of Střeleč (Sklopísek Střeleč a.s). One grading 0–4 mm was employed. The granulometric curves of the aggregate were measured by the standard grading test [15] and they are shown in Figure 2. The matrix of the plasters is composed of three binders. Primarily lime was used. Pure lime hydrate (with 99% of calcium hydroxide)

commercially labelled as CL 90 S was produced by the lime plant Čertovy schody a. s. Specific surface of this binder was $1,374 \text{ m}^2 \cdot \text{kg}^{-1}$. For the economic and ecological purposes, the ceramic powder was used as the second binder. This waste material was taken from the brick plant Hevlín of Heluz cihlářský průmysl, v.o.s and it was produced during grinding process of thermal insulating ceramic blocks, which gave rise to fine material with specific surface area of $641 \text{ m}^2 \cdot \text{kg}^{-1}$ and sufficient pozzolanic activity ($840 \text{ mg Ca(OH)}_2 [\text{g}^{-1}]$) [16]. Portland cement was employed as the third binder. This material was used in half amount and it was chosen for the sake of the matrix strengthening. Specifically CEM I 42.5 R, with specific surface are of $341 \text{ m}^2 \cdot \text{kg}^{-1}$, originated in Čížkovice (Lafarge company, a. s.), was used. Granulometry of the binders were measured by use of Analysette 22 Micro Tec plus, and the granulometric curves are delineated in Figure 1. The last component of the studied plaster was tap water. The amount was set experimentally with the respect of reaching standard flow [17] of lightened plasters.

The reference plaster was added for comparison with the special lightweight plasters. The reference plaster is composed of the lime (5 kilogram; CL 90 S), Portland cement (1 kilogram; CEM I 42.5 R) and silica sand (18 kilograms; fraction 0.3–4.0 mm). The water binder ratio was 0.22 and the flow was 160/160 mm.

Table 1. Mixture composition of the studied plasters.

Component	LP III		LP IV	
	[kg]	[%]	[kg]	[%]
Lime (CL 90 S)	50	29	50	29
Ceramic powder	50	29	50	29
Cement (CEM I 42.5 R)	25	14	25	14
Perlite (Experlit 180)	50	29	25	14
Silica sand	-	-	25	14
Water/binder ratio	1.05		1.61	
Flow	165/165		160/160	

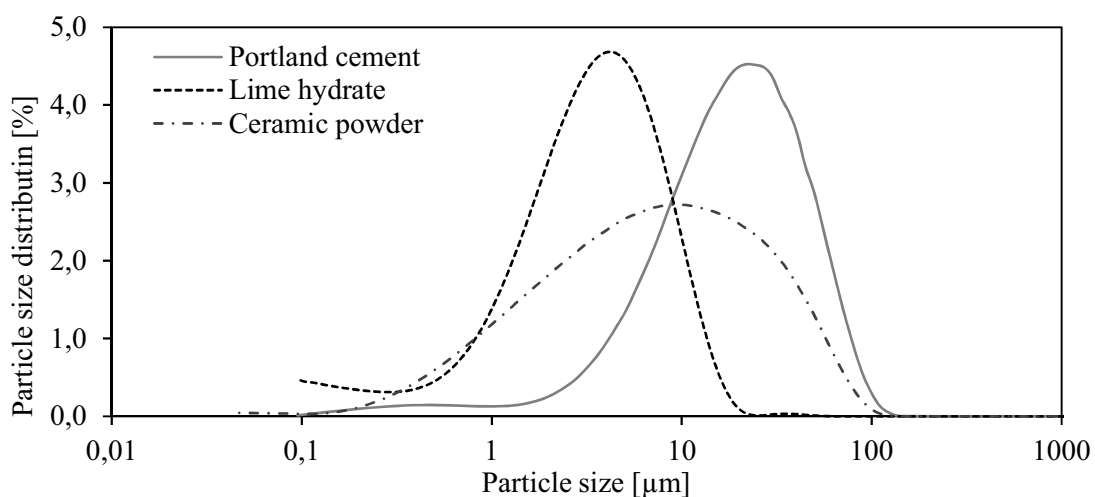


Figure 1. Particle size distribution of binders.

