Textiles incorporated with MicroPCMs for thermal management applications

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Abstract

Thermal properties of textiles play very important role in determining the comfort of textile and clothing system. Phase change materials (PCMs) contain latent heat. The increase or decrease in temperature of surroundings causes PCM to melt or solidify by absorbing hear from or release heat to surrounding environment. During melting and crystallizing process, the temperature of PCM does not change. A garment incorporated with PCM is able to main a relatively stable temperature within the micro-environment between the garment and the wearer depending on the amount the PCMs.

The aim of this research is to study the thermal properties of textiles affected by PCMs. Polypropylene filaments incorporated with microencapsulate PCM have been developed. The latent heat contained in the filaments having different amount of PCM was analysed using Differential Scanning Calorimetry (DSC). The mechanical properties of the developed filaments were also studied, together with the surface morphology of filaments using Scanning Electron Microscopy (SEM). Furthermore, Finite Element models of textiles incorporated with PCM have been developed and validated by experimental results. The thermal properties of the models were further studied through the post-processing process.

Keywords: phase change material, thermal management,

1. Introduction

Phase change materials (PCM) are smart material which melts on heating by absorbing heat energy and release the stored energy upon cooling. PCM are classified either by their chemical nature or by melting point [1]. The selection of PCM usually depends on its melting temperature with respect to the area of application. For textiles, n-octadecane, an organic PCM is used because of its 28 °C melting temperature which is closer to the human skin comfort temperature. PCMs are usually encapsulated into a protective shell called microcapsules to avoid any waste or leakage upon melting and to enhance the life of the product [2].

Heat transfer for textiles has been studied by different researchers. Pause [3], Nuckols [4], and Junghye et al [5] have studied the heat transfer properties of textiles. They investigated the thermal performance of textiles with and without PCM. In 2004 Ghali et al [6] investigated the effect of PCM on clothing experimentally and numerically during periodic ventilation. Fengzhi et al [7] investigated in porous textiles that heat loss from body is lowest when PCMs are located in outer layer of fabrics and did numerical simulation. Bendkowska et al [8] studied nonwoven fabric incorporated with microencapsulated PCMs and determined that thermo-regulating behaviour of garments strongly depends on the distribution of microPCMs and position of PCM layered garments. Alay et al [9] studies the thermal resistance of fabric containing microencapsulated PCMs under steady state conditions. Fengzhi [10] established a dynamic model to analyse the mechanisms of heat and moisture transfer in PCM incorporated clothing and investigated the effect of PCM distribution by considering the effect of water content on physical parameters of textiles and heat transfer with phase change. Ying et al [11] developed a dynamic mathematical model of heat and moisture transfer in multi-layer porous textiles, in which some layers incorporated PCM. A finite element volume difference scheme was used to numerically simulate the thermal regulating performance. Recently Hu et al [12] studied the heat transfer in protective clothing embedded with PCM for fire fighters. He developed the mathematical model based on finite element difference technique and simulated the temperature variation by comparing different thickness of clothing by varying the position of PCM in protective garments.

The purpose of incorporation of Microencapsulated PCMs (MPCM) is to avoid heating and cooling in textiles and provide thermal comfort to the wearer. The MPCM melts during increase in temperature and do not allow the textile to increase their temperature. The aim of this paper is to simulate the yarn for heat transfer analysis and validate the results of simulation with the experimental results obtained from Differential Scanning Calorimetry. The heat flux values and temperature delay can be predicted through ABAQUS through post processing.

2. Materials and method

The multifilament yarn was made of polypropylene incorporated with 4% MPCM by melt spinning process. MicroPCM was purchased from Microtek Laboratory Inc. MPCM contained melamine formaldehyde as shell material of the capsule and n-octadecane as core material. The physical properties of MicroPCM are listed in Table 1. A woven fabric constructed by the MicorPCM incorporated polypropylene yarn was made, its cross section and the actual geometry of the fabric is shown in Figure 1.

