SMART FUNCTIONAL TEXTILES CREATED BY THE APPLICATION OF MACRO-ENCAPSULATED PHASE CHANGE MATERIAL

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ABSTRACT

A phase change material (PCM) absorbs or releases a large amount of so-called "latent heat" in a material specific temperature range while its temperature remains nearly constant. When the PCM absorbs latent heat, it melts from a solid into a liquid. In a textile application, the PCM needs to be properly contained to prevent dissolution while in its liquid state. In the macro-encapsulation technology, the PCM is cross-linked into a polymeric compound and contained therein. The polymeric compound with the PCM added to it can be directly applied to a textile carrier material in the form of a coating.

Key Words: Phase change material, macro-encapsulation, thermal protection, thermal comfort, smart textiles.

1. INTRODUCTION

A phase change material (PCM) possesses the ability to change its physical state from solid to liquid and vice versa in a certain temperature range. When the melting temperature is obtained in a heating process of the PCM, the phase change from the solid state into the liquid state occurs. During this melting process, the PCM absorbs and stores a large amount of so-called "latent heat". The temperature of the PCM remains nearly constant throughout this process. In a cooling event, the stored latent heat is released into the environment and a reverse phase change from the liquid state into the solid state takes place. This return to the previous state also happens without a change in the material's temperature. The fact that a large amount of latent heat is absorbed or released without any temperature change makes a PCM highly desirable as a means of heat storage.

2. PHASE CHANGE MATERIALS

PCMs are characterized by the temperature ranges in which the phase change takes place and their latent heat storage capacities. Common PCMs are paraffin waxes, salt hydrates, bio-based materials, and eutectics. Paraffin-PCMs are nontoxic, noncorrosive, and non-hygroscopic. Their thermal behavior remains stable under permanent use. Paraffin-PCMs are byproducts of petroleum refining and, therefore, comparatively inexpensive. Salt hydrates are alloys of inorganic salts and water. They are non-combustible and, therefore, meet the fire-resistant requirements of a variety of products. An attractive property of salt hydrates is the comparatively high latent heat storage capacity. Bio-based materials are, for instance, fattic acids found in coconut oil. Eutectics are mixtures of salt hydrates.

3. MACRO-ENCAPSULATION

Before a PCM can be applied to a textile substrate, it needs to be durably contained in a carrier material in order to prevent dissolution while in its liquid state. A commonly used technology for such containment is the micro-encapsulation of paraffin waxes. In this technology, the paraffin-PCMs are enclosed in very small spheres with diameters between 1µm and 20 µm. These PCM-microcapsules are then integrated in polymeric compounds as a second containment. These polymeric compounds are used for manufacturing fibers, coating fabrics or bonding a fiber web to create a non-woven.

In contrast, in the recently developed macro-encapsulation technology, the PCM is directly integrated into a polymeric matrix such as a silicone rubber compound or an acrylic compound and durably contained therein by a cross-linking procedure. The cross-linking prevents leakage of the PCM out of the compound while liquid. The polymer matrix with the PCM treatment is either coated onto a fabric or is formed into a thin film which can be laminated onto a fabric. The coating of the fabric with the polymeric compound having the PCM macro-encapsulated therein can be carried out, i.e., by knife over roll coating, dip coating, spray coating, or screen printing.

By utilizing the macro-encapsulation technology, one containment step is eliminated, because micro-encapsulation as first containment is no longer needed. Micro-encapsulation is an expensive technology. Therefore, its avoidance makes the production of textiles with PCM-treatment more cost-effective. In addition to paraffin-PCMs, bio-based materials, salt hydrates, as well as eutectics can be macro-encapsulated. This offers the possibility to extent the temperature range in which PCMs can be utilized substantially. It also opens up the opportunity to use salt hydrates which possess significant higher latent heat storage capacities in comparison to paraffin-PCMs. Because the non-paraffinic shell of the PCM-microcapsules takes up about 50 % of the microcapsule’s volume, the occupancy of the same volume by macro-encapsulated PCMs leads to a 50 % higher latent heat storage capacity when equal PCMs are considered. Furthermore, when salt hydrates with high latent heat storage capacities are applied to the polymeric matrix in high concentrations, impressive thermal performance results are obtained. Such thermal performance characteristics enable the utilization of these polymeric compounds with PCM treatment in a variety of industrial applications.

