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Development of thermo-regulating polypropylene fibre containing microencapsulated phase change materials

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ABSTRACT

Phase change materials are used for thermal management solution in textiles because of the automatic acclimatising properties of textiles. Most of the phase change materials used in textiles is usually found in the range of 28–32 °C of their melting point. This paper reports a type of smart monofilament fibre development incorporated with microencapsulated phase change material through melt spinning process. Up to 12% microcapsules are successfully incorporated into the polypropylene monofilament showing 9.2 J/g of latent heat. Some of the mechanical properties of the developed fibre are also studied together with the surface morphology of monofilament. A statistical model is developed for latent heat, tenacity and modulus of monofilament fibre and is validated by experimental values. The fibre properties predicted by the developed models are agreed very well to the experiments results.

1. Introduction

The search of new and renewable storage of energy which can be converted conventionally into useful form is a present day challenge for technologists. One of the emerging techniques for the development of thermal energy storage system is the application of phase change materials [1]. Smart textile is an emerging area in textile field which is becoming more significant by the demand of society through consumer needs. Despite the increasing impact of science and technology, smart textile demands the advancement through interdisciplinary support like fashion, design, engineering, technology, human and life sciences. In textile sector, smart textiles have its vast application in interior textiles, technical textiles and clothing in which the last one contains higher percentage in terms of usage of smart textiles [2]. Phase change materials are kind of smart materials which were used in clothing by US National Aeronautics and Space Administration (NASA) in 1980 [3], they were used to make thermo-regulated garment for space and to protect apparatus in space with drastic temperature change [4]. This technology was then transferred to Outlast Technologies, based in Boulder, Colorado who used PCM (phase change material) in textiles and fabric coating [5].

When the temperature of environment or body increases, phase change materials absorb extra heat from environment or body as latent heat and keep this energy stored. When the temperature falls down outside the phase change material environment, it releases stored energy to body and environment keeping the wearer in comfortable zone. Different naturally occurring phase change materials are discovered comprising of inorganic and organic materials ranging their melting point from subzero to several hundred degrees Celsius. Phase change materials are those materials which can change their state within a certain temperature range. Phase change material stores heat in liquefied PCM when rise in temperature occurs and then becomes solid PCM by releasing stored heat when temperature falls [6].

It is reported that incorporation of phase change materials in textiles will perform buffering effect keeping the skin temperature constant against extreme weather hence prolonging thermal comfort for the wearer and is also claimed that using phase change materials can decrease the fabric thickness required to protect the human body from cold environment [7]. Currently, phase change materials are being used in different textiles including bedding, apparel, footwear under the trade names Outlast™ and ComforTemp®. Outlast Technologies has succeeded in marketing viscose and PAN (polyacrylonitrile) containing MPCM (microencapsulated PCM) [9]. Paraffins are organic phase change materials which absorb approximately 200 kJ/kg of latent heat during phase change. This high amount

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of heat is released to surroundings during reverse cooling process called crystallisation. By incorporating phase change materials to textiles, their heat storage capacity can be substantially enhanced [8].

Clothing containing microencapsulated PCM changes their state from solid to liquid by absorbing heat energy when worn in environment having temperature equal or greater than the MPCM melting point giving cooling effect. Heat energy required to melt PCM may come from body or environment. If environment temperature gone equal or below the melting point of MPCM, they become solid releasing heat energy back and giving warming effect. Shim et al. claimed that MPCM acts as buffer which controls the thermal comfort for wearer by reducing the change in skin temperature [10].

There are many ways to make thermo-regulating textiles containing phase change materials. Wet spun yarns are successfully launched in market while melt spun are still under investigations. Since melt spinning process is the most convenient and commercially accepted method. This is also environmentally friendly and economical method because of no use of any solvent as in wet spinning and simplest process. So researchers are making efforts to bring melt spun thermo-regulating yarns in market.

