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Ternary binder based plasters with improved thermal insulating ability

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Abstract. New kind of plasters with improved thermal insulating ability are presented in this article. Improvement was reached by utilization of lightweight expanded perlite with high porosity. The second used aggregate was silica sand. Regarding the binder, three kind were combined for the reason of better plaster performance. Pure lime, Portland cement and pozzolanic ceramic powder were employed. Basic physical properties and thermal characteristics were determined. The porosity of plasters reached desired higher value about 50% and the thermal conductivity in dry state was lower than 0.16 $Wm^{-1}K^{-1}$.

1. Introduction

In the last decade, the requirements on thermal protection of building have been increasing. New standards [1] demands thermal transmittance of external wall lower than 0.30 W $m^{-2}K^{-1}$ and recommended value lower than 0.20 W $m^{-2}K^{-1}$. Both economic and ecological aspects led to the growth of new building structure known as passive house with even higher energy efficiency, respectively higher demands on thermal protection. From those reasons, it is necessary to design such building materials with improved thermal insulating ability, and it becomes the aim of not only load-bearing materials but of all materials of structure despite their thickness.

Plasters are indisputably part of most of family houses and low-rise buildings and they could not deteriorate thermal insulating ability of the structure. The simplest and the most effective way to improved thermal insulating ability of plasters is by its lightening. It can be performed by introducing the air or gas into the mixture, increasing the water to plaster ratio or by utilization of carbonated water [2]. However, the most common is utilization of lightweight aggregate such as expanded clay [3], expanded perlite [3, 4], expanded polystyrene [4], and cork [5]. Also some uncommon materials were examined in current researches such as olive stones [6] or waste material [7]. Generally can be concluded, that plaster lightening led to decrease if mechanical strength. Therefore, it seems to be good idea somehow strengthen the matrix of plaster. Not only for this reason, but mostly for ecological and economical aspects, blended and ternary based binders have been designed. Ternary system were already investigated mainly in the case of concrete production. In this cases binder usually composed of cement and some pozzolanic materials. The most frequently used have been combination of silica fume with metakaolin [8], fly ash [9] or ground granulated blast-furnace slag

[10]. This approach seems to be applicable also in the case of plasters, however it has been study rarely.

Plasters in this article were lightened by expanded perlite and the binder part composed of lime and pozzolanic ceramic powder. For the reason of obtaining better mechanical performance, also Portland cement was used. Basic physical and thermal characteristics were measured and achieved results are presented hereinafter.

2. Studied materials

Studied materials were two lightened plaster with ternary-based binder. Particular composition can be found in Table 1. As lightening aggregate expanded perlite commercially labelled as EP 180 was used. The raw perlite were exposed to 850 – 1150°C and it give rise to material with low bulk density (95 kg m^{-3}), low thermal conductivity (0.049 W $m^{-1}K^{-1}$) and its compressive strength is 320kPa. The first plasters LP III was made just with this kind of aggregate, while in the second case of plaster (LP IV) also silica sand was employed. This sand originated in Sklopísek Střelč a.s and its grading is 1-6mm. used aggregate was mixed in mass ratio 1:1. As binder component, primarily pure lime CL 90S from lime plant Čertovy schody a.s. were employed. Its specific surface area is 1374 m^2kg^{-1} and it composed of 99% of calcium hydroxide. The second binder was pozzolanic material ceramic powder. It originated in grinding process of thermal insulating ceramic block in Hevlín brick plant (Heluz cihlářský průmysl v. o. s.). This waste material shows good pozzolanic activity and its specific surface area is 665 m^2kg^{-1}. The third binder was Portland cement CEM I 42.5, with specific surface are of 641 m^2kg^{-1}, originated in Čížkovice (Lafarge company, a.s.). Used binder were mixed in ratio 2:2:1. The last component of studied plaster was tap water. The amount was set experimentally with the respect of reaching standard flow [11] of lightened plasters. Chemical compositions of raw-materials were determined by X-ray fluorescenece spectroscopy, specifically with the use of Thermo ARL 9400 XP device. Achieved results are presented in Table 2.

The production process of plasters was as follows: primarily All the dry components (aggregates and binders) were homogenized in a standard mixer. Then the water was gradually poured in and for 4 minutes the mixture was slowly mixed. After that the speed of rev was increased and mixing in higher speed took another six minutes. The resulting fresh blends were put into a specific moulds. Next day the specimens were demoulded and left in laboratory conditions (temperature 20 ± 1 ° C and relative humidity 50 ± 5 %) for 28 days.

Table 1. Composition of studied plasters.

