Thermochimica Acta 600 (2015) 35–44

Contents lists available at ScienceDirect

Thermochimica Acta

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

Effect of expanded graphite on the phase change materials of high density polyethylene/wax blends

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ARTICLE INFO

Article history:
Received 2 June 2014
Received in revised form 20 November 2014
Accepted 21 November 2014
Available online 22 November 2014

Keywords:
Phase change composites
DSC analysis
Thermophysical properties
Latent heat thermal energy storage

ABSTRACT

Phase change materials fabricated from high density polyethylene (HDPE) blended with 40 or 50 wt% commercial wax (melting point of 43.08 °C) and up to 15 wt% expanded graphite (EG) were studied. Techniques including scanning electron microscope (SEM), differential scanning calorimetry (DSC), thermogravimetric analysis (TGA), and an experimental device to measure diffusivity and conductivity (DICO) were used to determine the microstructural, mechanical and thermal properties of the composites. The composites possessed good mechanical properties. Additionally, no leaching was observed during material processing or characterization. Although the Young's modulus increased with the addition of EG, no significant changes in tensile strength were detected. The maximum Young's modulus achieved was 650 MPa for the HDPE/40% wax composite with 15 wt% EG. The EG was well dispersed within the composites and did not affect the melting or crystallization of the HDPE matrix. The incorporation of EG increased the thermal stability of the composites by reducing chain mobility and inhibiting degradation. The intensification of thermal conductivity occurred with increasing fractions of EG, which was attributed to the high thermal conductivity of graphite. The maximum quantity of heat stored by latent heat was found for the HDPE/40% wax composite with EG. The addition of a relatively small quantity of EG enhances the heat conduction in the composite.

1. Introduction

Phase change materials (PCMs) have recently attracted increased interest because of their efficient use and storage of thermal energy [1–5]. Latent heat storage is one of the most efficient ways of storing thermal energy. Because of their high storage density and the small temperature differential between stored and released heat, PCMs are effective and useful in thermal management applications [1–4].

Paraffin wax has many applications, although, the widespread use of paraffin wax has low thermal conductivity [5–7]. However, thermal conductivity can be improved by a variety of methods [8–21]. Several studies have shown that phase change materials (PCMs) with a large thermal conductivity can be produced by using PCMs that contain a dispersion of highly conductive particles, such as metal additives [22–25]. Nevertheless, these additives can add significant weight and cost to the production of these storage systems and some are not compatible with PCMs.

Recently, carbon-based materials, which are economical, stable and chemically inert with a high thermal conductivity and a low bulk density, have been investigated as attractive constituents to enhance the heat transfer of PCMs [11–21].

Porous carbon materials have an open cell structure that is interconnected with graphitic ligaments of high thermal conductivity (bulk thermal conductivity, 180 $W^{-1}\,m^{-1}\,K^{-1}$) that allow the rapid transport of heat throughout PCMs [13–21]. Therefore, many studies have examined the effect of graphite in PCMs on thermal conductivity [16–21].

Recently, polymer-based nanocomposites reinforced with expanded graphite (EG) [26,27] have been shown to significantly improve the mechanical and thermophysical properties of PCMs, including the electrical and thermal conductivities. Expanded graphite is produced by reacting natural graphite flakes in sulfuric acid and subjecting the graphite to thermal shock, which causes a unidirectional expansion of the initial graphite platelets and produces highly porous worm-like accordions of graphite. EG is composed of hundreds of stacks of graphene nanosheets that have an enormous surface area (up to 2630 m^2/g if both sides of the sheet are considered accessible) [28].

Krupa et al. [29] and AlMaadeed et al. [30] studied the polyethylene as a good matrix for the phase change materials.

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http://dx.doi.org/10.1016/j.tca.2014.11.023
0040-6031/

Zhang et al. previously developed a phase change composite (PCC) with a high density polyethylene matrix (HDPE), commercial paraffin wax (melting temperature of 51.22 °C), 5% expanded graphite and flame retardants [31].

In their investigation, they determined that the paraffin wax and EG were well dispersed within the HDPE matrix and that the thermal conductivity improved with the addition of EG. Other additives that can be used in PCC are graphite [32] which increased the thermal conductivity and date palm fibre [33,34] which increased the stability and mechanical properties.

In the current work, PCCs were developed with a HDPE matrix, a wax with a low melting temperature (melting temperature of 43.08 °C) and up to 15 wt% EG. The morphological, physical, mechanical and thermal properties of the composites were examined and are presented in this paper.

2. Experimental details

2.1. Materials

High density polyethylene (HDPE), with a melt flow index (MFI) of 0.35 g/10 min, and a density of 0.95 g/cm^3, was obtained from QChem company in Qatar used to prepare the PCMs. Commercially available RT42 from Rubitherm Technologies (Germany), with a heat conductivity of 0.2 W m^{-1} K^{-1}, a density of 0.88 kg/l at 15 °C, a melting point of 43.08 °C, and an enthalpy of 133.832 J/g (heating rate of 10 °C), was used as the wax component. The expanded graphite (EG) (GFG200, SGL Carbon, Germany) consisted of 200 μm graphite platelets.

