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Evaluation of Thermal and Moisture Management Properties of PCM Treated Denim Fabrics

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ABSTRACT

In this study, woven and knit denim fabrics were printed with micro capsulated phase change material (MPCM) using screen printing technique followed by the curing process. The thermoregulatory properties of printed denim fabrics were evaluated by analyzing their thermal properties. Moisture management capacities of the developed printed samples were evaluated by moisture management tester (MMT). Besides, the morphology of MPCM incorporated denim fabrics were characterized by digital microscopic analyzer and Fourier transforms infrared spectroscopy (FTIR) was used to evaluate the presence of various functional groups in its. Moisture management properties showed that MPCM treated samples are water repellent, fast absorbing and slow drying fabric compared to the conventional denim fabrics. Results of thermal analysis revealed that MPCM incorporated printed fabric conducted more heat as the melting temperature of the MPCM increased.

Keywords: MPCM; Denim fabric; Printing; Thermal properties; Moisture properties

1. Introduction

One of the easy ways of producing functional textile materials is to entrap active substances in the microcapsules form [1-9].The number of commercial applications of microencapsulated PCM in the textile industry continues to grow with new properties and added value, e.g., medical textiles and technical textiles [7]. Usually, PCM materials absorb energy during heating process as phase change takes place and release energy to the environment in the phase change range during a reverse cooling process [10]. Most commonly used PCM is paraffin wax due to its high heat storage capacity among the 500 different PCMs including water (ice) [11]. Due to high heat storage capacity, easy availability and low cost Paraffin wax was used in this work. Generally, paraffin wax cannot be incorporated directly into textiles because of their low melting point and, therefore, need to be microencapsulated [12]. The microencapsulation technique of PCMs involves enclosing them in thin and resilient polymer shells so that the PCMs can be changed from solid to liquid and back again within the shells [13] and give effect accordingly. Applications of PCM containing microcapsules into textiles include apparel, blankets, medical field, insulation, protective clothing and many others. The technology for incorporating PCMs into textile structure to improve their thermal performance was developed in the early 1980s under NASA research programed [14]. The thermal properties of a microcapsule are influenced by three factors: mean diameter, expansion during the phase change process, and shell's chemical structure[6]. Several techniques are being used for incorporation of PCM microcapsules into the textile structures such as coating, lamination, finishing, melt spinning, bi-component synthetic fiber extrusion, injection molding, encapsulation, etc. The most common is microcapsules dispersing in binding agents, then applying such dispersion using e.g., padding, coating, printing, spraying techniques [3,15,16]. Although PCM microcapsules impart thermoregulatory properties to materials, they can also affect other comfort-related properties and manufacturing of textiles, especially when the topical application of microcapsules results in drastic changes in the surface characteristics of materials. The extent of change in these properties depends on the loading amount of PCM microcapsules. Therefore, the properties of fabrics treated with PCM microcapsules need to be measured and considered before use in a garment [17]. Several studies have been conducted in this context. For instance, Shin et al. [17] incorporated melamine formaldehyde microcapsules containing Eicosanoid on polyester knit fabrics by means pad dry cure method with a polyurethane binder Mengjin et al. [18] developed a new kind of thermo-regulating fiber based on PVA and paraffin. Koo et al. [19] have attempted to demonstrate the application of PCM microcapsules to waterproof nylon fabrics by using a dual coating method. As it is known, denim is one of the most fashionable, dynamic, and innovative textile products. Several brands are now actively engaged to innovate more technological, sustainable, and comfort fabrics and jeans to improve their innovative line. Considering its unavoidable rise, it should be understood in all respects such as its manufacturing, finishing, and applications [20]. In this study, woven and knit denim fabrics were printed with paraffin based PCM of three different melting temperatures using screen printing technique followed by the curing process. After successful application, thermal, moisture and morphological analysis was done.

1. Materials and methods

1.1 Materials

Knit denim fabric (wales/cm 38, course/cm 48 and GSM 184) and woven denim fabric (warp count 7Ne, weft count 10Ne, ends per cm 74, picks per cm 46 and GSM 410) was used. Paraffin based microencapsulated phase change materials (MPCMs) with melting temperature of 26°C, 28°C and 30°C were purchased from RivoChem, Shanghai Lizoo Commodity Ltd., China. Acrylic based binder; pigment gum and titanium dioxide were also used in printing paste. All the chemicals were lab grade and used as received without further treatment.

1.2 Preparation of printing paste

At first, 80gm binder was taken in a plastic container and 100gm titanium was added into it which was stirred for 30min. Then 8gm pigment and 772gm water was added into the bath and stirred for few minutes for homogeneous mixing. After that, 40gm MPCM powder of each melting temperature was added to the solution and mixes them with the help of stirring.

1.3 Printing process

Manual screen printing method was followed to impart the printing paste into fabric surface. In brief, fabric was placed on a flat printing table and the screen was placed on the sample fabric. The printing paste was taken on the screen and applied to the fabric with the help of rubber squeegee. The angle of rubber squeegee was kept at 75^0C. After application, samples were dried by curing at 150^0C for 2min. After that hot and cold wash was done respectively.