Component	LP III		LP IV	
	[kg m^{-3}]	[%]	[kg m^{-3}]	[%]
Lime	61	28.6	96	28.6
Portland cement	61	28.6	96	28.6
Ceramic powder	30	14.3	48	14.3
Expanded perlite	61	28.6	48	14.3
Silica sand	0	0	48	14.3
Dry comp./water	1.05		1.61	
Flow [mm/mm]	165/165		160/160	

Table 2. Chemical composition of raw-materials.

	Lime	Ceramic	Cement	Perlite	Sand
SiO_2		51.3	21.9	65.3	99.2
Al_2O_3		20.0	5.6	18.7	
Fe_2O_3		6.0	3.8	3.0	0.0
CaO	99.3	11.5	62.3	3.5	
MgO	0.5	4.5	1.0	2.3	
K_2O		3.2	0.9	3.8	
Na_2O		1.3	0.1	3.1	
TiO_2		0.1	0.3		
SO_3	0.1	1.0	2.9		
P_2O_5			0.2		
MnO			0.1		

3. Experimental methods and results

3.1. Basic physical properties

Water vacuum method [12] was used for determination of bulk density, matrix density and open porosity. Five samples with dimension 50 x 50 x 50 mm were prepared and their mass in different moisture state was determined. From dry mass, water saturated mass and mass under the water level the basic physical properties were calculated. Achieved results can be found in Table 3. Both plaster proved low bulk density. Lower value by about 30% were obtained in the case of plaster LP III, where just expanded perlite was used. Also the matrix density reached quite reduced value (in comparison with ordinary lime plaster). Similar as in the case of bulk density lower matrix density showed plaster LPIII, the difference was about 8%. The most important basic physical characteristics is open porosity which reached desired high rate. In accordance with previous characteristic plaster LP III with just expanded perlite proved by almost 20% higher open porosity than material LP IV where combination of aggregate was used.

Table 3. Basic physical properties.

Plaster	Bulk density	Matrix density	Open porosity
	[kg m^{-3}]	[kg m^{-3}]	[%]
LP III	612	1584	61.4
LP IV	871	1722	49.4

3.2. Thermal characteristic

Special device ISOMET 2104 [13]. For this measurement three samples with dimension 70 x 70 x 70 mm were used. Because both thermal conductivity and specific heat capacity are strongly influenced by moisture content, they were determined in several moisture state. In Figure 1 the dependency of thermal conductivity is drawn. Plaster LP III with just expanded perlite showed lower value in all moisture states. The difference in comparison with plaster LP IV with both kinds of aggregate was in dry state 27%. Achieved results are in accordance with final values of plasters porosity (Table 2) and assumption that with increasing porosity of material its thermal conductivity decreases. However more serious than kind of used aggregate was moisture content of plaster. Due to the water saturation the thermal conductivity growth sharply. In the case of plaster LP III, the increase is by about 82%. While the thermal conductivity of plaster LP IV with lightweight aggregate and silica sand grew due to the water saturation by about 79%.

