Thermochimica Acta 636 (2016) 33–41

Contents lists available at ScienceDirect

Thermochimica Acta

journal homepage: www.elsevier.com/locate/tca

Finite element analysis of functional yarn with thermal management characteristics

Kashif Iqbal, Danmei Sun*

School of Textiles & Design, Heriot-Watt University, TD1 3HF, United Kingdom

ARTICLE INFO

Article history:
Received 25 January 2016
Received in revised form 21 March 2016
Accepted 20 April 2016
Available online 22 April 2016

Keywords:
Heat transfer
Finite element method
Thermoregulating effect
MPCM
DSC
ABAQUS

ABSTRACT

Phase change materials (PCMs) provide thermal management solution to textiles for the protection of wearer from extreme weather conditions. PCMs are the substances which can store or release a large amount of energy in the form of latent heat at certain melting temperature. This research reports the heat transfer property of multifilament yarn incorporated with microencapsulated PCM (MPCM) using finite element method under ABAQUS environment. The results of simulation after post processing have been validated against experimental values which were tested through Differential Scanning Calorimetry. It shows a strong correlation between the predicted and experimental results. The time dependent thermoregulating effect of yarns containing different amount of PCMs has been predicted based on the validated finite element model.

1. Introduction

Smart materials are becoming more significant in different filed of science and technology. Phase change materials (PCM) are materials which are used in smart clothing for thermoregulating applications [1]. PCMs are the kind of smart materials which have been used in clothing by US National Aeronautics and Space Administration (NASA) in 1980 to make thermo-regulated garment for space and to protect apparatus in space with drastic temperature change [2–4]. This technology was then adopted by Outlast technologies based in Boulder, Colorado who used PCM in textile fibres and fabric coating [5].

PCMs are attractive due to the ability of storing energy in all the available heat energy storage techniques due to high density, compact storage system and high latent heat [6,7]. The pioneer study of phase change material was applied for space crafts on small scale and then on large scale was applied in buildings and solar energy systems to build thermal energy storage system [8–10]. A large number of inorganic and organic PCMs are available in the temperature range of −5 °C to 190 °C [11–15]. The organic phase change materials are extensively used in textiles and buildings as thermal energy storage systems to store energy in the form of latent heat [16].

Heat transfer investigations on textiles have been performed by different researchers with or without PCM. Lamb and Duffy-Morris [17] investigated heat loss by ventilation in the fabrics with and without PCM additives and claimed that incorporation of PCMs at the proper location of layered garment can significantly enhance the insulating properties of fabrics. Pause [18] studied the development of heat and cold insulating membrane structures containing PCMs and determined that thermal insulation of materials can be substantially enhanced using PCM but he did not use any numerical simulation for further theoretical study of thermal properties of PCM textiles. Nuckols [19] developed an analytical model for diver dry suit with comfortemp® foams containing MPCM and studied the thermal performance of fabric using different MPCMs. He concluded that octadecane microcapsules gave better thermal protection against hexadecane microcapsules due to higher melting temperature of octadecane. Shim et al. [20] investigated quantitatively the effect of PCM in clothing for thermal performance of fabric and claimed that heating and cooling effect could last for 15 min depending on the number of PCM garment layers and combination of garments. Kim and Cho [21] developed thermostatic fabrics treated with microencapsulated octadecane and compared the thermal storage/release properties with untreated fabric.

In 2004 Ghali et al. [22] investigated the effect of PCM on clothing experimentally and numerically during periodic ventilation. They claimed that thermoregulating effect could last for approximately 12.5 min in fabric treated with MPCM depending on the amount of MPCM and outdoor temperature conditions. Yi and Qingyong [23]

* Corresponding author.
E-mail address: D.Sun@hw.ac.uk (D. Sun).