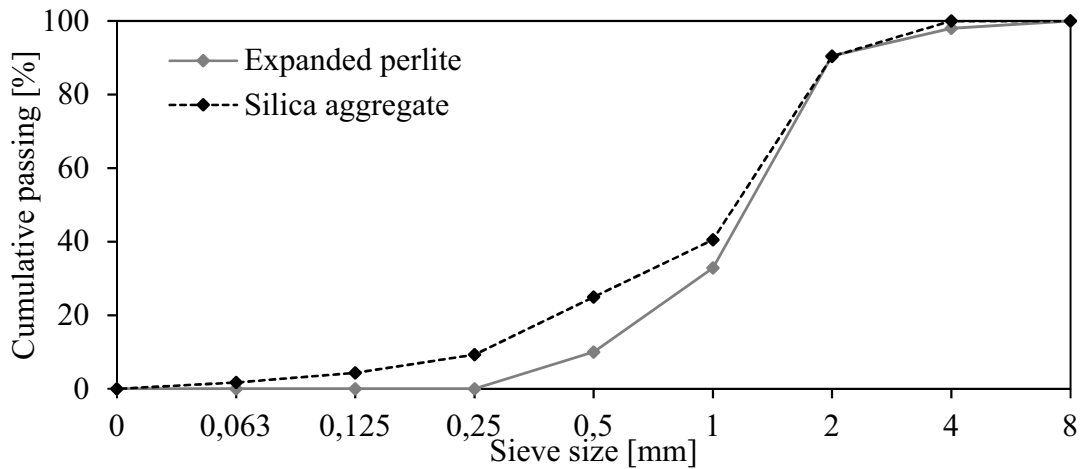


Figure 2. Particle size distribution of aggregates of the special plasters.

3. Experimental measurements and results

3.1. Pore structure.

The most influencing property for the hygric parameters is indisputably porosity of the studied material. However, more detailed description than just a value of the porosity is required for better comprehension. The pore structure of the studied plasters was determined by use of mercury intrusion porosimetry. For this experiment, the measurement apparatus PASCAL 140 + 440 was used.

Results are presented in Figure 3 and Figure 4. Both plasters had pores in similar range, from 0.1 μm to 10 μm . However, it can be seen that the plaster LP III with expanded perlite had higher porosity and also higher amount of pores in range from 1 μm to 10 μm . This amount of pores is reduced by finer sand application in the case of the plaster LP IV. The reference plaster has shown the lowest pore curves (Figure 3 and Figure 4). This reference graphs confirm the theory of the highly pore system compared to the lightweight plasters.

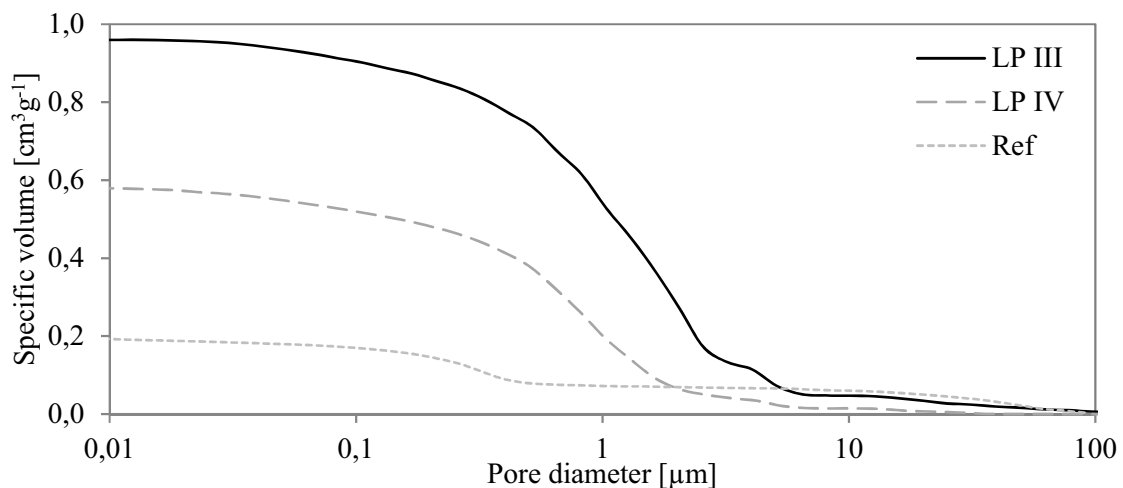


Figure 3. Cumulative curve of the studied plasters.