Table 1 Thermo-physical properties of materials in MPCM yarn

Property	n-octadecane	Melamine Formaldehyde	Polypropylene
Density (kg/m^3)	777	1500	910
Specific heat (KJ/Kg °K)	1.9	1.2	1.925
Thermal conductivity (W/m°K)	0.3	0.5	0.137
Latent heat of fusion (KJ/Kg)	238		

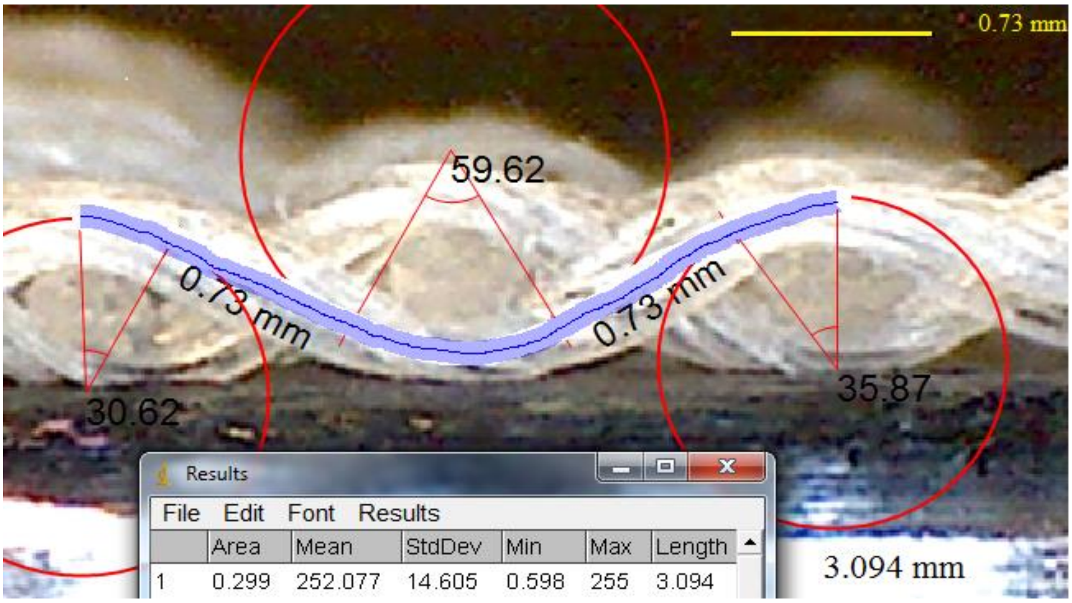

Figure 1 Yarn cross section and crimped yarn path made in Image Analysis

Finite element method was used to study the thermal property of PCM incorporated yarns and fabrics using a commercial software Abaqus. FE models consisting of a geometrical model have been developed based on the actual yarn and fabric made of multifilament polypropylene yarn incorporated with 4% MPCM. The thermoregulating behaviour of the models was investigated based on the validated models.

3. Results and discussion

Figure 2 shows heat flow results of 4% MPCM yarn obtained by DSC experimentally and ABAQUS theoretically. The Figure clearly shows good agreement between the values obtained from experiment and from ABAQUS after post processing. The absolute error of the maximum heat flow between the two methods is 9%.