4. THERMAL EFFECTS

A PCM utilized in a textile configuration regulates the heat flux through the fabric by absorbing or emitting latent heat and adapts the heat flux to given requirements. This feature enhances the protection again hot or cold environments and provides thermal comfort where needed.

The efficiency of the heat flux regulation and the duration of the thermal effects (absorption or release of latent heat) are mainly dependent on the latent heat storage capacity of the PCM itself. However, the overall latent heat storage capacity and, thus, the duration of the thermal effects can be further controlled by the quantity of the applied PCM. Furthermore, phase change temperature range and application temperature range need to correspond in order to realize the desired thermal benefits.

Because all of these thermal effects are triggered by temperature, textiles treated with PCM are considered to be **"**smart**"** materials.

5. SPECIAL FEATURES OF TEXTILES EQUIPPED WITH MACRO-ENCAPSULATED PCM

The application of macro-encapsulated PCMs creates new features for fabrics and textile composites which are unattainable by the utilization of micro-encapsulated PCMs.

Such features are:

- An increased heat protection and enhanced flame-retardant properties of textile products due to the application of thermally potent, fire-resistant PCMs.
- Changes in light transmission through the textile carrier material.
- Creation of environmentally-friendly and skin-friendly products by the application of bio-based PCMs.

6. APPLICATIONS OF TEXTILES EQUIPPED WITH MACRO-ENCAPSULATED PCM

6.1 Heat and Fire Protection Products

The protection against contact heat and radiant heat can be improved substantial by the application of macro-encapsulated PCMs in various kinds of protective equipment. For the first time, non-combustible salt hydrate PCMs and eutectics are available for such applications. These PCMs enhance the heat protection, but increase the fire-resistance at the same time.

6.1.1 Heat Protective Gloves

Heat protective gloves consist of three layers - an outer shell layer, an inner liner, and an insulation layer in between. The overall thickness of these three layers makes these gloves very bulky. When PCM is applied to such gloves, the absorption of latent heat would, for instance, delay the heat transfer from a carried hot object to the skin, increasing the protection against contact heat exposure and preventing burn injuries. Besides such a desirable longer protection period, the PCM application inside the glove could also be used to reduce the glove's thickness and bulkiness. i.e., by using a thinner insulation layer which would increase the hand's dexterity when carrying hot items.

In the product design, a non-combustible salt hydrate PCM absorbing latent heat at about 70°C and possessing a latent heat storage capacity of about 350 J/g was integrated in a proprietary polymeric compound which was coated on the inside of the Kevlar fabric used as the glove's outer shell material.

Gloves with and without the PCM treatment were tested against contact heat exposure emitted from a heat source with a surface temperature of 500 °C. The temperature increase inside the glove during the contact heat exposure was measured. The time for a temperature increase from 25 °C to 45 °C was extended from 17 s to 49 s by the PCM application. Furthermore, the integrity of the fabric treated with PCM was not compromised under the contact heat exposure due to the heat absorption of the PCM. [1]

6.1.2 Fire Curtains

Fire curtains are used to close an opening between two adjacent rooms inside a building in case a fire incident occurs. The material composition of the curtain provides a barrier function against the spread of flames from one part to another part of the building and limits the transfer of radiant heat for a certain period of time. The duration in which the spread of flames can be prevented and the transmission of heat can be delayed depends currently on the flame resistance, the thermal resistance and the heat storage capability of the coated fabric the curtain is made of. When PCM is applied to the fire curtain configuration, it absorbs heat generated by the fire source and transferred to the fire curtain by radiant heat. The latent heat absorption by the PCM without a temperature increase interrupts the heat flux through the curtain and prevents the decomposition of the fire curtain over an extended period of time, leading to an increase of the curtains overall heat barrier function.