2.2. Methods

2.2.1. Sample preparation

Composites formed by HDPE, wax (up to 50 wt%) and expanded graphite (up to 15 wt%) were fabricated using a lab scale Brabender twin screw extruder with screw diameter D of 20 mm and screw length of 40 D. The throughput of the extruder was programmed to 0.7 kg/h, and the screw speed was set to 110 rpm.

The extruder has five zones, zone one with 200 °C while the other four zones have 180 °C.

To fabricate the final samples, the composites were dried for 30 min at 70 °C and then loaded into the injection molding machine at 180 °C.

2.2.2. Morphology analysis

The morphology of the HDPE/wax composites was characterized using an environmental scanning electron microscope (ESEM) FEI Quanta 200 (at 3.0 keV). Thin surface of freeze-fractured samples in liquid nitrogen were analyzed.

2.2.3. Differential scanning calorimetry (DSC)

DSC analysis was performed under nitrogen gas using a PerkinElmer DSC8500. To eliminate the effect of thermal history, results from DSC analysis were collected during the second heating cycle, which occurred from 20 to 170 °C at 10 °C/min. The total enthalpy of fusion was calculated by the following Eqs. (1) and (2):

$$\Delta H^{\text{total}} = \Delta H^{\text{HDPE}} + \Delta H^{\text{wax}} \quad (1)$$

and

$$\Delta H^{\text{theo}} = w^{\text{HDPE}} \Delta H^{\text{HDPE}} + w^{\text{wax}} \Delta H^{\text{wax}} \quad (2)$$

where ΔH^{HDPE} and ΔH^{wax} are the enthalpy of fusions for the HDPE matrix and the paraffin wax, respectively, and w^{HDPE} and w^{wax} are their fractional weight compositions.

2.2.4. Thermogravimetric analysis (TGA)

TGA was performed using a PerkinElmer TGA7 analyzer from 50 to 600 °C at a heating rate of 10 °C/min in a nitrogen-rich atmosphere (20 ml/min).

2.2.5. Tensile tests

A tensile analyzer (Lloyd Instruments, 50 kN) was used to determine the mechanical properties of the composite materials at room temperature. Tensile testing was performed according to the ASTM D638 standard at a rate of 50 mm/min. Average values and standard deviations were obtained from the analysis of at least five measurements.

2.2.6. DICO device: thermophysical property measurements

A periodic method was used to simultaneously estimate the thermal conductivity, diffusivity and specific heat of the paraffin/graphite composite materials at room temperature. The composite sample being analyzed was fixed between two metallic plates. Efficient thermal exchange between the two plates and the sample was guaranteed by using heat conductive grease (Fig. 1). The front side of the first metallic plate was periodically heated using a sum of five sinusoidal signals. The temperature was measured using

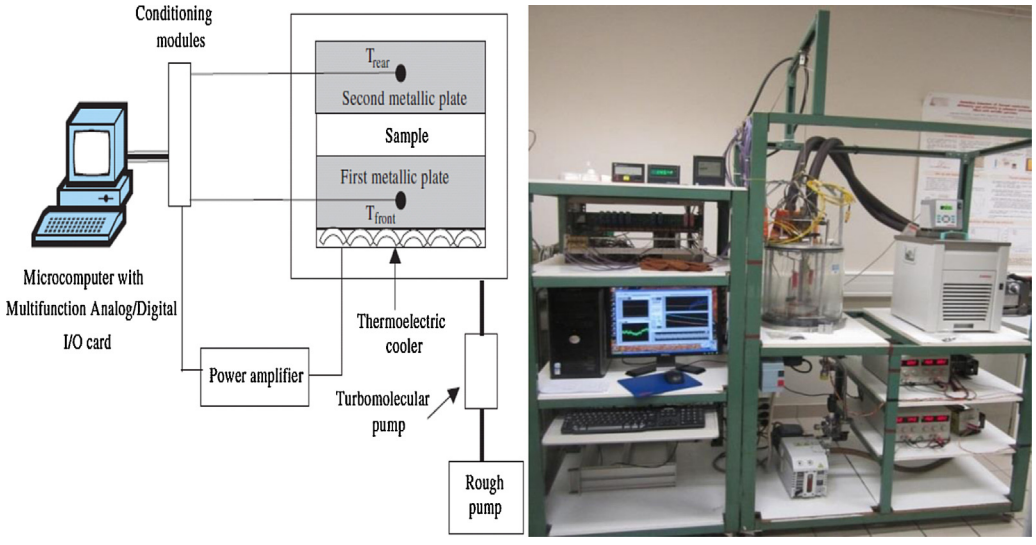

Fig. 1. Experimental set-up of periodic method.