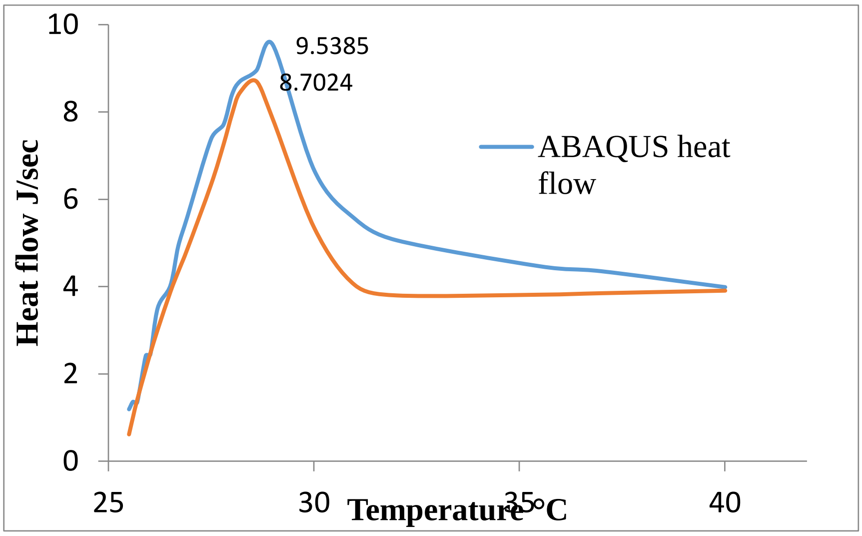

Figure 2 Heat flow results obtained by ABAQUS vs DSC

Based on the above validated model, A bicomponent yarn consisting of core and sheath was modelled to predict the thermal properties. The bicomponent (70%core/30%sheath) yarn model generated in ABAQUS is shown in Figure 3, where core is an organic PCM n-octadecane and sheath is composed of polypropylene.

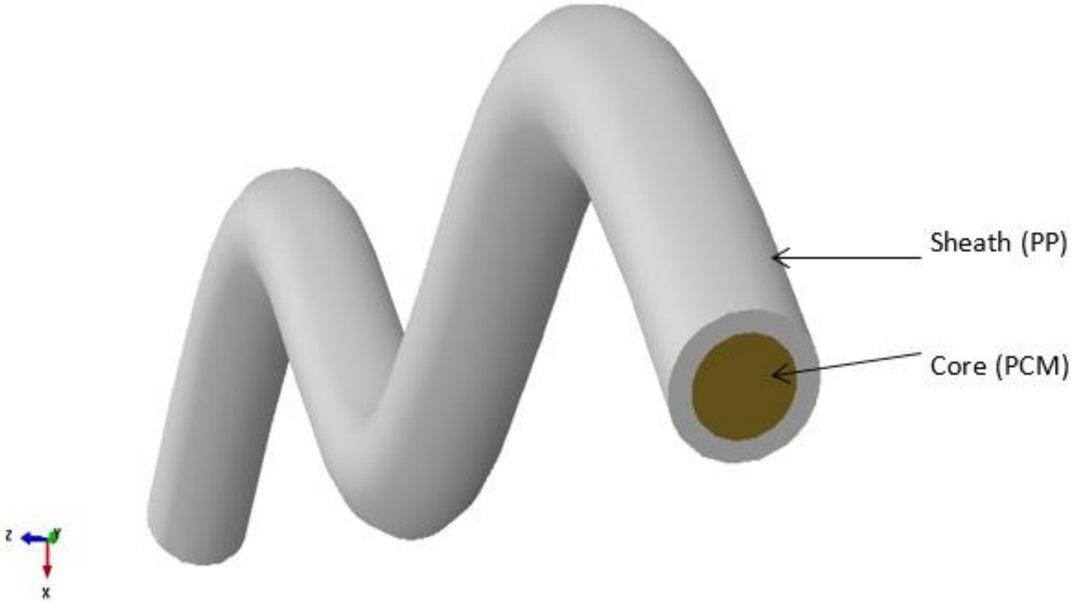

Figure 3 Geometry of Core/Sheath bicomponent yarn

The thermoregulating behaviour of different yarns is shown in Figure 4: control yarn without MPCM, yarn with 4% MicroPCM, yarn with 10% MicroPCM and a bicomponent yarn (70%core/30%sheath). The yarn without MicroPCM reaches the highest temperature very quickly while the yarn containing MicroPCM is delayed to reach the same level of temperature. As the percentage of MicroPCM increases, the time increases for yarn to reach the highest level of temperature. The increase in temperature with yarn containing 10% MicroPCM delays up to 8 minutes and yarn with core/sheath structure takes more than 17 minutes to reach the temperature of 28 °C due to the large amount of PCM contained. The three separate dashed boxes drawn in Figure 5.6 show the thermoregulating zone of each yarn containing different amount of MicroPCM and core/sheath yarn.

