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Development of Latent Heat Storage Phase Change Material Containing Plaster

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This paper reviews the development of latent heat storage Phase Change Material (PCM) containing plaster as in passive application. Due to the phase change, these materials can store higher amounts of thermal energy than traditional building materials and can be used to add thermal inertia to lightweight constructions. It was shown that the use of PCMs have advantages stabilizing the room temperature variations during summer days, provided sufficient night ventilation is allowed. Another advantage of PCM usage is stabilized indoor temperature on the heating season. The goal of this study is to develop cement and lime based plaster containing microencapsulated PCM. The plaster is expected to be used for passive indoor applications and enhance the thermal properties of building envelope. The plaster was investigated under Scanning Electron Microscope and the mechanical, physical and thermal properties of created plaster samples were determined.

Keywords: phase change materials, plaster, latent heat, passive cooling, thermal inertia.

1. INTRODUCTION

Demand for higher thermal comfort and climate changes has brought new challenges for designers of cooling systems, because of increased usage of air conditioning in building environment, resulting in higher electricity demand and CO_2 emissions. Today the thermal energy storage plays an important role in building energy conservation, which can be achieved by the incorporation of Phase Change Material (PCM) into building envelope. PCM incorporated in building envelope, for example, in walls with plasters, absorb redundant heat, which leads to improved thermal inertia of the building, lower and shifted in time temperature peaks. References have been found for improving the thermal properties of concrete and plasters containing PCM [1 – 6].

During the phase change (solid – liquid), PCMs can absorb heat in the day when the indoor air temperature rises above the PCM melting point and release it and solidify in the night when the indoor air temperature drops below the melting point. Due to this every day cycle, PCMs can be used for cooling a building in three conventional ways [7]:

• Passive cooling: Cooling through the direct heat exchange of indoor air with PCMs incorporated into the existing building materials such as plasterboards, floorboards and furniture

• Assisted passive cooling: Passive cooling with an active component (for example, a fan) that accelerates heat exchange by increasing the air movement across the surface of the PCM

• Active cooling: Using electricity or absorption cooling to reduce the temperature and/or change the phase of the PCM

As active cooling, and supportive passive cooling, require the use of additional energy (refrigeration and fans). It is likely that the simplest, most cost-effective and environmentally friendly usage of PCM is in a purely passive way. The focus of this paper is on the use of PCMs for passive cooling.

A preliminary study was done to evaluate the indoor temperature in an ordinary office room in Latvia, Riga. It was established that there are more than 70 days per year, where the indoor temperature rises over 25 °C.

The goal of this study is to develop cement and lime based plaster containing microencapsulated PCM. The plaster is expected to be used for passive indoor applications and enhance the thermal properties of building envelope. The plaster was investigated under Scanning Electron Microscope and the mechanical, physical and thermal properties of developed plaster samples were determined.

2. EXPERIMENTAL DETAILS

The developed plaster consists of cement, lime as binders, mineral aggregates, different admixtures for the improvement of application workability and PCM. Two kinds of microencapsulated PCM products were investigated: AERO polymer microcapsules containing Rubitherm RT27 in slurry state and BASF Micronal DS 5001x in powder state. RT27 is a pure paraffin PCM heat storage material utilizing the processes of phase change between solid and liquid (melting and congealing) to store and release large quantities of thermal energy at nearly constant temperature. BASF Micronal DS 5001x powder of polymer microcapsules contains a latent heat storage material made from a special wax mixture. From AERO technical datasheet the density of slurry was 950 – 1000 kg/m^3 and the PCM solid content 30 – 35 %. Respectively, the bulk density of BASF Micronal was 350 kg/m^3. Different mixture compositions were made to achieve the accurate workability and mechanical properties for the designed plaster. The components of the mixture were batched, mixed in dry state, water was added and it

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was ready for use. The solid PCM content in plaster was 10 % of plaster mass.

To determine the PCM latent heat capacity and phase change temperature, Differential Scanning Calorimetry (DSC) measurements were made with equipment Mettler Toledo DSC 1. The heating rate was 0.5°C/min. The measured latent heat capacity for BASF Micronal DS 5001x was 99.8 kJ/kg with a melting range from 22 °C to 29 °C (Fig. 1), but according with the technical datasheet latent heat should be 110 kJ/kg.