http://dx.doi.org/10.1016/j.tca.2016.04.011

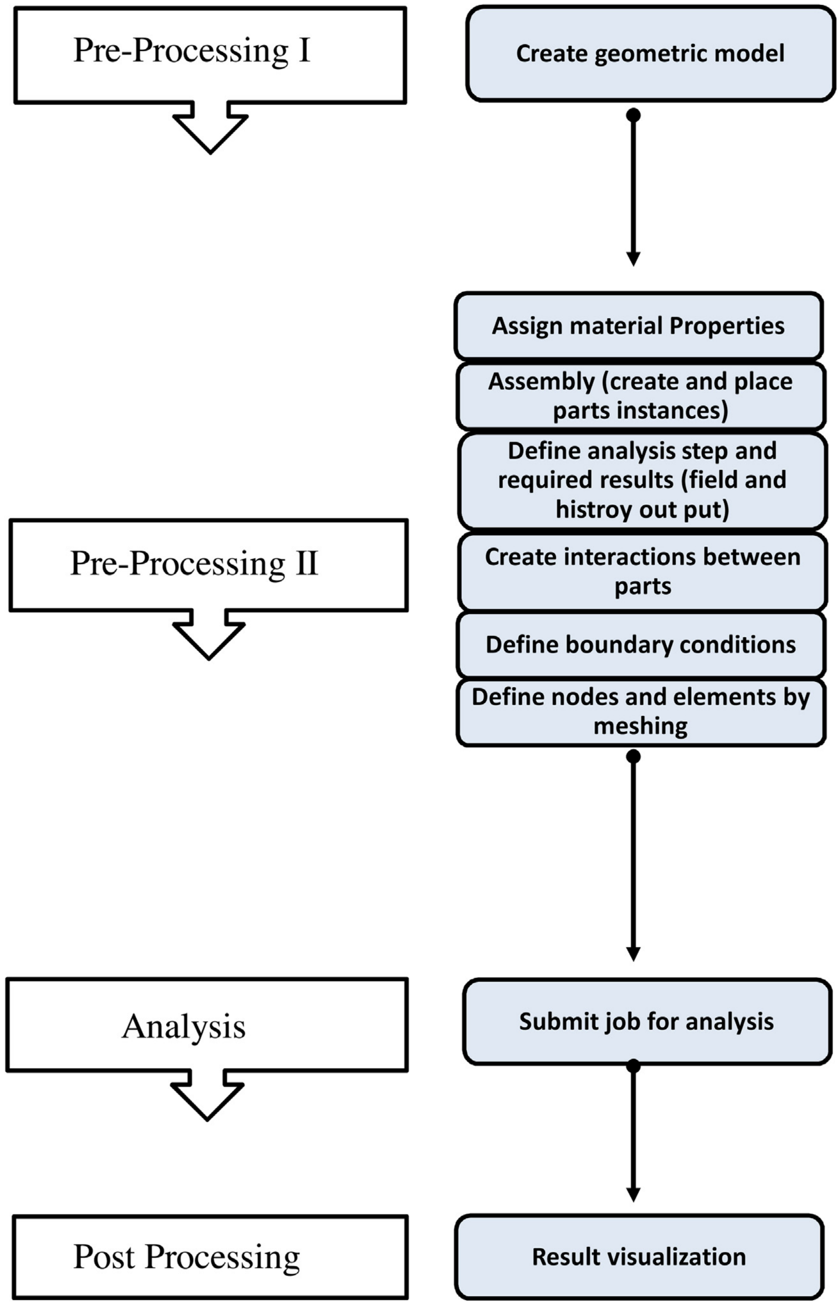

Fig. 1. Finite element analysis steps in ABAQUS.

performed coupled analysis of heat and moisture transfer by developing a mathematical model with PCMs and simulated the thermal buffering effect of PCM in fabrics. They validated their model with experimental results by numerically computing the temperature distribution and moisture concentration in porous textiles with and without PCM. Fengzhi et al. [24] developed a mathematical model of heat and moisture transfer in hygroscopic textiles containing MPCM and investigated the effect of fibre hygroscopicity on heat and moisture transfer properties of textile with MPCM. On the basis of proposed model they claimed that fibre hygroscopicity not only has influence on the distribution of water vapour concentration in the fabrics and water content in fibres but also on the effect of MPCM in delaying fabric temperature variation during environment transient periods.

In 2009, Fengzhi [25] investigated the effect of MPCM distribution on heat and moisture transfer in porous textile materials by numerical simulation and claimed that the total heat loss from body is the lowest when PCMs are located in the outer layer of fabrics. Ying et al. [26] numerically simulated the heat and moisture transfer characteristics on multilayer PCM incorporated textile assemblies using finite difference volume method. Bendkowska et al. [27] studied heat transfer in nonwoven with MPCM and determined the amount of latent heat per unit area of nonwoven fabrics. They reported that distribution of MPCM in fibrous substrate and position of PCMs layer in garments has significant effect on thermoregulating behaviour of the garments. Alay et al. [28] studied the thermal conductivity and thermal resistance of fabrics containing MPCM under steady state conditions. Yoo et al. [29] developed four layered garment treated with nanosilver nonadecane PCM and studied the thermoregulating properties with the effects of number and position of fabric layers. They found that outer layer containing