



# Investigation of different materials for macroencapsulation of salt hydrate phase change materials for building purposes

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## HIGHLIGHTS

- Macroencapsulation materials for salt hydrate phase change material.
- Water vapor impermeable sealants made of foils or liquids.
- Cheaper sealants compared to microencapsulated paraffins.
- Additional spherical shape for salt hydrates enable a more variable selection for the application.

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## ABSTRACT

Most of the installed phase change material in buildings is expensive microencapsulated paraffin, which is flammable. Salt hydrates are corrosive and hygroscopic but cheap. A suitable salt hydrate encapsulation material would be of great interest to the construction industry. Thus, macroencapsulation can be a possible and cheap opportunity. Therefore, different methods to macroencapsulate phase change material, consisting of 50 wt%  $\text{MgCl}_2 \times 6\text{H}_2\text{O}$  and 50 wt%  $\text{CaCl}_2 \times 6\text{H}_2\text{O}$ , were investigated. The investigation results show that the foils with a layer of aluminum or polyvinylidene chloride and liquid spar varnish with additives (mica, graphite, glass flakes) are suitable materials. Furthermore, liquid rubber (Noxyde®), liquid EPDM (ethylene propylene diene (M-class)) and liquid polyvinylidene chloride as well as butyl rubber as extruded tape, malleable modelling clay or injectable mass were tested. These materials are also usable, whereas liquid two-component polysulfide and other foils are not suitable. In conclusion, the supplier can decide to use foils or liquid materials based on the application, the construction material and the price.

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## 1. Introduction

The main advantages of phase change materials (PCMs) are a significantly high amount of energy that can be stored in a small volume and a constant temperature when the energy is released [1]. These characteristics are particularly reasonable and useful for applications in the construction industry. For example, within the EU the construction sector is responsible for 40% of the energy consumption and consequently for 40% of the overall carbon dioxide release [2,3]. In addition to private households office buildings consume 28% of the overall energy [4]. Savings in these sectors are important to reach the milestones of climate contracts.

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Besides ecological effects, companies are interested in the economic optimization of their products, which can be realized by decreasing the wall thickness to improve material and transport costs and reduce construction time [5].

In countries with high solar incidents and simultaneously high temperature differences between day and night time, thermal storage materials can be important [6,7]. During the daytime, heat is usually generated because of solar absorption on the outer wall of the house and transferred into the living rooms. High room temperatures are a logical consequence. By decreasing the outside temperature, heat is released, and the room temperature decreases. This issue can be prevented by adding PCM to the wall to increase the overall heat capacity and reduce the temperature fluctuations, which commonly cause discomfort [8]. This works particularly well because solid mass liquefies due to a surrounding air temperature higher than the melting point, and thereby takes

up a high amount of melting energy. During the nighttime when temperature decreases, heat is released and liquid PCM crystallizes.

In addition to temperature fluctuations, PCM can help to reduce the electrical energy demand for heating or cooling and decreases the overall energy consumption and thus the carbon footprint [1,9]. Furthermore, it can help to overcome a coincidence when renewable energy, e.g. when heat must be generated via a heat pump by solar or wind energy, is not available but required [10].

Many investigations examined PCM applications in buildings made of concrete or in prefabricated houses, which have a particularly low heat capacity due to physical data of the construction material (e.g. timber and wood fiber insulation) and the low wall thickness [1,8,11–14]. In these cases, the most often used and investigated phase change materials are fatty acids, paraffins or salt hydrates [15–17]. Paraffins are mainly sold and already purchasable as microencapsulated spheres enclosed in construction panels. This type of material has several disadvantages compared to materials such as salt hydrates. The most important problem is a high investment (>10,000 €/t) for a wall impregnated or equipped with paraffin spheres because of the expensive microencapsulation process to retain it in the walls, where it should remain even if it is liquid [2]. Furthermore, these materials are flammable, and the melting temperature is not consistent during melting [11]. All of these reasons cause a small installed PCM weight in walls and thus a low storage effect compared to investment costs.

Alternatively, salt hydrates can be used because they are cheap ( $\approx 450$  €/t, technical grade) and easily obtainable. The main disadvantages of salt hydrates are the corrosiveness, hygroscopicity and low cycle stability, many of which can be controlled by using a suitable encapsulation [18]. However, till now, salt hydrates and their encapsulation materials have not been intensively investigated, besides using aluminum compound foil or plastic bottles [19].

Published encapsulation processes mainly focus on microencapsulation, as for instance pan and air-suspension coating, centrifugal extrusion, vibrational nozzle, spray drying, interfacial polymerization, in situ polymerization and matrix polymerization [4,20]. Furthermore, shape-stabilized PCMs (SSPCMS) can be produced [12,21]. However, these techniques are only used to produce small spheres, which can negatively affect the heat transfer because polymers with a low heat conductivity are mainly used as encapsulation materials, and the amount of polymer compared to the PCM mass is high. Moreover, because the spheres are small, natural convection is inhibited, which results in a longer melting time and can theoretically be improved by adding particles such as copper, aluminum or graphite to the PCM or the matrix of the PCM and encapsulation material [2,22,23].