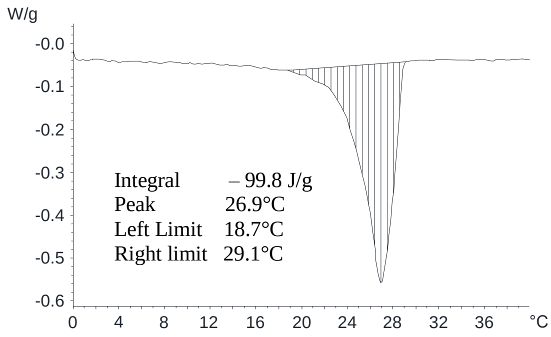


Fig. 1. DSC results for BASF 5001x

AERO microcapsules with DSC were tested in two different ways: after drying out the water from the slurry (solid state) (Fig. 2) and slurry state (Fig. 3) where the solid content was 38 %. In slurry state the latent heat was 39.3 kJ/kg, but solid state – 85.6 kJ/kg with a melting range from 24 °C to 28 °C. Latent heat for the slurry by calculating theoretically from technical datasheet, if the latent heat of raw PCM is 184 kJ/kg, 70 – 75 % of microcapsules mass are PCM and the solid content in the slurry is 30 – 35 %, it should be from 38.6 to 48.3 kJ/kg. Latent heat with this data for AERO in solid state should be from 128.8 to 138.0 kJ/kg. So it could be concluded that real DSC measurements compared with technical datasheet values are lower by 9 % for BASF and 9.6 % for AERO in slurry state, and 35.8 % for AERO in solid state. It should be mentioned that preparing AERO samples for DSC measurements in solid state, microcapsules near the surface were damaged (Fig. 5 b).

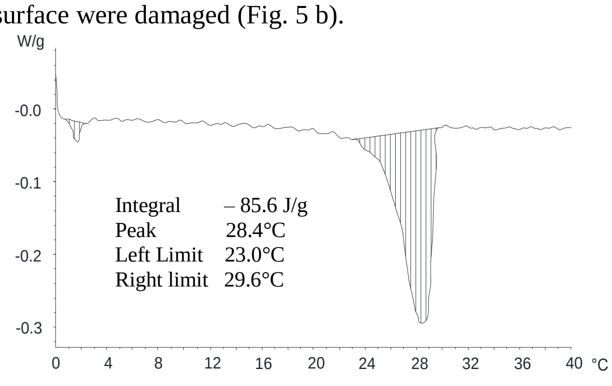


Fig. 2. DSC results for AERO in solid state

Microscopic observation for PCM was done by scanning electron microscope (SEM) TESCAN Mira\LMU Field-Emission-Gun.

In Fig. 4 is seen that BASF microcapsules are agglomerates of the individual microcapsules encapsulated twice, where the small microcapsules are from 4 to 10 μm in diameter, but after second encapsulation the diameter sizes are from 50 to 300 μm.

