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Research Article

Investigation on the Thermo-Regulating Fabric by Using Phase Change Material for Modern Textile Practical Application

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Abstract

Phase change materials (PCM) which can store energy and increased thermal properties of fabric applied on over a narrow temperature range. It is antiphonal to temperature change by absorbing or releasing heat which is potential for human skin. PCM for Thermal Energy Storage (TES) are materials supplying thermal regulation and change particular phase in temperatures by absorbing and emitting medium condition heat. Polyethylene glycol (PEG-1000) used as PCM in this experiment and we took a 2.5% concentration that was encapsulated by using an in-situ polymerization technique. PEG microcapsules are verified by measuring FTIR analysis and DSC studies. The heat storage capacity of 2.5% PEG coated fabric was determined to be 2842.5120 J/g and for binder coated fabric 1557.8 J/g by DSC analysis and FT-IR analysis of PEG microcapsules exhibited the highest peak at 3400-2400cm^{-1} this is the characteristic absorption peaks of –OH stretching vibrations and we got average stiffness values for binder coated is 0.49 (warp wise) and 0.57(weft wise) and for 2.5% PEG coated is 0.71(warp wise) and 0.98(weft wise). After that the treated fabrics were characterized with respect to their morphology and the laundering durability testing of 5 and 10 cycles was evaluated for practical use. In this paper we investigated about cooling effect of Fabric by using 2.5%. PCMs via the storage of latent heat by producing microcapsules showed higher thermal energy amount, than the binder coated fabric.

Keywords: Phase Change Material (PCM); Binder; Thermal comfort; Cotton; Encapsulation; laundering durability
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1. Introduction

In recent years, application of functional textiles have been developed to enhance and broaden the textile performance[1]. In this case the demands of temperature regulation fabric have attracted more and more attention dynamically[2]. An example of intelligent textile can be considered as thermo regulated textile that can change its temperature according to the environment[3]. The suitable temperature for human body is 33.4^{o}C. If the fluctuation in the temperature of the skin is ±4.5^{o}C, the human body will feel discomfort[4]. In this situation PCM can be a principle way to reduce discomfort feel. For manufacturing and improve thermal comfort of thermo regulated fabric PCM is used[5]. Enhancing the thermal behavior of textile fibers in 1987 scientists discovered a new pattern of technology which is integrating microencapsulated PCM[6]. Microencapsulation is the process of enveloping microscopic sized droplets or particles in a shell material for the purposes of protection or controlled release. PCMs are set up in a microcapsule to prevent their leakage during their liquid phase[7]. In order to preventing drip off clothing melt situation PCM's must be place into microcapsules, because PCM containing microcapsules must be durable and safe through the finishing process [8]. The properties of microcapsules are walls less than 1 μm thick and 20 - 40 μm in diameter with 80% - 85% of PCM. In textile field it is the most effective ideas of using thermal energy storage of PCM with 15 to 35^{0}C melting point. Inadequacy of water PCM's are more than 500 natural and synthetic[9]. Phase-change material can storage thermal energy systems offer other advantages, such as a small temperature difference between storage and retrieval cycles, small unit sizes and low weight per unit storage capacity[10, 11]. Phase change material possesses the ability to absorb and store large amounts of latent heat during the heating process and can release this energy during the cooling process. PCMs will change phase with the temperature between the body and the outer garment layer. Indeed, for textile applications[12]. Three types of heat storage were reported: sensible, latent, and chemical reaction. The storage of sensible heat is based on increasing the temperature of any substance without changing its phase. The storage of latent heat is the most important type of heat storage[13]. PCMs are used to achieve latent heat storage. The storage of latent heat or thermal regulation is based on the transition of a material (PCM) between phases[14]. Phase change materials are able to theoretically to change state at nearly constant temperature and therefore to store large quantity of energy[15]. Definitely, PCM incorporated textile would take a major role in future smart textiles segments. In today's competitive market situation in world, the demand of today's customer is to get comfort in cloth, which is to be worn in different situations from daily wear to functional wear. Phase change materials are the source to be incorporated in textile material to add value i.e. comfort to wearer[16].

In this article an account of PCM, 2.5% PEG is used in cotton fabric to find out stiffness of clothing and by using SEM we got good results after 5 and 10 cycles for laundering durability testing. As we know at present garments sector widely used this properties of PCM with microcapsules that attributed into fibers with coated materials.