1.4 Characterization

1.4.1 Thermal analysis

Thermal behavior in terms of thermal conductivity under compression (TCC) and thermal conductivity under recovery (TCR) and maximum thermal flux (Q_{max}) of the developed samples were evaluated by a fabric touch tester (FTT M293, SDL Atlas, Hong Kong).

1.4.2 Moisture management test

Moisture management properties of developed samples were evaluated by MMT (M290, SDL Atlas, UK) according to AATCC 195-2009. Wetting time, absorption rate, maximum wetted radius and spreading speed of inner and outer surface including accumulative one-way transport capacity (R) and overall moisture management capacity (OMMC) were evaluated following the above mentioned standard to categorize the samples due to its interaction with liquid.

1.4.3 Morphological analysis

The arrangement of PCM microcapsules on fabric surface was observed by a digital microscope (Jiusion digital microscope, USB type, China) at a magnification of 40X to 1000X. Samples were tested at raw condition and after application of PCM respectively. FTIR was used to identify and match the chemical groups. Samples were directly exposed to an infrared beam which was monitored with attenuated total reflectance. An IRPrestige21 (Shimadzu Corporation, Japan) FTIR was used for this purpose.

2. Results and discussion

2.1 Analyses of thermal properties

Heat transfer between fabric and human skin is perceived as coolness feel. Thermal stimulus is triggered by the temperature difference between human skin and fabrics. Thermal conductivity when compression (TCC) is the important index which reflects the warm keeping ability of fabric. Another index name thermal maximum flux (Qmax) was defined as the maximum thermal flux during the measurement process. Because the instant heat fluxes value provide directly reference for coolness feel. The higher of Qmax meant the more coolness of the fabric during the touching process. TCC and Qmax were increased for woven denim and decreased for knit denim samples after PCM applied printing process, which meant the keeping of warm and coolness character was decreased for losing heat. The result of analysis of thermal properties of the developed sample have been shown in the in the Table 1.

Table 1: Thermal properties of developed samples

Sample code	Flax		
	TCC W*mm/(m^2*C)	TCR W*mm/(m^2*C)	Qmax W/(m^2)
W-26	69.26	70.85	745.94
W-28	69.36	71.48	747.40
W-30	71.14	73.59	780.79
K-26	60.14	61.09	1046.99
K-28	53.91	54.26	961.03

2.2 Moisture management properties

In spite of having the thermoregulation property, the denim should also have a high comfort of thermal level of human skin. Hence it is necessary to evaluate the capacity to transfer liquids (water or perspiration) from the shin to the environment. The results of moisture management properties of the developed samples have been shown in the Table 2.

Table 2: Moisture management properties of developed samples

Sample code	Wetting time (S)		Absorption rate (%/s)		Max wetted radius (mm)		Spreading speed time (mm/s)		AOTI (%)	OMMC
	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom		
W-26	9.921	18.813	105.8934	31.9521	15	15	0.7719	0.5801	31.9	0.2
W-28	10.297	15.07	109.4831	43.1594	20	15	1.0661	0.7388	145.2	0.3
W-30	6.364	6.177	63.9141	16.557	10	10	0.895	0.8906	-100.5	0.2
K-26	9.548	35.007	94.6835	17.8177	5	5	0.5136	0.1421	-681.6	0.02
K-28	15.631	16.286	465.2012	13.8871	5	5	0.3161	0.3018	-486.6	0.01
K-30	10.109	46.894	146.7686	3.8562	5	5	0.4856	0.106	-1194.6	0

The result of wetted radius and spreading speed of top and bottom surface of PCM treated fabrics followed the same pattern. Wetting of bottom surface is more than top surface due to the insertion of coating on the surface. Absorption rate of PCM treated samples showed the highest value on topsurface. However, the value of one-way transport capacity (R%) of PCM treated samples showed very poor value indicating their poor one-way transport capacity of the liquid. It also indicated that solution took more time to pass from top to bottom surface. Overall moisture management capacity (OMMC) has been calculated using all parameters that indicate that the most of the fabrics are in moisture transport property and thus should be considered as water repellent and fast absorbing and slow drying fabric respectively.

2.3 Morphological analysis

As the 40gm of MPCM particles has been used to prepare the printing paste that was applied on the fabric surface, that's why the microscopic views of all samples were observed that is shown in Fig. 1. The distribution of the slurry on fabric surface is not well mannered rather the aggregated deposition of MPCM was observed due to their mixing with thickener which restricts them to spread evenly.