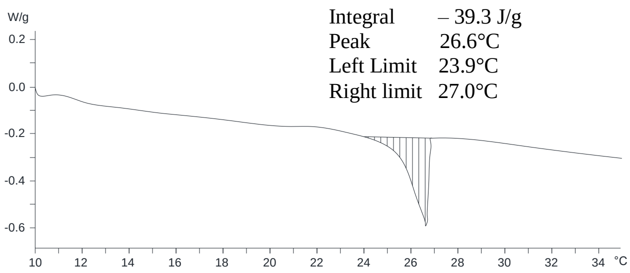


Fig. 3. DSC results for AERO in slurry state

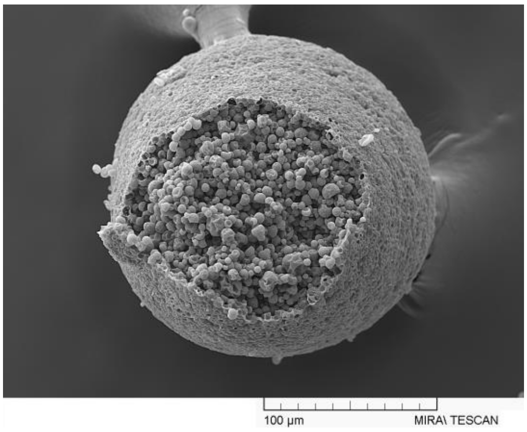
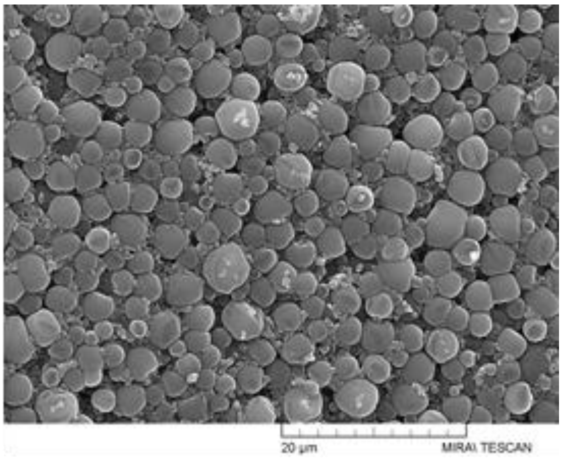
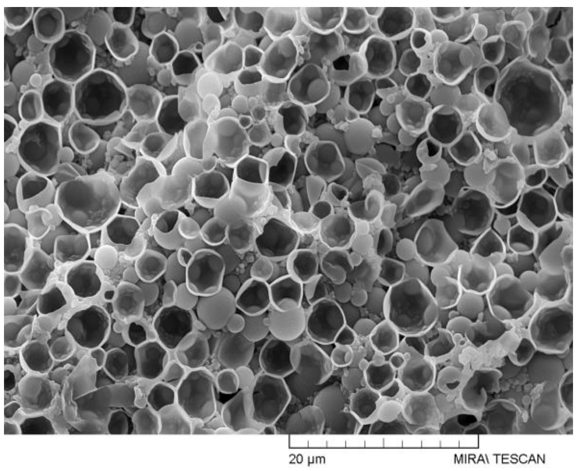


Fig. 4. SEM micrographs of BASF Micronal DS 5001x microcapsules (100 μm)



a



b

Fig. 5. SEM micrographs of AERO microcapsules (20 μm): a – slurry state, b – dry state (broken surface)

The investigation of AERO PCM under SEM was done in a slurry state Fig. 5 a and in dry state Fig. 5 b on the broken surface so that the approximate shell thickness could be measured. The AERO microcapsule sizes were from 2 to 6 µm and the shell thickness was 0.2 µm.

Properties, like bulk density, flexural strength in three points bending and compressive strength, for hardened plaster samples were measured [8]. The properties of a standard plaster without PCM also were measured in the same conditions and are presented as reference. The size of the specimens was 40 × 40 × 160 mm. and were cured in water in room temperature 20 ± 2°C for 28 days. Hydraulic press was used for mechanical tests. Plaster density was measured in air-dry state. DSC measurements in heating and cooling and SEM images were taken for hardened plaster samples.

3. RESULTS AND DISCUSSION

The flexural and compressive strength was measured in 7 and 28 days and it can be seen in Fig. 6 and Table 1. Mechanical properties are greatly affected by PCM addition, which results in twice a decrease in strength for both PCM plasters comparing with reference. Still, the mechanical properties of the matrix are good enough to satisfy the suitability of operation as an indoor plaster. PCM addition to the mixture composition decreases the density of the plaster by 8 % with AERO, but by 19 % with BASF DS 5001x.

Table 1. Mechanical and physical properties of plaster

	Reference	AERO	BASF DS 5001x
Density, kg/m^3	1530	1410	1240
Flexural strength, MPa (28 days)	2.3	1.3	1.4
Reduction %		43.5%	39.1%
Compressive strength, MPa	6.0	2.4	2.3
Reduction %		60.0%	61.7%

The developed plaster after solidification was examined under SEM. From Fig. 7 b it is obvious that after dry and wet mixing, BASF microcapsules separated fully or partially in Fig. 8 from the agglomerates and are homogenous dispersed in the plaster matrix. The only difference is that BASF microcapsules in some places could be in a higher concentration, near to the partially separated agglomerates (Fig. 8). In spite of that, for both PCM no leakage is observed through the cover of the microcapsule.