2. Experimental

2.1 Fabric

Table 1 Specification of the Fabric

Substrate	specifications
Warp yarn count	24
Weft yarn count	24
Ends per inch	110
Picks per inch	44
GSM	210 g/m^2

2.2 Chemical

Table 2 Specification of the chemicals

Type of chemical	Chemical nature	Brand
Polyethylene glycol-1000	Paraffin based	Applichem
Sodium Alginate	Natural based	Sodium Alginate
Calcium Chloride	Inorganic	BDH Laboratory reagent
Binder	Acrylic based	BASF(Helltow)
Ammonia liquor	Organic	

2.3 Encapsulation procedure for PEG- 1000

Recipe for microencapsulation

1. Polyethylene Glycol = 2.5 %
2. Sodium Alginate = 1.0 %
3. Calcium chloride = 2.0 %

2.3.1 Formation of microcapsule with 2.5% concentration of PCM

A mixture of polyethylene glycol (PEG-1000) and hot water was prepared in 250.0 ml glass beaker in which 2.5g of PEG was added to 100.0 ml water, followed by addition of 1.0g of sodium alginate. We added 5.0g dispersing agent to the solution. The mixture was thoroughly stirred with the help of an electric stirrer for 10 minutes. Then a mixture of calcium chloride and hot water was prepared in 250.0 ml glass beaker in which 2.0 g of calcium chloride was added to 100.0 ml water. The solution containing calcium chloride was added drop wise to solution containing sodium alginate and PEG-1000 by using syringe with high speed stirring. The added droplets were retained in calcium chloride solution for 15 minutes to complete the curing reaction and to produce microcapsules. The solution was filtered by using filter paper and washed with water to remove the remaining calcium chloride. The precipitate was removed from filter paper and put in to a conical flask; dispersion was made by using magnetic stirrer by adding water to the precipitate present in conical flask. The dispersion made was examined with microscope; it was proved that microcapsules were formed.

2.4 Application method on Fabric

Stock paste recipe:

1. Thickener = 40 g/kg
2. Ammonia liquor = 10 g/kg
3. Binder (Urethane based) = 50 g/kg

The stock paste was prepared according to above recipe and microcapsules were also prepared. Then the stock paste and microcapsules were mixed with ratio of 80:20 by using stirring rod. The paste was formed and then applied on to the fabric with the help of rubber squeegee. The angle of rubber squeegee was kept at 75^{o}c. The paste was applied in the form of two layers. After the application, the samples were dried at a temperature of 110^{o}c.

2.5 Analytical Methods

A DSC-60/60A Differential Scanning Calorimeter was used to study the thermal behavior of the microcapsules. The sample weight used for the testing ranged from 8-12 milligram. After the sample is ready, it is placed into the DSC cell and machine is turned ON. The experiment is designed onto the computer in which parameters like temperature range, temperature change interval, weights of sample, type of test, and comments are entered. Once the test is completely done, the DSC graph is opened in the DSC analysis software where we can integrate the peaks the enthalpy given out or absorbed during these processes. FTIR is a technique which is used to obtain an infrared spectrum of absorption, emission, photoconductivity, or Raman scattering of a solid, liquid, or gas. A Bruker FTIR study was important in our study to determine the presence of PEG in the microcapsules. The FTIR spectrum is taken and the peaks are marked out with the help of a peak-finding tool to get the wavelength of all the peaks shown on the spectrograph. A stereo microscope of CzM6 model was used to determine the shape and size of the microcapsules. SEM was analyses for measuring laundering durability test.

2.6 Testing Methods

2.6.1 Laundering durability testing

Laundering durability of the treated fabrics was evaluated with an LHD-EF launder-o- meter (Atlas Electric Devices Co., Houston, TX) according to AATCC test method 61-1989.

