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A new method of application of hydrated salts on textiles to achieve thermoregulating properties

Zeinab Kazemi, Sayed Majid Mortazavi *

Department of Textile Engineering, Isfahan University of Technology, Imam Khomeini Street, Isfahan 84156/83111, Iran

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ABSTRACT

Recently there has been a lot of attention to fibers and fabrics with thermoregulatory effects. We can acquire this quality using Phase Change Materials (PCM). In this investigation a simple method was used to keep $Na_2SO_4 \cdot 10H_2O$ as an inorganic PCM on textile structure. By this method it is not necessary for PCMs to be microencapsulated. Thermophysical properties and thermal stability effects of treated fabric was checked out by differential scanning calorimetry (DSC) and thermo gravimetric analysis (TGA). Fourier transform infrared spectroscopy (FT-IR) and X-ray diffractometry (XRD) analysis were used to study the chemical structure of the fabric with PCMs. The air transfer, water permeability, and some physical properties of treated fabric were also investigated. The results showed that, silicone rubber polymer could be applied on textile structure to hold PCM without microencapsulating, and treated textile can be served as an appropriate smart thermal insulator.

1. Introduction

Phase change material possesses the ability to change its physical state within a certain temperature range. When the melting temperature is obtained, the PCM stores a large amount of latent heat. The temperature of PCM remains nearly constant during the entire process [1]. Inorganic hydrated salts are one of the most promising materials for application in heat storage and retrieval because of its low melting point, great latent heat per unit volume, nonflammability, high heat transfer and low cost. As thermal energy storage materials, they usually exhibit many intrinsic drawbacks such as phase segregation and supercooling. These will weaken their capability of heat storage-release in practical usage [2,3].

Subcooling (also called supercooling) is the effect that a temperature significantly below the melting temperature has to be reached, until a material begins to solidify and release heat. If that temperature is not reached, the PCM will not solidify at all and thus only store sensible heat. In technical applications of PCMs, subcooling therefore can be a serious problem [4].

The use of PCMs, improve the thermal insulation capacity which differs significantly from the insulation properties of any other material [5]. Currently this property of PCMs is widely exploited in various types of garments [6].

In most cases, except for some applications of water–ice, the PCMs need to be encapsulated. The two main reasons are to hold the liquid phase of the PCMs, and to avoid contact of the PCMs with the environment. Furthermore, the surface of the encapsulation acts as heat transfer surface. In some cases, the encapsulation also serves as a construction element, which means it adds mechanical stability. Besides the containment of the liquid phase, other advantages of microencapsulation regarding PCMs are the improvement of heat transfer, and the improvement in cycling stability since phase separation is restricted to microscopic distances. Furthermore, it is also possible to integrate microencapsulated PCMs into other materials. A potential drawback of microencapsulation is however that the chance of subcooling increases [4]. Currently, microencapsulation on a commercial scale is applied only to PCM that are not soluble in water. The reason is the used process technology. Besides that, to microencapsulation of hydrated salts there is an additional problem: the tightness of the shell material to the small water molecules has to be sufficient to prevent changes of the composition of the salt hydrate [4]. There is another method to apply PCMs in a clothing system: PCMs are sealed in a plastic bag and the whole bag is inserted into the clothing package. Gao and coworkers designed a personal cooling system by this method [7].

Composites of PCMs and other materials as a mechanically stable structure are often called shape-stabilized PCM (ss-PCM). Inaba and Tu describe the preparation of ss-parafine with about 75 wt%

* Corresponding author. Tel.: +98 311 3915007; fax: +98 311 3912444.
E-mail address: mortaza@cc.iut.ac.ir (S.M. Mortazavi).

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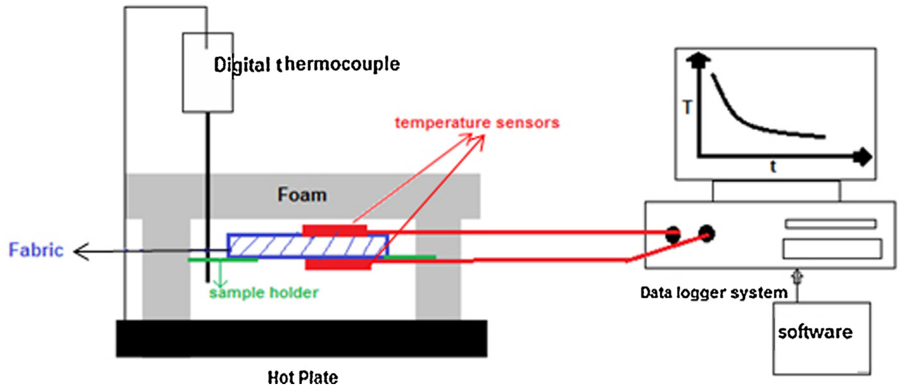