The DSC analysis for hardened plaster samples was done. From Fig. 9 it is seen that for plaster with BASF microcapsules the latent heat in heating is 6.0 kJ/kg, but in cooling 6.9 kJ/kg. Also 1.3 °C hysteresis is observed. Repeated DSC measurements for plaster with AERO microcapsules (Fig. 10) showed that the PCM has a very large, approximately 14°C, hysteresis between melting and crystallization points, which makes this microencapsulated PCM unsuitable for development of plaster. Also it is seen that for AERO the latent heat capacity in heating and cooling is relatively lower, 5.1 and 4.5 kJ/kg respectively.

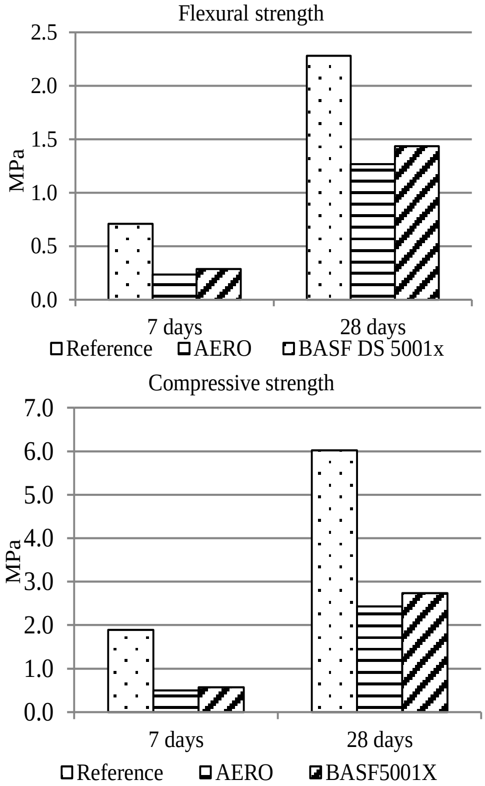


Fig. 6. Flexural and compressive strength of plaster

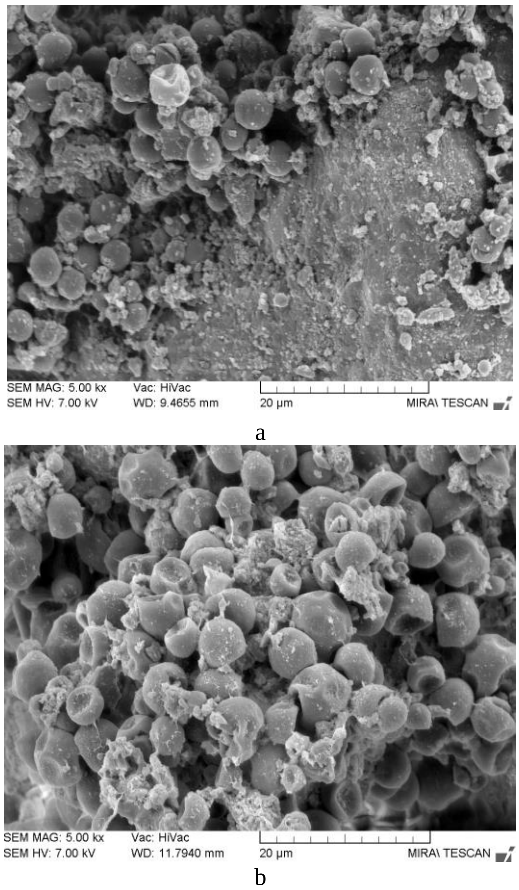


Fig. 7. SEM micrographs for developed plaster (20 µm): a – plaster with AERO microcapsules; b – plaster with BASF DS 5001x)

By theoretical calculation for developed plaster with BASF microcapsules 1 m^2 of 1.5 cm thick plaster layer would result in a latent heat capacity of 112.16 kJ/m^2, but for a layer of 2.5 cm it would be 186.93 kJ/m^2.