2.6.2 Stiffness Testing

This test method covers a procedure to measure the resistance to bending using the Taber type tester (ASTM D 5342 – 97). Ten test specimens of 1.5inch x 2.75 inch are cut in warp and weft direction. Each sample is then clamped and bent 15^{o} from its center line to right and left hand side of the testing instrument. The resultant bending moment was recorded from the instrument scale, and resistance to bending was calculated by using the below formula.

$$\text{Stiffness values in millinewton.meters} = \text{Taber unit x } 0.098066$$

3. Result and Discussion

3.1 Optical Microscopy Analysis

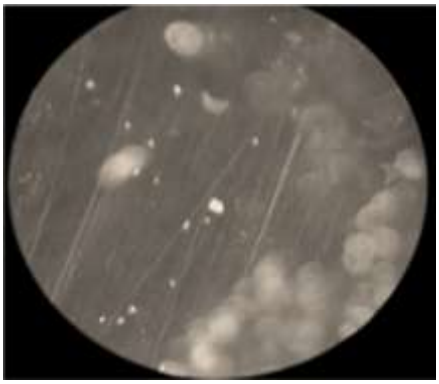
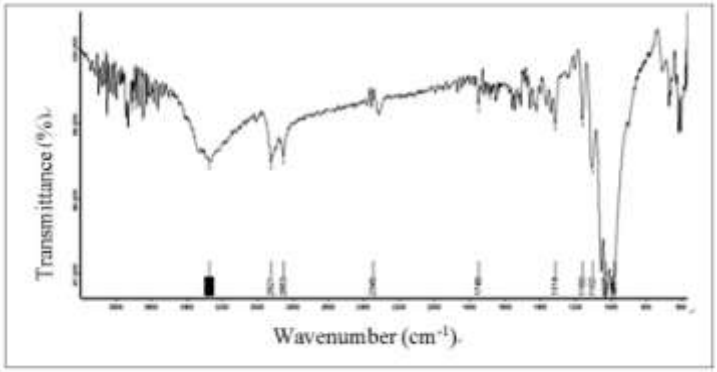


Figure 1 Formation of microcapsule through CzM6 microscope

3.2 FT-IR Analysis

(a)



(b)

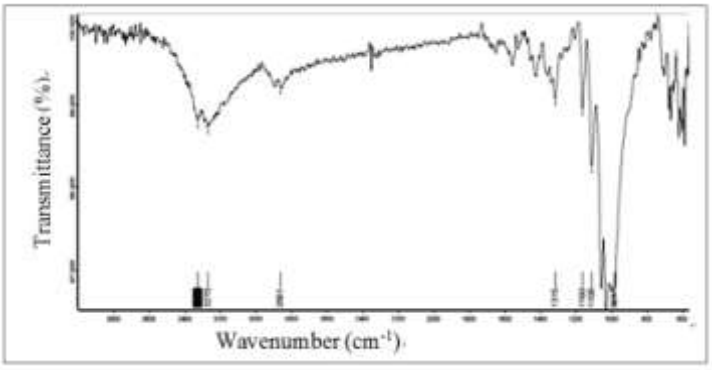


Figure 2 FT-IR spectra of (a) cotton with binder (b) cotton with 2.5%PEG

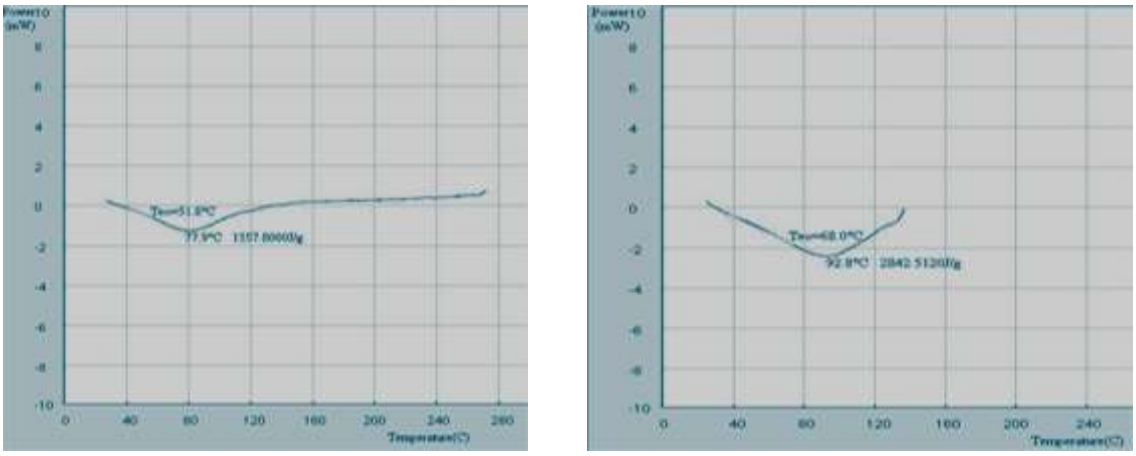
Table 3 Shows the relative groups attached