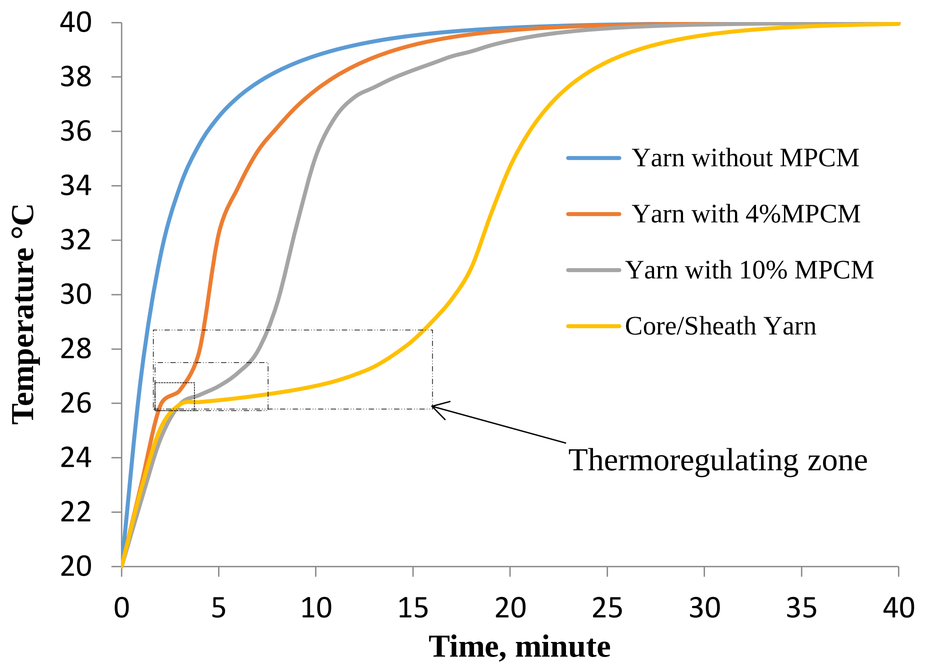

Figure 4 Delay in the rise of temperature over time.

The thermoregulating zone is also called the thermal arrest zone which means that the temperature is arrested for some time because of the phase change effect. In Figure 4 the curve of yarn without MicroPCM proceeds linearly over time showing no temperature arrest whereas the yarn containing MicroPCM shows thermal arrest which lasts as long as the PCM changes completely from solid to liquid phase. After the latent heat effect completes, the temperature again starts rising and leaves the thermoregulating zone.

Figure 5 shows the translucent visualization of fabric model after simulation. The model is shown as a single part containing MPCM inside of yarn and distributed evenly. The magnified image shows the heat transfer through the fabric and MicroPCM.

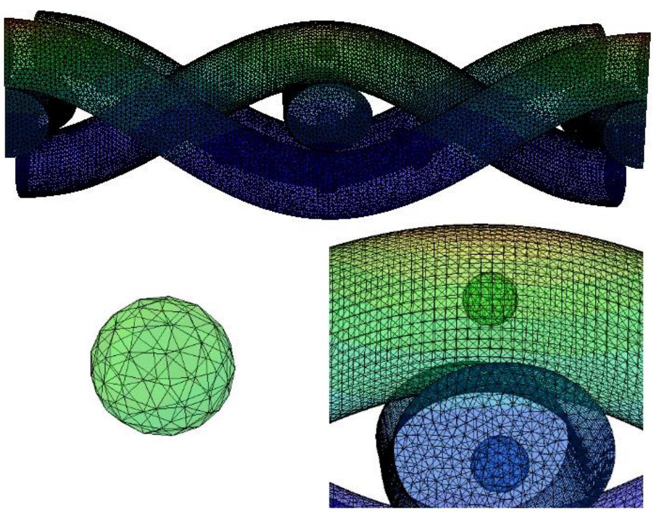

Figure 5 Visualization of fabric model containing MicroPCM

Table 2 shows the heat flux values obtained experimentally and predicted from FE model post processing in Abaqus. The agreement between the two is 91.02% which shows that the model is reliable and can be used for further study of heat transfer characteristics of MicroPCM fabrics.

Table 2 Results comparison between FE model and experiment

Obtained from experiment (W/m^2)	Predicted from simulation (W/m^2)	Relative Error
583.33	635.70	8.98%

Figure 6 shows a unit model of meshed fabric made of core/sheath yarn, containing pure PCM in the core. Its thermal property was further studied through post-processing in Abaqus.