A mixture of non-combustible PCMs operating in a temperature range between 80°C and 140°C is macro-encapsulated in a silicone compound which is topically applied to both sides of a steel-reinforced fiberglass fabric. The fire curtain with PCM treatment was tested in a lab furnace configuration. During the test, the sample was clamped into a frame located at the front of the furnace which was heated by a gas burner to about 1000 °C . The temperature development on the back side of the cutain facing away from the heat source is shown in Fig. 1.

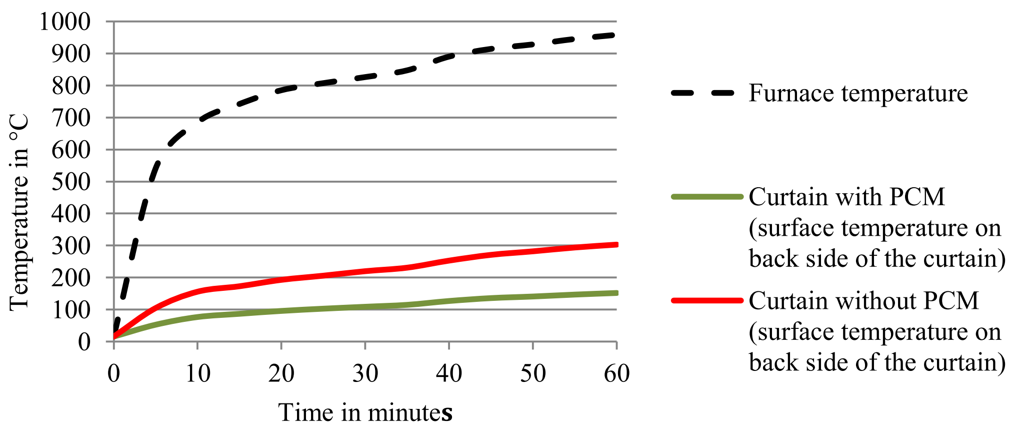

Fig. 1: Temperature development on the back side of the fire curtain

The test results summarized in Fig. 1 indicate that the desired heat barrier effect, where the temperature on the side of the curtain facing away from the heat source does not exceed 140°C + the given ambient temperature, was obtained over a period of about 60 minutes.

In contrast, this temperature boundary was already exceeded after 10 minutes when a sample of a regular fire curtain was tested. The PCM application in such fire curtains extents the heat and fire protection and makes changes in the overall curtain configuration from multi-layer systems to single layer systems possible. [2]

6.2 Architectural Membranes

Many PCMs change their appearance from opaque to transparent when they melt from a solid into a liquid. The reverse change in appearance takes place when they solidify again. When such PCMs are applied to a transparent compound which is then coated onto a fiberglass fabric possessing a high translucency, a change in light transmission of about 25 % can be experienced while the fabric is utilized in architectural structures or textile facade systems.

Throughout the day, the PCM absorbs latent heat starting at a given trigger temperature. During this latent heat absorption, the PCM reduces the transfer of infrared (heat) radiation into the structure. At the same time, the PCM’s transformation from a solid into a liquid leads to a change in the membrane’s appearance from opaque to transparent which, in turn, results in an increased visible light transmission into the building. Therefore, the use of artificial light in the interior during the day can be minimized. The stored latent heat is released overnight into the environment and the PCM’s appearance changes from transparent to opaque again which aids privacy and increases the efficiency of interior lighting. [3]

6.3 Utilization of bio-based PCMs in Mattresses

Bio-based PCMs are generated from plant products. Their macro-encapsulation in proprietary, breathable and lightweight compounds creates environmentally-friendly and skin-friendly products. Bio-based PCMs are inexpensive. Possible applications comprise bedding products and sports equipment, such as helmets. In a bedding application a bio-based, non-toxic, and non-combustible PCM is macro-encapsulated in a transparent binder which is topically applied to the upper surface of a mattress in a spray-coating procedure.

The mattress was tested with a heated and sweating torso. The test results received for the temperature development in the microclimate for mattresses with and without PCM treatment over a seven-hour period are summarized in Fig. 2.