In 1988, Bryant and Colvin succeeded in incorporating capsules containing eicosane as phase change material into viscose rayon or acrylic by wet and dry spinning method which gave thermo-regulating characteristics when subjected to heat and cold. So viscose rayon successfully came into the market containing leak resistant capsules [11]. Outlast Technologies assigned many projects to researchers to get enhanced with reversible thermal properties. Hartmann et al. published patent in 2010 describing manufacturing of viscose rayon containing microencapsulated phase change materials which was in continuation of his previous work. The latent heat mentioned in his patent was from 1 J/g to 20 J/g according to the different embodiments [8].

Magill et al. [12] prepared a multi-component containing phase change material by keeping the PCM in core and any thermoplastic or elastic in the outer sheath using polyester, nylon, and many other polymers. They claimed that material contains 6.9 J/g and 8.4 J/g of latent heat in different embodiments. Hagstrom from Swerea IVF Sweden prepared core/sheath melt spun PA6 and PET containing *n*-octadecane as phase change material in core. According to Hagstrom the fibre gave 80 J/g of latent heat against 70% of PCM in core [13].

This research has been focused on melt spinning of polypropylene containing microencapsulated phase change materials. The latent heat of the developed fibres, together with some of the mechanical properties is studied. The surface morphology of monofilament is also studied through SEM analysis.

2. Experimental

2.1. Materials

Microencapsulated phase change materials were supplied by American company Microteklab. Capsules contain *n*-octadecane as phase change material in core and Melamine Formaldehyde as shell. The capsules were in the form of dry powder and claimed to be extremely stable and have less than 1% leakage when heated to 250 °C.

The melting point of *n*-octadecane was 28 °C having enthalpy of fusion 180–190 J/g (claimed by company) and determined as 160–180 J/g (confirmed by DSC).

Raw polypropylene granules were supplied by Basell Polyolefins.

2.2. Methodology

For incorporation of MPCM into polypropylene, Benchtop extruder made by Extrusion System Limited was used. The Monofilaments polypropylene was made with different percentage of MPCM by varying the processing parameters. The most important parameters observed were temperature, metering speed and the extruder speed. They had to be set differently with different percentages of MPCM. The filament was collected by a winder through water bath. After spinning, the filaments were drawn on drawing machine to enhance the strength and get the appropriate fineness of the fibre. MPCM were mixed with PP granules from 2% to 12% on the weight of polymer in a container and well shaken manually to get homogenous mixing of capsules with granules.

The micrographs of the filaments were obtained by using SEM (Scanning Electron Microscopy) Hitachi S-4300 model.

The latent heat of filament containing MPCM was obtained using Mettler DSC (differential Scanning Calorimetry) 12E.

The modulus and tenacity of filament were determined according to the British Standard BS-EN-ISO 2062:2009 using Instron Tester 3345 series.

3. Results and analysis

3.1. SEM observation

Scanning electron microscopy images show the presence of capsules in MPCM incorporated polypropylene filament. Fig. 1 clearly indicates the difference between filaments with and without MPCMs. The images of cross sections of fibres with and without MPCM were taken by SEM are shown in Fig. 1(a) and (b) respectively. The fibres in Fig. 1(a) show rough surface and many particles presented in the surface of the fibres, indicating the presence of MPCM in comparison to the fibre without MPCM in Fig. 1(b) having very smooth surface.

In Fig. 2 below, the images have been taken at higher magnification to actually show the presence of PCM microcapsules. It shows from the cross section of the fibre that the PCM capsules are in both mono and aggregated forms within the fibre.

3.2. Latent heat

DSC results are shown in Fig. 3. The graph shows the latent heat against different percentages of MPCM. The latent heat is defined by area under the peak of the curve. The higher the percentage of MPCM, the larger the area under the curve indicating more latent heat stored in the material. PP monofilament without MPCM does not indicate any peak throughout the temperature range. For those fibres with MPCM, the peak of curve increases with the increase of the percentage of MPCM in the fibre, indicating increase in latent heat by increasing the amount of MPCM.

3.3. Yarn modulus and tenacity

Fig. 4 shows the load and extension relationship of a yarn tested by Instron tensile testing equipment following the yarn tensile testing standard.

The modulus and tenacity of yarn indicate the stiffness and strength of yarn. Modulus is the property of a material representative of its resistance to deformation. In tensile testing the modulus is expressed as the ratio of tenacity to strain, while the