Fig. 1. Guarded hot plate system.

of paraffin and report that there is no leakage of the paraffin out of the HDPE (high density polyethylene) structure [8]. Royon has developed a new material where water as a PCM is integrated into a three dimensional network of polyacrylamide during the polymerization process [9]. Another approach to improve the mechanical stability by forming a composite material is the impregnation of mechanically stable, porous materials with PCMs. Wang investigated the effect of preparation methods on the structure and thermal properties of stearic acid/activated montmorillonite phase change materials [10]. Yang prepared the form-stable polyethylene glycol/silicone dioxide composites as solid–liquid PCMs [11].

In the present applications of microencapsulated PCMs in the textile industry, the crystalline alkyl hydrocarbons are used exclusively. In the last decade several methods of incorporating micro PCMs into fibrous structures were developed to produce fabrics having enhanced thermal properties. In this research Glauber's salt, was used as an inorganic PCM in a thin film on fabric surface for the first time and a new simple method was introduced to keep inorganic PCMs without dehydration on fabric structure. By this method there is not necessary for PCMs to be micro encapsulated.

2. Experimental

2.1. Materials

Glauber's salt ($Na_2SO_4 \cdot 10H_2O$) was used as an inorganic PCM. It was obtained from Applichem company (purity > 98%, Germany) which its energy storage capacity is 254 J/g and its melting temperature is 32 °C. Sodium dodecyl sulfate from Armin Chemic (Iran) was used as an anionic surfactant. Nano montmorillonite cloisite Na^+ purchased from Rock Wood company (USA) as thickening agent and sodium tetra borate (commercial grade) as nucleating agent were used to reduce phase separation and subcooling problems of Glauber's salt, respectively. Silicone rubber was prepared from Rodia company (Turkey) to fix inorganic PCM on the textile substrate. This kind of liquid silicone rubber is paste-like, flow-able, two component blend and could be cured at room temperature. The used fabric was scoured 100% cotton. Its characterization is shown in Table 1.

Table 1
Fabric specifications.

Sample	Warp (yarn cm^{-1})	Weft (yarn cm^{-1})	Weight (g/m^2)	Thickness (mm)	Texture
Cotton	24	20	152	0.36	Plain

2.2. Preparation of coating formulation

The coating formulation was a mixture of Glauber's salt, the saturated solution of sodium dodecyl sulfate, nano montmorillonite, sodium tetra borate and silicone rubber. Prepared coating formulation was applied on textile by coating technique. At the end of progress, the coated layer was vulcanized at room condition (22 °C, 60% RH) during 12 h.

2.3. Characterization

2.3.1. Heat transfer

In this investigation, a guarded hot plate system, shown in Fig. 1, was applied to measure the thermal regulatory properties of the PCM treated fabrics. It consists of a hot plate as heat source, a controlled environmental chamber and data acquisition system. The hot plate was surrounded by foam insulation, which also creates a test chamber. The temperature of test chamber can be controlled by a digital thermocouple [12]. The test specimen is placed above the hot plate within the test chamber; two RTD temperature sensors were located above and below the sample to detect the surface temperature of the sample. Finally the mean temperature of these two sensors was reported. For test procedure, the digital thermocouple will be set up on specific temperature (above PCM melting temperature) and the change in fabric temperature will be recorded, finally the temperature–time diagram of each sample will be compared. Control sample was a fabric without PCM, which was coated with liquid silicone rubber only.

2.3.2. Differential scanning calorimetry (DSC)

Phase change temperatures and energy storage capacities of different materials were measured using DSC technique (DSC 2010, TA Instrument) equipped with a refrigerated cooling system and nitrogen as the purge gas. Measurements were done varying the temperature in the range from −20 to 50 °C with a heating and cooling rate of 10 °C/min. Different samples of each experiment were analyzed three times consecutively to ensure the recyclability of treated fabric and measuring changes in thermo physical properties after three thermal cycles [3].

2.3.3. Thermo gravimetric analysis (TGA)

Thermo gravimetric analyzer (Rheometric scientific^{TM} 1998) was used to study the thermal stability of treated fabrics in the temperature range from 25 to 800 °C with a heating rate of 10 °C/min in a flow of nitrogen gas.