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Research Paper

Novel shape stabilized phase change material based on epoxy matrix with ultrahigh cycle life for thermal energy storage

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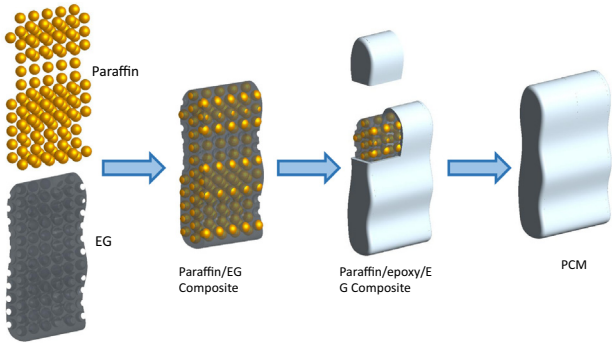
HIGHLIGHTS

- New shape stabilized PCMs were prepared using epoxy as matrix.
- A curing method was proposed to reduce the volume change of PCMs.
- Microstructural and mechanical properties of PCMs were investigated.
- Epoxy framework fixes the melted PCM, preventing PCM leakage to a great extent.

GRAPHICAL ABSTRACT



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ABSTRACT

A novel phase change material with compact three-dimensional network structure and long cycle life was proposed, in which energy can be obtained from the thermal motion of surround molecule in environment. The composite was made from paraffin mixed with impact structure and shape stabilized epoxy at 70 °C. During the phase change process, the epoxy not only provided a flexible encapsulated scaffold structure, but also maintained a highly tight network morphology. The thermal analysis results displayed the paraffin was distributed uniformly in the polymer matrices, moreover, there was no paraffin leaking during sample preparation. Mechanical test results showed an excellent performance on composites and the mechanical properties increased with an increase in epoxy content, meanwhile, when the paraffin and epoxy was prepared in a mass ration of 1:1, the composite can be cut into any shape, and also maintain good mechanical properties and thermal stability without any leakage. The results revealed that this new styling composite phase change material have good mechanical properties and thermal stability, it can be applied significantly in the long-term effective use of thermal energy storage.

1. Introduction

Accompany with the growing population and rapid industrial development, the problems of limited energy consumption and emissions of CO_2 are gradually presented [1]. In order to avoid the excessive dependence of fossil fuels, the researches focusing on the development of alternative energy sources [2] and new recycled energy [3], moreover, the efficient use of energy is taken seriously gradually [4]. One of the promising efficiently methods to utilize thermal energy is the latent heat storage of phase change materials (PCMs) [5–7], which can absorb and release large

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amounts of latent heat during the process of phase changing [8]. However, compared with the preparation of microencapsulated PCMs which has tedious multistep process and relatively high cost [9], the method of utilizing matrix materials to stable composite PCM is the most practical and efficient approach for addressing the PCM leakage issue [10]. Through this method, the composite of PCM wrapped by the matrix materials can maintain the solid shape all the time.

Recently, the development of novel types of matrix materials promoted its application in the field of composite PCMs. These matrix materials can be categorized approximately into two kinds: inorganic materials and organic materials. The former includes expended graphite [11], porous carbon [12], graphene aerogel [13] and carbon nanotubes [14]. And organic matric materials include low-density polyethylene [15–17], linear low-density polyethylene [18], epoxy [19], polyethylene glycol [20], high-density polyethylene [21–24], polypropylene [25] metal–organic frameworks [26] and so on. In comparison to inorganic matrix materials, organic matric materials can provide a lot of advantages such as practical melting temperatures, high latent storage capacity, small volume change, and high chemical and thermal stability [27]. Epoxy as an organic supporting material is ascribed to its large mechanical properties, thermal stability, solvent resistance and easy preparation [28]. Epoxy can show excellent thermosetting mainly due to its epoxide groups, which reacts with a hardener (curing agent) and offer a highly crosslinked, three-dimensional network after the processing of cure chemical reaction [29].