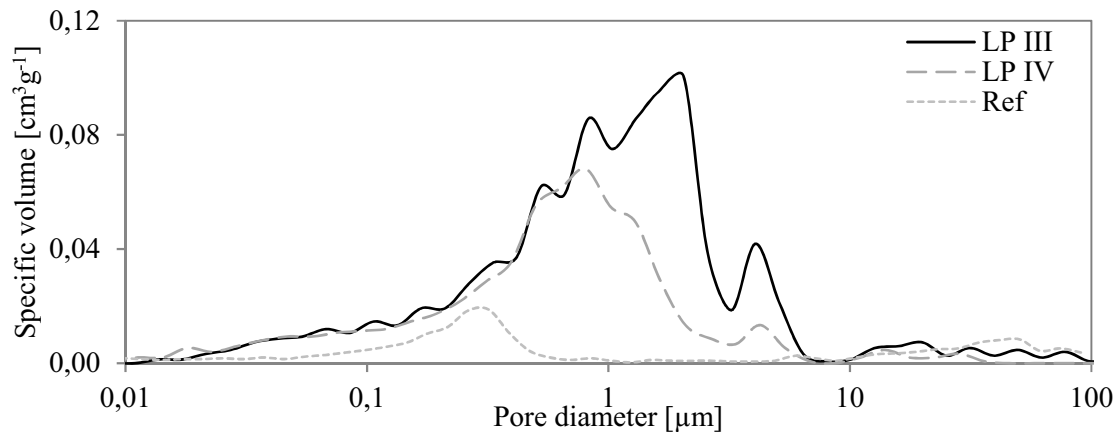


Figure 4. Distribution curve of the studied plasters.

3.2. Mechanical properties

Compressive strengths were measured according to standard methods [18] by using loading device EU40. The experiments were performed at various times to be able to describe potentially longer evolution of compressive strength due to the presence of pozzolana in the binder and its prolonged pozzolanic reaction. Achieved results of the compressive strength are presented in Figure 5. Both plasters reached quite high compressive strength, with values over 3 MPa, which were desired results reaching by binder combination. The compressive strength of the plaster LP III with just expanded perlite showed lower value of the compressive strength in comparison with the plaster LP IV with combined aggregate. The difference was in 28 days by about 23%. Regarding the influence of the time, both plasters showed quite high increase; 17% and 14% in the case of the plaster LP III and LP IV respectively. The reference plaster has shown lower mechanical properties than the special plasters with the expandite perlite. In the time evolution the behaviour of the compressive strength (reference plaster) was relatively constant from 0.6 MPa to 0.9 MPa. These results of the compressive strength of the lightweight plaster LP III are more than 3 times higher than plaster Ref.

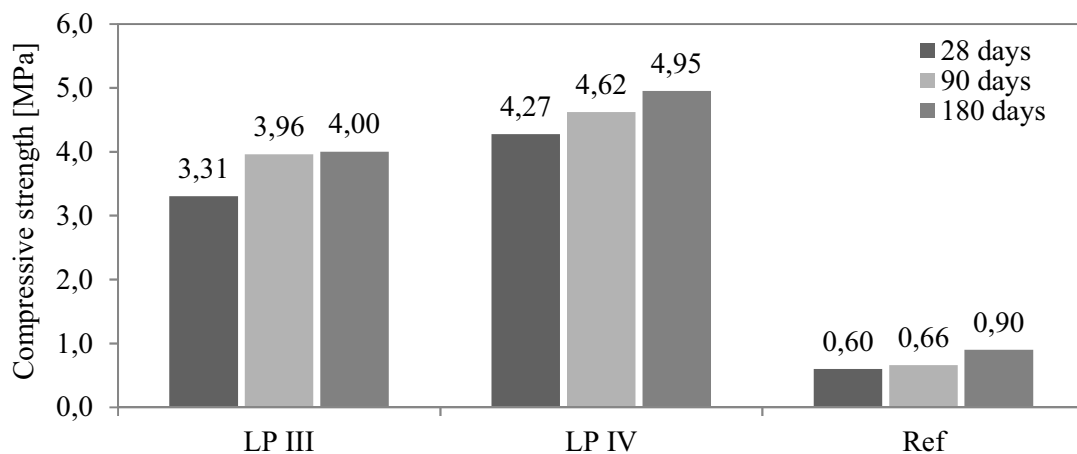


Figure 5. Time evolution of the compressive strength.