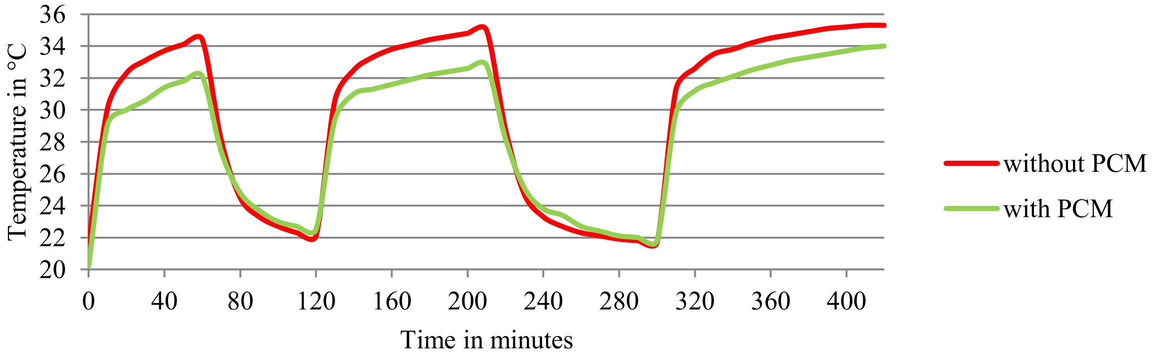

Fig. 2: Temperature development in the microclimate of mattresses with and without PCM- treatment

The change in positions during the sleep of real people overnight was considered in the test. When the human body is in contact with the mattress, heat emitted from the body penetrates into the mattress. Because of the thermal resistance of the foam the mattress consists of, the heat generated by the body cannot transferred away fast enough which leads to an increase in the microclimate temperature. The PCM's latent heat absorption prevents this overheating of the microclimate. When the body is not in direct contact with the mattress, the heat stored in the surface of the mattress and the PCM is released into the environment which enables a recharge of the PCM. The test results summarized in Fig. 2 confirm these assumptions. The temperature measured in the microclimate of the untreated mattress exceeds a critical value of 34 °C after about 40 minutes in each of the three heat exposure periods. At this temperature, the body would feel uncomfortable hot and would react with perspiration. In comparison, the test results of the bio-based PCM-treated mattress show a substantial delay in the rise of the microclimate temperature. The critical temperature of 34 °C is only obtained at the end of the third heat exposure period. Consequently, the moisture content in the microclimate of the mattress with the bio-based PCM treatment stays lower far longer as a result of decreased perspiration, as test results received in the first one-hour direct heat exposure period indicate. These test results are summarized in Fig. 3.

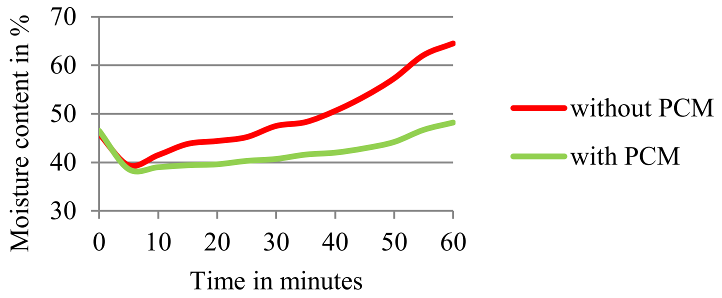

Fig. 4: Moisture development in the microclimate of the mattresses
with and without PCM treatment

7. CONCLUSION

The macro-encapsulation of PCMs provides the opportunity to utilize a vast variety of materials which canno be micro-encapsulated. In this way, the macro-encapsulation of PCM enables to creating of new products with exceptional thermal performance characteristics as well as fire-resistant properties. Furthermore, the macro-encapsulation of PCM leads to new features such as changes in light transmission which are unattainable when using PCM microcapsules. The macro-encapsulation technology is very cost-effective.

8. REFERENCES

1. ASTM F1060 (2008): Standard test methods for thermal protective performance of materials for protective clothing for hot surface contact.
2. EN 1363-1 (2012): Fire resistance tests, Part 1: General requirements
3. Pause, B., New membrane materials with adaptive heat and light transmission properties. Tensinet Symposium 'Rethinking lightweight structures' Istanbul, May 2013