Functional Group	Molecular Motion	Wavenumber (cm^{-1})
carboxylic acids	O-H stretch	3400-2400
Aldehydes	C-H aldehyde stretch	~2850 & ~2750
Anhydrides	C-O stretch	1300-900

Table 4 Shows the relative groups attached

Functional Group	Molecular Motion	Wavenumber (cm-1)
carboxylic acids	O-H stretch	3400-2400
Alcohols	O-H stretch	3400-3300
Ethers	C-O-C stretch (dialkyl)	1300-1000

3.3 DSC Analysis



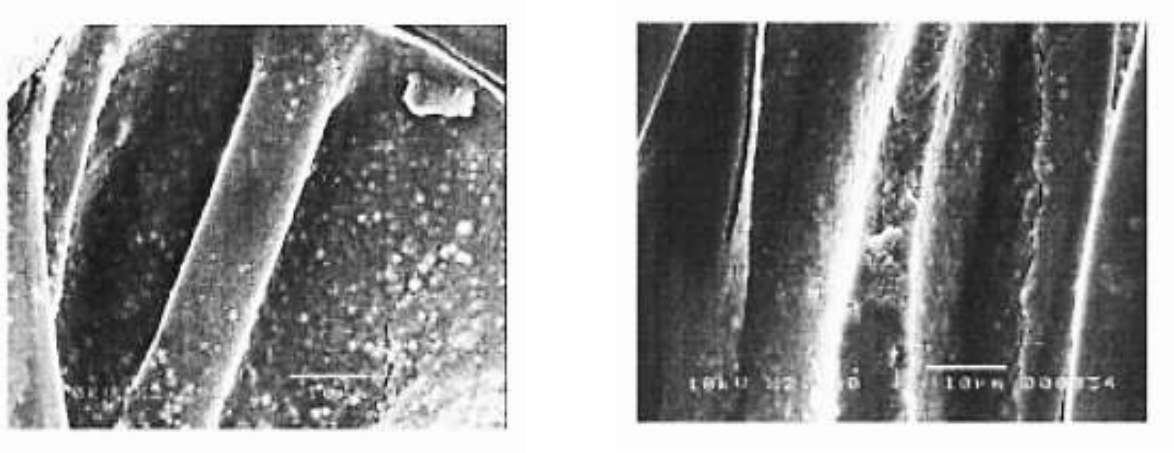
(a) (b)

Figure 3 DSC analysis of (a) cotton with binder and (b) cotton with 2.5%PEG

Table 5 Concentration of PEG and binder coated fabric v/s amount of energy absorbed

S. No	Sample	Amount of energy absorb (joule/gram)	Temperature range ^{0}C
1.	Cotton with binder	1557.8	30-140
2.	Cotton with 2.5% PEG	2842.5120	30-140

3.4 Laundering Performance by SEM analysis



(a) (b)

Figure 4 SEM photographs (original magnification of microcapsule-treated samples after laundering: (a) 5 cycles, (b) 10 cycles

3.5 Stiffness testing values

Table 6 Stiffness testing values

Sample No.	Binder coated		2.5% PEG coated	
	Warp	Weft	Warp	Weft
1	0.5	0.5	1	1
2	0.5	0.6	0.7	0.9
3	0.4	0.3	0.4	1
4	1	0.4	0.5	0.7
5	0.6	1	0.6	0.6
6	0.5	1	0.7	1.5
7	0.4	0.4	0.5	1.5
8	0.5	0.3	0.7	1
9	0.2	0.5	1	0.8
10	0.3	0.7	1	0.8
Average	0.49	0.57	0.71	0.98

This research was carried out to investigate a new In-situ polymerization technique to encapsulate Polyethylene Glycol (PEG-1000) of 2.5% concentrations. For optical microscopy of the microcapsules we used the stereo microscope of CzM6 model with magnification of 180x.the images taken by the camera are shown in **Figure 1** the formation of micro capsule. First it formed macro capsules instead of microcapsules. While showed that crystals were formed rather than microcapsules because of aggregation among capsules. It was concluded that we had successful production of microcapsule. FTIR spectra of coated fabric with binder is shown in **Figure 2 (a)** functional group of sodium alginate is carboxylic acid which spectra showed peaks at 3400-2400 cm^{-1}, Then for Aldehydes peaks at 2850-2750 cm^{-1}, and for Anhydrides spectra is 1300-900cm^{-1}. These peaks are attributed to O-H, -C-O and C-H aldehyde stretching vibrations **Table 3**.