3.3. Water vapour transport

For measuring of the water vapour transport, the cup methods described in the standard ČSN 72 7031 were used [19]. Calculated the water vapour resistance factors of the studied plasters are presented in Figure 6.

In both arrangements, the plaster LP III with the expanded perlite reached lower values, which is in accordance with higher porosity of the studied plasters (Figure 3 and Figure 4). The differences were 18% and 31% for dry – cup respectively wet – cup arrangements. Regarding the difference between both arrangements, this was in accordance with results obtained for other porous materials where a significant acceleration of water vapor transport with increasing relative humidity was observed [20]. This phenomenon can be explained by the added capillary condensed water transport in the wet-cup conditions [21]. The reference plaster shows the lowest values of the diffusion resistance factor in the dry cup arrangement and the highest values in the wet cup arrangement.

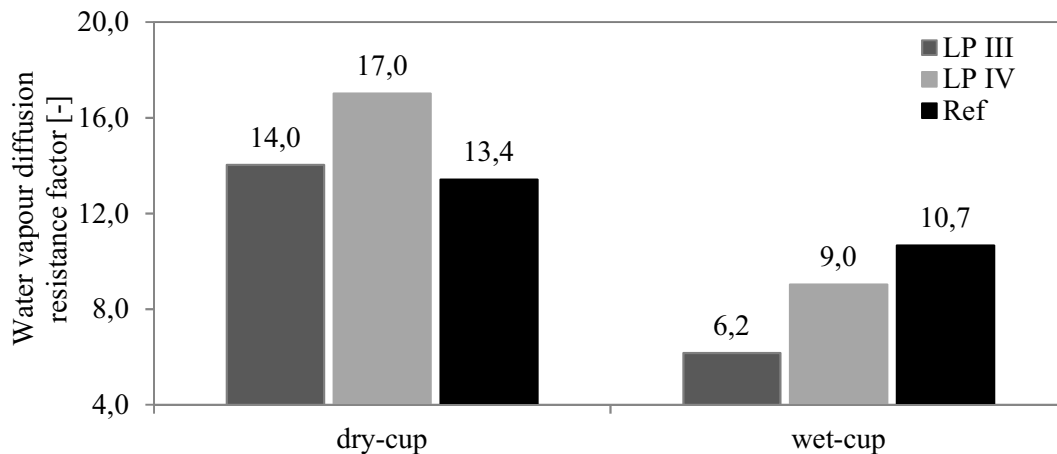


Figure 6. The water vapour transport of the studied plasters.

3.4. Water liquid transport

The water absorption coefficient was measured applying sorption experiments and determined from the sorptivity plot [22]. Approximate values of apparent moisture were also calculated [23].

Achieved results are given in Table 2. As in the case of water vapour transport, the plaster LP III with expanded perlite showed higher ability of water liquid transport compared to the plaster LP IV where aggregate combination was used. Water absorption coefficient differed by 29%, while apparent moisture diffusivity varied by 25%. Greater difference is caused by higher amount of bigger pores in the plaster LP III, which has two times greater amount of pores with diameter over 1 μm . The reference plaster Ref has the greatest water absorption coefficient. This result reaches that value of the plaster LP III. The difference at this both plasters of the water absorption coefficient is 15%.

Table 2. The water liquid transport parameters.