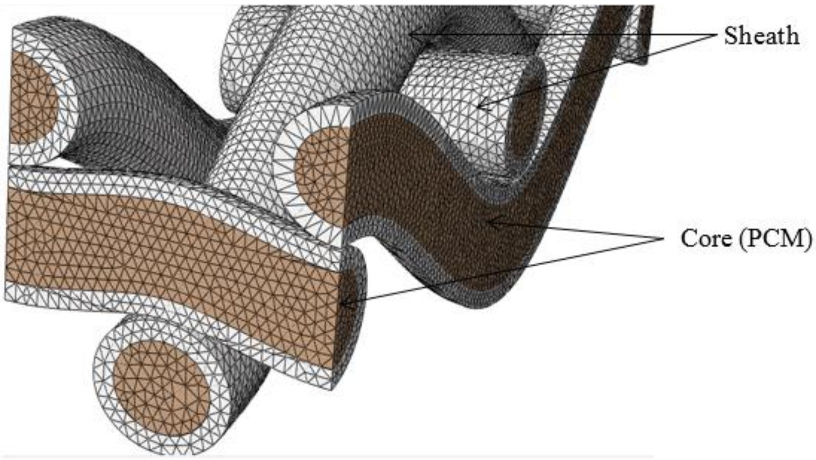

Figure 6 Core/Sheath fabric containing PCM in core of yarn

Figure 7 shows the time dependent temperature change of fabrics: (1) without MPCM, (2) with 4% MPCM, (3) with 10% MPCM, and (4) PCM in core of yarn in the fabric. The maximum effect can be seen in fabric made of core/sheath yarn where the amount of PCM is 70% showing that as the amount of PCM increases in the fabric from 4% to 70%, the thermo-regulating effect is enhanced. The thermoregulating zone is shown by dashed boxes for all the fabrics in Figure 7. There is no thermoregulating zone for the fabric without MPCM.

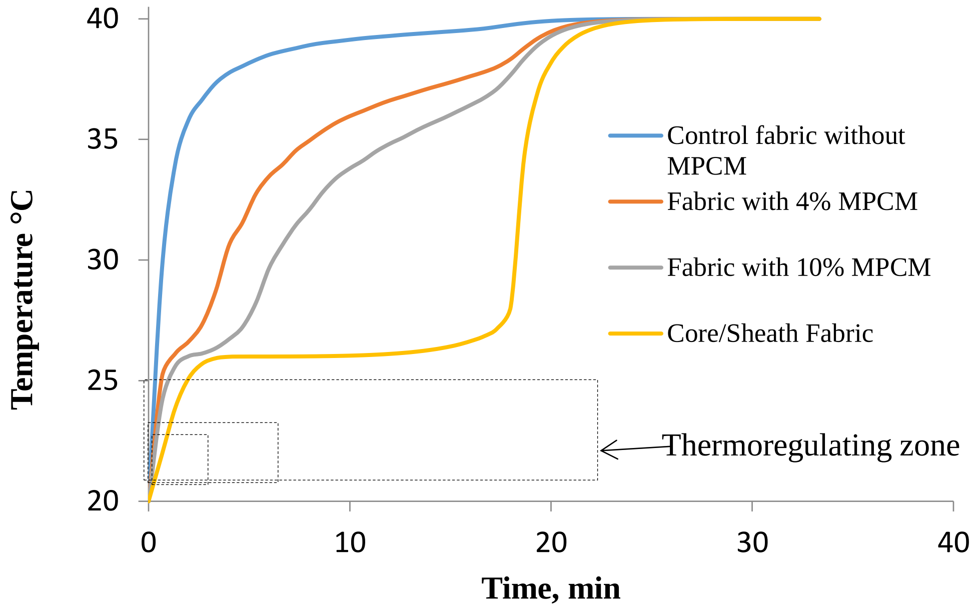

Figure 7 Time dependent thermoregulating effect at 40 °C

4. Conclusions

The heat transfer analysis of yarn and fabric incorporated with MPCM was studied using finite element method in ABAQUS. The results of simulated models were compared with experimental results for model validation. The thermoregulating effect for the protection of wearer against extreme weather was predicted against different amount of PCM.

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