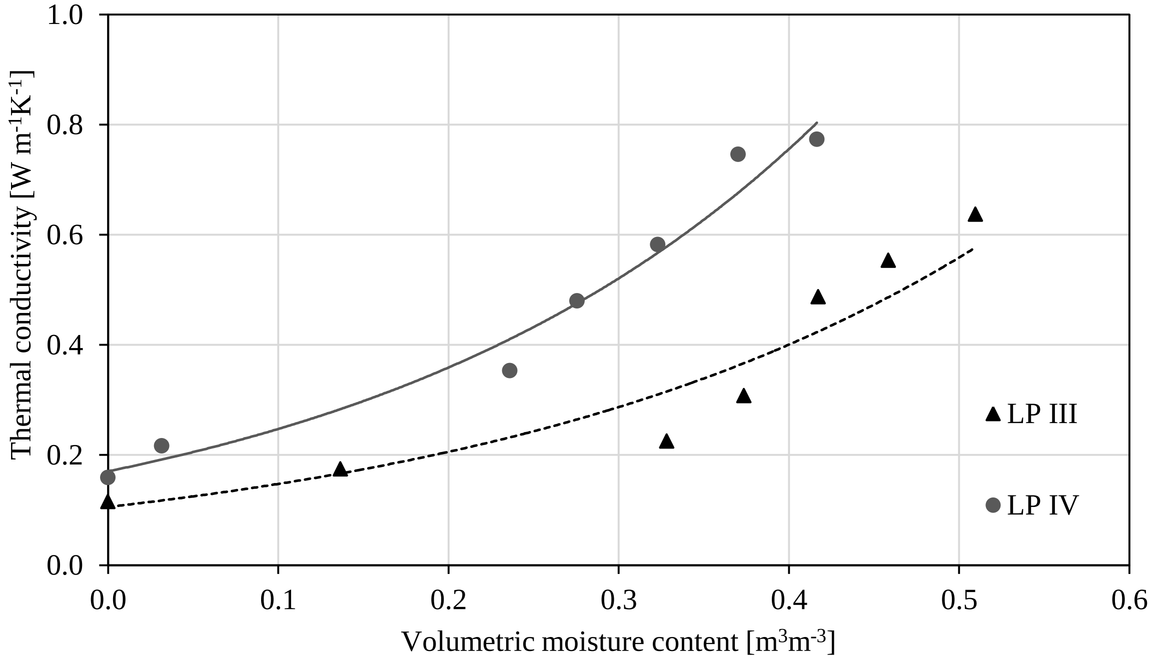

Figure 1. Thermal conductivity depending on moisture content

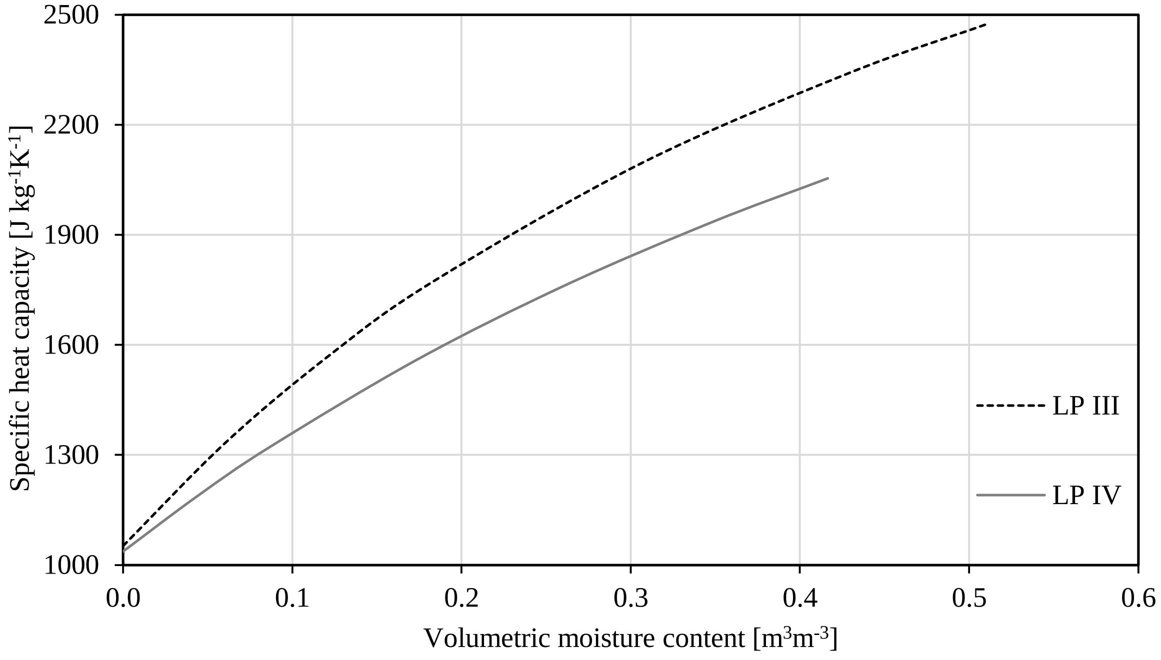

Figure 2. Specific heat capacity depending on moisture content

Achieved dependencies of specific heat capacity on moisture content are delineated in Figure 2. Both plasters reached almost similar values in dry state. The specific heat capacities varied by less than 2%. Taking into account the measurement accuracy, they could be considered as equal values. As in the previous cases of thermal characteristic, also for specific heat capacity is more important the moisture content of plaster than its composition or porosity. Due to the water saturation the specific heat capacity increased by about 57% and 50% for plaster LP III and LP IV respectively.

4. Summary

In this article, new kinds of plasters are presented. Since the requirements on thermal protection of building are increasing, plasters were designed in consideration of having better thermal insulating ability. This improvement was performed by plaster lightening. Expanded perlite with low bulk density and high porosity was used as main aggregate. For economic reasons also plaster with aggregate combination was designed. As second aggregate, ordinary silica sand was employed. Matrix of both designed plaster was composed of three kind of binder. Primarily pure lime was combined with pozzolanic ceramic powder. Utilisation of waste pozzolana bring positive not only from the point of view of mechanical performance, but also from the ecological aspects (lowering of consumption of primary binder as well as processing of waste material). The third kind of binder was Portland cement, which was dosage in lower amount. Both plasters showed low bulk density and matrix density. Regarding the open porosity, it fulfilled the desired higher values. Specifically when just expande perlite was used the open porosity was over 60%. This led to the improvement of thermal insulating ability of plasters. The thermal conductivity was lower than 0,16 Wm-1K-1 in the case of aggregate combination and even by 27% lower when just perlite was used. It can be concluded that plaster with just expanded perlite reached better properties; however also in the case of aggregate combination, the plaster performance is suitable.

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