For getting more comfortable behavior use PEG-1000 then observed FTIR spectra of coated fabric with 2.5% PEG is shown in **Figure 2 (b)** The resulting FTIR spectra of both samples, PEG encapsulated microcapsules show the expected peaks at 800-1200 cm-1, and around 2400-3400cm^{-1} show the presence of alcohols and ethers functional groups of polyethylene glycol and carboxylic acids functional group of sodium alginate. These peaks are attributed to O-H, -C-O-C (dialkyl) and O-H bond stretching vibrations **Table 4.**

The heat analysis was done of the standard sample to examine its thermal behavior. It showed

Figure 3 (a) that the heat storage capacity of the coated fabric with binder was 1557.8 J/g in the range from 40^0C to 130^0C which shows that cotton coated fabric shows an endothermic behavior in the specified range of temperature. The heat analysis was done of the microcapsules coated fabric (2.5% PEG) to examine the thermal behavior of PEG

Figure 3 (b) the sample was heated up to 140^oC at a constant rate of 10^oC/min. The phase change temperature Tm of the microcapsules was found to be around 92.8^oC. The heat storage capacity of the microcapsule was 2842.5120 J/g. When the PCM microcapsules are heated, they absorb energy and go from a solid state to a liquid state. This phase change produces a temporary cooling effect in the clothing layer. If the PCM microcapsules are cooled down below the freezing point of PCM material, the material will change back to solid state from the liquid state, releasing heat and thus developing a temporary warming effect. Near 30^oC the recrystallization of the PCM material can be seen causing the exothermic reaction, thus releasing heat to the fabric.

Table 5 it was concluded that the maximum amount of energy was absorbed by the fabric coated with microcapsules having 2.5% concentration of PCM**.** This phenomenon is helpful to the wearer of the fabric in winter because it provides body comfort.

Figure 4 shows SEM photographs of the samples after **(a)** 5 and **(b)** 10 launderings. The sample with 18% addition was used for the laundering durability test. The microcapsules were observed on the fiber surface and at the interstices between the fibers in the samples after five laundering. On the other hand most of the microcapsules were located at interstices in the samples after 10 laundering. This result indicated that the microcapsules on the fiber surface tended to come off more easily than those at interstices during laundering.

Table 6 shows data of stiffness values the measurements of the bending force were noted and then multiplied by 0.098066 to convert the bending force to milli-newton. The calculated bending force is given below

Warp stiffness (Binder Coated) – 0.49 X 0.098066 = 0.048052 milli-newton
Weft stiffness (Binder Coated) – 0.57 X 0.098066 = 0.055897 milli-newton
Warp stiffness (PEG coated) – 0.71 X 0.098066 = 0.069626 milli-newton
Weft stiffness (PEG coated) – 0.98 X 0.098066 = 0.096104 milli-newton

Form the results we can conclude that significant change in stiffness of the fabric after being PEG-1000 coated with the microcapsules. Thus the garments made from the coated fabric will show similar stiffness properties of the binder coated fabric.

4. Conclusion

In this investigation PEG-1000 microcapsules were produced by an in-situ polymerization technique. FTIR analysis confirmed the presence of PEG within the microcapsules. Furthermore, DSC analysis showed that the thermal energy storage amount of the 2.5% PEG microcapsules was 2842.5120 J/g.

By application on to cotton fabric, it is clear that, a homogeneous distribution of spherical particles deposited on the surface of the coated cotton fiber. These particles are representing the PCM materials which are reacted with cotton fiber, which make the PCM material more stable and did not leak from the fibre surface after washing. In addition, the PEG coated one has better result than its binder coated cotton fabric.

The results suggest that microcapsules with higher mixing ratios need to be made to improve the thermo regulating efficiency of fabrics. Also, a finishing process including binder types and loading methods needs to be studied further to improve laundering durability. People are giving higher preference to comfort by using 100% cotton or other such fibers which are comfortable to the body. Thus application of PCM in daily wear in addition to the industrial use will increase in the future, bringing potential research and business.

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