In addition, practical applications of phase change materials have been obsessed by another difficulty: The leakage of PCMs occurs during repeated use due to a loose structure and considerable volume expansion by phase change. In order to resolve the precipitation of the PCMs, many researchers have focused on analyzing the masses of the testing result before and after to verify the PCM leaking or not. Yi Luan et al. placed the PCM composites on filter papers into an oven at 150 °C temperature (above the melting point of PCM) for 30 min, the effect of energy storing was showed excellent when the latent heat of PCM composites value was 120.53 J/g [26]. Xinyu Huang et al. heated the pure PCM and PCM-impregnated compact blocks in a hot plate separately, in the condition of the target temperature being set a little higher than the melting point of the PCM for 150 s, the PCM-impregnated block with a latent heat value of 104.13 J g^{-1} remained essentially intact [30]. Shibing Ye et al. heated samples under different temperatures, and followed on storing for 30 min, through observing the appearance changes by the storage modulus of samples, the results exhibited the little leakage of PCM composite by the encapsulated preparation method [13]. From these investigations, it can be concluded that shape stabilized PCM require a compact structure to prevent leakage when phase change occurs so as to improve the service life of PCM.

In this research, paraffin was adopted as a solid-liquid organic PCM because of its low vapor pressure, high latent heat and chemical stability [31]. For resolving the leakage of the PCM, a novel ternary stabilized material which was composed of paraffin/epoxy/expanded graphite is fabricated by sol-gel method at a target temperature above the melt point of phase change temperature. Meanwhile, mechanical and thermal properties of the ternary material were investigated furtherly for practical application.

2. Experimental

2.1. Materials and preparation of PCMs

Pure paraffin (a melting point of 48 °C, supplied by Shang Hai Joule Wax. Ltd.) was firstly poured into an aluminum drum at 70 °C until it melted to liquid completely, then expanded graphite (EG, with the mass percentage of 6% in paraffin), which is regarded as porous material with high thermal conductivity, was added into the liquid state PA, and a homogenizer was used to disperse blends at 2000 rad/min for 0.5 hours (h) for improving the heat-transfer capability. Thirdly, a vigorous stirring for 20 min at 70 °C in a water bath was adopted to distribute the three kinds of materials after pouring epoxy (Supplied by Changsha Baxiongdi Ltd.; with resin and curing agent mass ratio of 1 to 1) into blends, to obtain stable and homogeneous epoxy-paraffin-EG emulsions. The sample's three-dimensional network came into being after standing its melt at a high temperature which is between the melting temperature point of the epoxy and that of the paraffin in a calorstat for 24 hours at least. PCMs with different mass percentage of epoxy (20%, 30%, 40%, 50% and 60%) were prepared by analogous methods as shown in Fig. 1.

2.2. Property analysis

The morphology of Micro-PCMs was characterized by scanning electron microscope (SEM, 3400N, JPN). Thermo-physical properties of the prepared ternary composite PCMs with different mass percentage of paraffin such as transition temperature, melting temperatures and latent heats, were measured by using a Different Scanning Calorimeter (DSC2910, Texas Instrument Inc, USA) instrument and Thermogravimetric Analysis (STD 2960, Texas Instrument Inc, USA) instrument.

The DSC thermal analysis were performed in the temperature range of 10–70 °C for those composite samples with a heating rate of 5 °C min^{-1} and under a constant stream of nitrogen at atmospheric pressure. Machine properties of the PCMs were measured such as extension test, bending test and impact test under room temperature. And the thermal decomposition of shape stabilized PCM was measured by a TGA with a heating rate of 20 °C min^{-1}

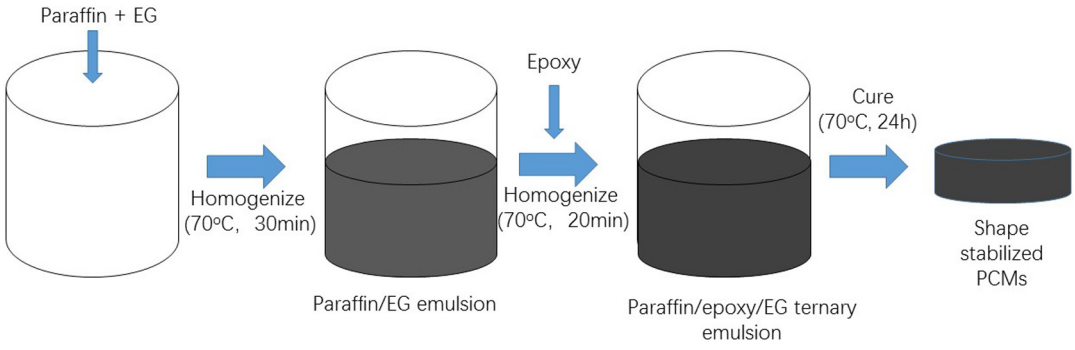

Fig. 1. The process of preparing the ternary material.