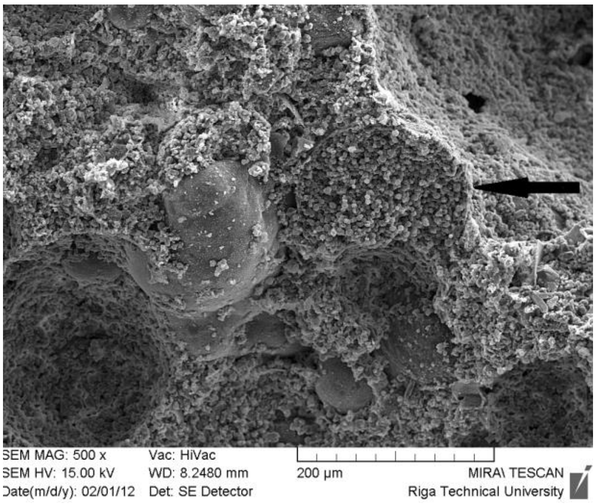


Fig. 8. SEM micrograph for plaster with BASF DS 5001x (200 μm)

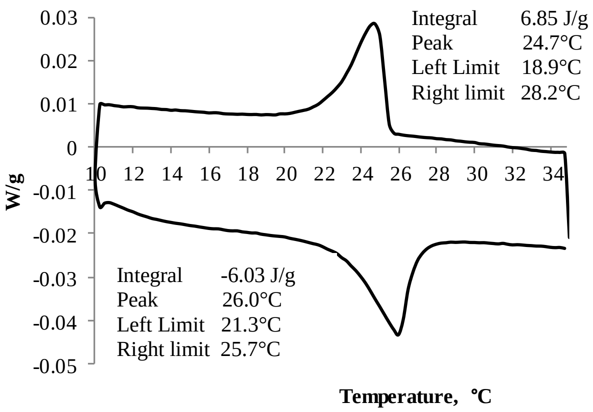


Fig. 9. DSC results for plaster with BASF 5001x

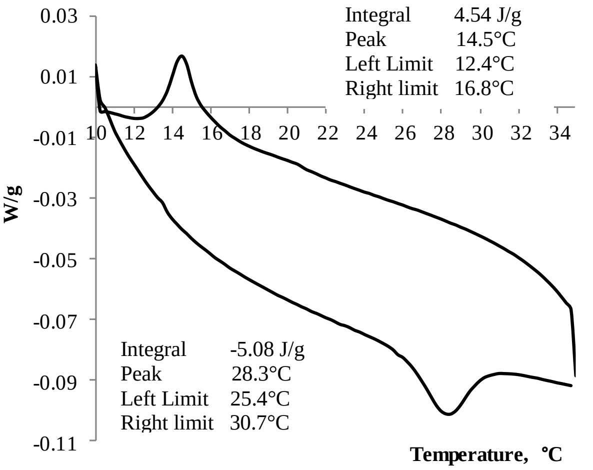


Fig. 10. DSC results for plaster with AERO

4. CONCLUSIONS

It was feasible to develop cement and lime based plaster with microencapsulated PCM. In wet mixing process BASF microcapsules separated from the agglomerates and were homogenous dispersed in the plaster matrix without any damage and PCM leakage.

DSC measurements for hardened plaster samples showed that plaster with BASF DS 5001x has latent heat capacity of 6.0 kJ/kg, but plaster with AERO microcapsules showed unsatisfied results, because of large hysteresis (14 °C). The phenomenon of such a large hysteresis should be investigated further.

Using plaster with BASF DS 5001x microcapsules, latent heat will result in 112.16 kJ/m^2 using it in 1.5 cm thick layer and 186.93 kJ/m^2 in 2.5 cm thick layer. Still, in further research the amount of PCM in plaster should be increased.

The mechanical properties for the developed plaster decreased twice compared with the reference one, but still they are good enough to satisfy the suitability of operation as an indoor plaster.

According to obtained plaster mechanical and thermal properties, it was expected to allow the use of this new plaster for indoor applications where standard plasters are commonly used and improve the indoor thermal comfort by absorbing the latent heat, thus increasing the thermal inertia of a building.

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