Macroencapsulated materials are easier to produce and consequently cheaper. Furthermore, because of the small amount of material compared to the PCM mass, the negative effect on the heat transfer is negligible. In comparison to paraffins, fewer materials are applicable for salt hydrates because a notably low water permeability must be ensured to guarantee long-term stability.

In this paper, different methods and materials to macroencapsulate salt hydrates are investigated in terms of the application, permeability or durability, investment costs and flexibility of different shapes.

## 2. Materials and methods

### 2.1. Reagents

Prior to the experiments, PCM was prepared with deionized water,  $\text{MgCl}_2 \times 6\text{H}_2\text{O}$  and  $\text{CaCl}_2 \times 2\text{H}_2\text{O}$ , which were purchased

from common fertilizer manufacturers. For all measurements, the PCM was a mixture of 50 wt%  $\text{MgCl}_2 \times 6\text{H}_2\text{O}$  and 50 wt%  $\text{CaCl}_2 \times 6\text{H}_2\text{O}$  with a melting temperature of approximately  $21^\circ\text{C}$ .

Aluminum compound foil (AC foil), which is a known impermeable sealing against water vapor, was purchased from Long Life for Art and consists of three different layers: 12  $\mu\text{m}$  PET, 12  $\mu\text{m}$  aluminum, and 165  $\mu\text{m}$  LDPE. The PET layer is a protection against mechanical damage, the aluminum layer prevents all penetration of water vapor, and the LDPE layer thermally seals the foil to a bag. Further impermeable foils were obtained from ac-Folien GmbH. The thickness of each layer as well as the water vapor transmission rates (WVTR) are listed in Table 1.

As a liquid supporting material for different solid, impermeable materials, spar varnish (SV) was purchased by Bootsacke Nord (Epoxy Primer Anticorrosion Sea-Line®). Spar varnish was selected because it is easily mixed with solid materials and is easy diluted by adding a thinner if solids significantly thicken. Mica can be used to improve the WVTR, so it was purchased with a mesh of 325 from Mahlwerk Neubauer-Friedrich Geffers GmbH. Graphite was obtained as expandable graphite with a mesh of <50 from Georg H. Luh GmbH. Micro glass flakes with a size of 45–300  $\mu\text{m}$  and a thickness of 5  $\mu\text{m}$  were also tested and obtained from Mühlmeier GmbH & Co. KG.

Liquid materials were of interest because of their flexibility to apply it on every possible shape. Therefore, liquid waterborne polymer (Noxyde®) was purchased from Kölbel Vertriebs GmbH, liquid two-component polysulfide (Proxan® KV 3) was purchased from Fugentechnik Ott, and Liquid Rubber EPDM® (ethylene propylene diene (M-class)) was obtained from Pro Guard Coatings. As a new material, liquid PVdC (Diofan® A050) was supplied by IMCD Deutschland GmbH & Co. KG. Butyl rubber is also a known impermeable material but difficult to process. Therefore, extruded sealing tape (RB 81), malleable modeling clay (RB IX) and injectable mass (RB 2759) were purchased from suppliers of Henkel AG & Co. KGaA products.

All test materials were chosen because of their chemical inertness against each other and against building materials. Therefore, long-term stability should be guaranteed if the material is generally suited.

### 2.2. Sample preparation

To measure the permeability of these materials, three different methods were applied.

#### 2.2.1. Foil specimens

Direct measurements of the foils were performed by producing bags with a specific area (20,020  $\text{mm}^2$  for alumina compound foil; 38,400  $\text{mm}^2$  for PE foil; 62,370  $\text{mm}^2$  for Perlalux® foils) and a minimally added PCM mass of approximately 2000  $\text{g/m}^2$  considering the surface of the foil. All foils were folded from one piece, and the remained openings were sealed with a hand-held sealing machine (Polystar® 600 D) purchased from Long Life for Art. The thickness of the PE foil was 0.2 mm.

#### 2.2.2. Liquid specimens

To enable the use of permeable foils, the surfaces can be impregnated with different liquid materials. Therefore, to ensure

**Table 1**

Data of impermeable Perlalux® foils purchased from ac-Folien GmbH (PVC: Polyvinyl chloride; PE: Polyethylene; PVdC: Polyvinylidene chloride).

Foil	PVC [ $\mu\text{m}$ ]	PE [ $\mu\text{m}$ ]	PVdC [ $\mu\text{m}$ ]	WVTR [ $\text{g}/(\text{m}^2 \cdot \text{d})$ ]
Duplex	250		36	0.10
Ultra 120	250	25	71	0.11
Ultra 180	250	25	107	0.06

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