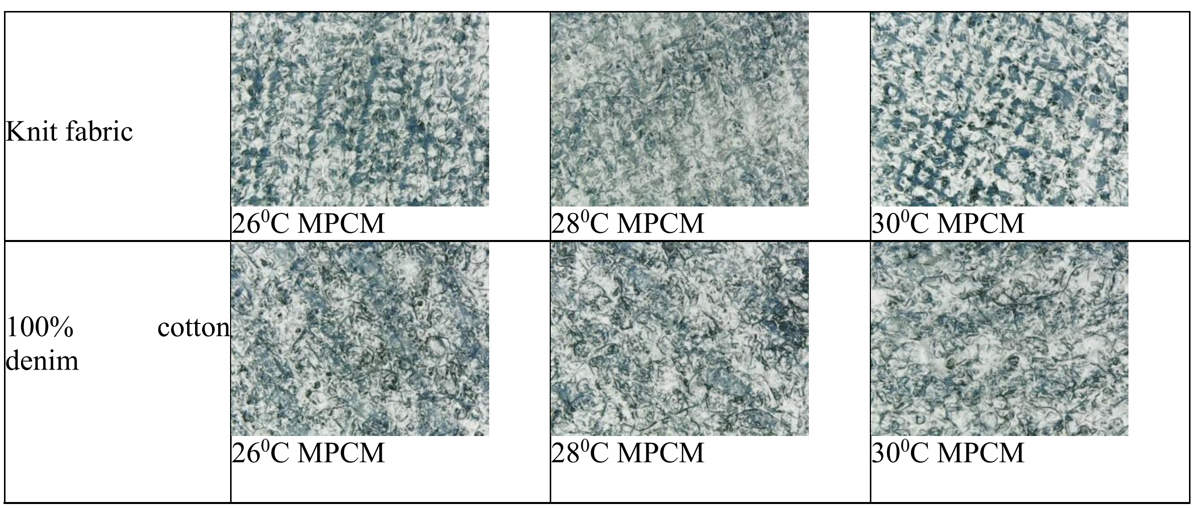

Figure 1: Microscopic view of the developed samples

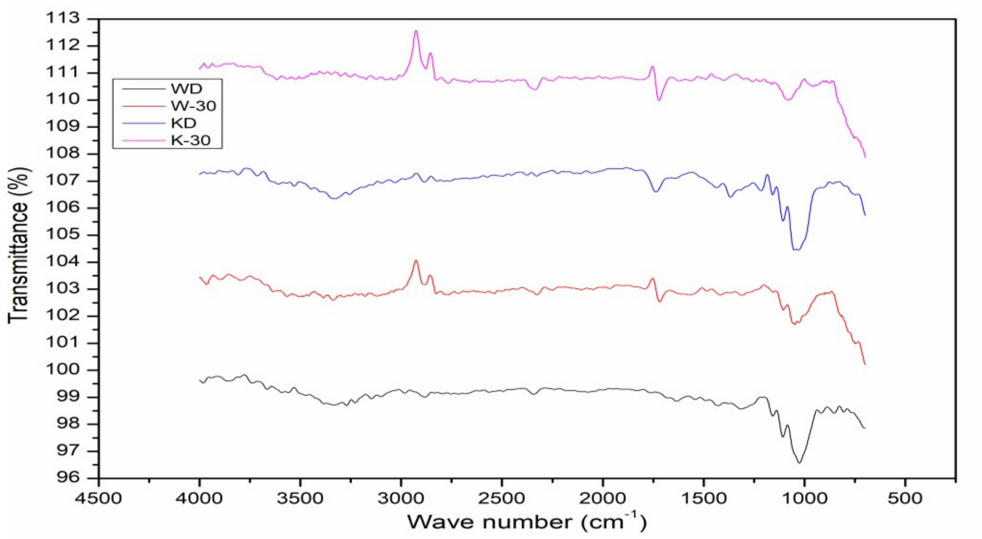

Figure 2: Characteristics peaks in FTIR spectra

On the other hand, Sample of woven denim without MPCM (WD), MPCM (30^0C) incorporated woven denim (W-30), knit denim without MPCM (KD) and MPCM (30^0C) incorporated knit denim (K-30) fabrics were investigated by FTIR that is shown in the Fig. 2. FTIR confirmed the presence of functional group of cellulose polymer as shown in the Fig.2. Apart from the characteristics peaks of cellulose polymer, the carbon–hydrogen stretching and bending absorption bands are at 2940-2855cm^{-1} and 1470cm^{-1} respectively. The symmetric carbon- hydrogen bending absorption of the CH_3 at 1380cm^{-1} and the CH_2 rocking absorption band at 725cm^{-1}confirm the linear saturated aliphatic structure of the paraffin wax [21].

Conclusion

In this study, woven and knit denim fabrics were treated with micro capsulated PCM by printing technique followed by the curing process to fix it. Fabric touch tester tests were applied to examine heat flux. Morphological analysis and moisture management properties were accomplished and evaluated. From the analysis of all results, it can be concluded that the addition of different micro capsulated PCMs on different types of denim fabric may create thermo-regulation property by obtaining latent heat at the melting temperature of selected PCM. The microscopic results reveal that the presence of MPCM on the fabric surface lies aggregately because of the application method. Therefore, this study can be a way to add value to the fast fashion denim fabric and medicated bed sheet in order to impart thermal comfort to user.

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