Property	Ref	LP III	LP IV
Water absorption coefficient [$\text{kg}\cdot\text{m}^{-2}\cdot\text{s}^{-1/2}$]	0.393	0.334	0.238
Apparent moisture diffusivity [$\text{m}^2\cdot\text{s}^{-1}$]	1.40E-07	4.22E-07	3.17E-07

3.5. Moisture storage.

The last measurement describes water vapour accumulation ability. Water sorption isotherms were determined by the special device DVS Advantage 2, which uses dynamic vapor sorption method [23]. In accordance with higher porosity of the plaster LP III, or more precisely with its bigger pores surface area, the plaster with expanded perlite proved higher ability for moisture storage. It is obvious that with increasing relative humidity the difference between both plasters become more remarkable. When the relative humidity was equal to 20%, the difference was 26%. The deviation continuously grew up to 49% in the case of 98% relative humidity. The sorption isotherm of the reference plaster is displayed as the lowest curve. This observation corresponds to the results of the porous system.

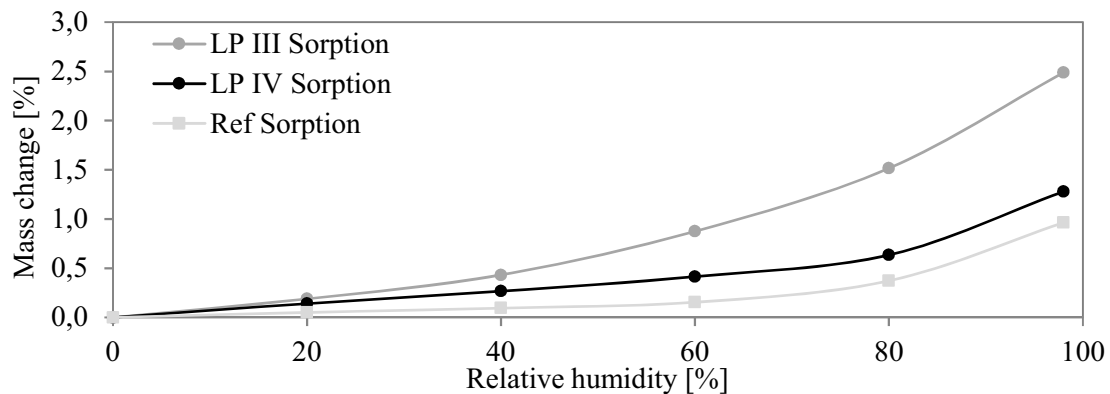


Figure 7. The sorption isotherms.

4. Summary

In this article, two kinds of the lightweighted plasters were presented. The main emphasis was focused on research of the moisture characteristic, the matrix strengthening and on the lightweight plaster. The lightening was achieved by utilisation of highly porous expanded perlite as main aggregate. The silica sand was employed in the case of the second plaster as the half replacement of the lightweight perlite. Utilisation of the lightweight aggregate usually had led to deterioration of the mechanical behaviour. This effect was confirmed also in the case of the studied plasters. The one with combined aggregate showed greater values of the mechanical properties than the plaster with just expanded perlite. However, the deteriorating effect of the lightweight aggregate was partially compensated by improvement of the matrix of the studied materials. The plasters had ternary based matrix, which composed of the lime, pozzolana and lower amount of the cement. This approach brought positive effect. The application of combined binders had economic and ecological benefits, but especially had positive effect on the mechanical performance of the studied plasters. Despite the high porosity of the designed plasters, the compressive strength reached sufficient values greater than 3 MPa. Utilisation of the expanded perlite led to desired increase of porosity, specifically the amount of pores with diameter from 1 to 10 μm went up. The water vapour permeability of both plasters was high. Satisfactory results were achieved by including higher porosity of the plasters. The difference between both plasters was not so significant. Regarding the water liquid transport, the utilisation of the expanded perlite led to the considerable growth of both water absorption coefficient and the apparent moisture diffusivity comparing to aggregate combination. Moisture storage capability was also influenced by utilisation of the expanded perlite, especially in higher level of the relative humidity. But similar to the water vapour transport, the measured sorption isotherms were not as high as they could be due to high porosity of the studied plasters.

Acknowledgments

This research has been supported in the Czech Republic under projects SGS16/199/OHK1/3T/11, P105/12/G059, and No. LO1408 "AdMaS UP - Advanced Materials, Structures and Technologies", supported by Ministry of Education, Youth and Sports under the „National Sustainability Programme I”.

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