Polymer 133 (2017) 250–262

Contents lists available at ScienceDirect

Polymer

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

Synthesis of novel phase change material microcapsule and its application

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ARTICLE INFO

Article history:
Received 13 September 2017
Received in revised form
15 November 2017
Accepted 21 November 2017
Available online 22 November 2017

Keywords:
Phase change material
Microcapsule
Copolymer

ABSTRACT

A novel phase change material (PCM) microcapsule possessing a thermally conductive but electrically insulated shell is synthesized. The vinylsilane compound is polymerized with the acrylic monomer to first form a copolymer, with the thermally conductive inorganic material subsequently added. Thereafter, the PCM microcapsule with the paraffin core and the thermally conductive but electrically insulated material-containing copolymer as the shell is prepared through mini-suspension polymerization. The results of the heat transfer rate test revealed that PCM microcapsules can store and release heat more quickly and can reduce the heating and cooling times by approximately 48% and 42%, respectively. With PCM microcapsules applied in a battery module, the decrement of temperature at the center of the battery module could reach 7.3 °C. Therefore, PCM microcapsules which possess heat conductive and electrical non-conductive properties could be applied in electronic devices such as in batteries to prolong their service life.

1. Introduction

With the rapid development of society and economy, demand for energy is increasing at an exponential rate. Due to the depletion of conventional energy sources and a series of environmental problems caused by extensive use of fossil fuels, sustainable management of energy, such as development of new energy sources and improvement in utilization of existing energy sources becomes increasingly important. Since the first oil crisis in 1970, scientists around the world have begun seeking new sources of energy and exploring new ways to manage energy. Energy storage in industrial energy conservation and new energy applications have gained the most attention; among these, low-cost phase change materials (PCMs) became popular because of their high storage capacity and thermostatic effect during energy storage. PCM can absorb or release heat, change its physical state (e.g. from solid to liquid and vice versa) and provide latent heat with changes in temperature. As the PCM undergoes physical state changes, the temperature of the material remains almost unchanged [1,2]. The use of PCM can improve the utilization of existing energy sources. PCM has been widely used in air-conditioning, building materials, textiles, energy-saving equipment, health care, food preservation and warm supplies as one of the typical environmentally friendly energy-saving materials [3–5].

PCM microcapsules are made up of micro-materials in a shell that coats the surface of another material. The microcapsule technology helps eliminate the problem of material leakage when the PCM is melted, and provides a large heat transfer area because of the small particle size and large surface area of the micro-encapsulated material [6,7]. However, most of the PCM microcapsules with low thermal conductivities which are highly undesirable in heat transfer application. The microencapsulation materials are mostly made up of organic polymer, contributing to the very low thermal conductivities. Although the microencapsulation materials can prevent leakage of PCMs, they slow down the rate of heat transfer, resulting in a reduction in PCM energy storage or cooling

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https://doi.org/10.1016/j.polymer.2017.11.046

effect. The following methods can be employed to increase the rate of heat transfer: (1) adding metal or metal oxide of nanometer or micrometer grade [8–10], (2) adding a metal mixture [11,12], (3) adding carbon nanotubes (CNTs) and nanofibers (CNFs) [13,14], and (4) adding graphite and expanded graphite [15,16]. However, the use of such additives can impart microcapsules with high electrical conductivity and increase the risk of short-circuiting in electronic applications. This problem can be easily mitigated by using thermal interface materials such as aluminum nitride and aluminum oxide due to their high thermal conductivity and low electrical conductivity. Especially, nanosized thermal interface materials (Nano-TIMs) take advantage of high specific surface area to optimize thermal transfer efficiency in high-performance PCM microcapsules.

Nano-TIMs are mostly inorganic materials while PCMs and microencapsulation materials are often organic materials, so the compatibility between the two components is usually poor. Surfactant or silane coupling agents are commonly used to modify the surface of the Nano-TIMs to enhance their compatibility with organic materials. Bauer et al. [17] used trialkoxysilanes coupling agent to modify nano-silica and alumina, resulting in the formation of polysiloxane oligomers and a polysiloxane layer. However, even with the use of surfactant or silane coupling agent, the adhesion between Nano-TIMs and microencapsulation materials is still not strong enough for the two materials to combine without separation. The two materials are exposed to different environments such as oil phase and water phase because they are synthesized via bulk polymerization and mini-suspension polymerization respectively. Therefore, if Nano-TIMs only uses silane coupling agent, it is impossible to disperse the material in both oil and aqueous phase simultaneously. Hayakawa et al. [18] reported that one end of triethoxyvinylsilane (TEVS) condensed with silica gel surface and formed -Si-O-Si- bond while the other vinyl end reacts with styrene or methyl methacrylate (MMA) to form a copolymer. When the inorganic material was added after polymerization of either TEVS and styrene or TEVS and MMA has completed, the polar functional groups on the surface of the inorganic material could form bonds with TEVS, resulting in a product material that can be dispersed in both oil and aqueous phases at the same time.

The aims of this study are to improve the shortcomings of existing PCM microcapsules by making them thermally conductive, but not electrically conductive, such that they can be used in electronic devices. The TEVS compound is polymerized with the MMA monomer to form a copolymer first, and then suitable Nano-TIMs (i.e. aluminum nitride and aluminum oxide) are added. Thereafter, the PCM microcapsule having the paraffin as the core and the thermally conductive but electrically insulated material-containing copolymer as the shell is prepared through mini-suspension polymerization. The resultant well-dispersed Nano-TIMs in microcapsule shell will assure efficient thermal transfer to PCMs so as to achieve effective heat conduction, heat dissipation and energy storage function. The effects of mass ratio of core to

Table 1
List of PCM microcapsules with their corresponding labels.

Sample label	PVA wt%	Paraffin (g)	BPO (g)	AlN (g)	Al_2O_3 (g)
0.5PPSN	0.5	40	0.56	30	0
1PPSN	1	40	0.56	30	0
1.5 PPSN	1.5	40	0.56	30	0
3 PPSN	3	40	0.56	30	0
1.5PPSO	1.5	40	0.56	0	30

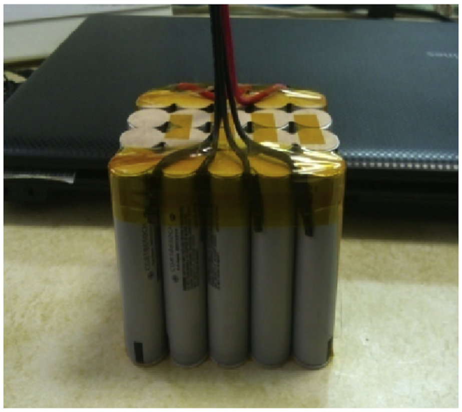
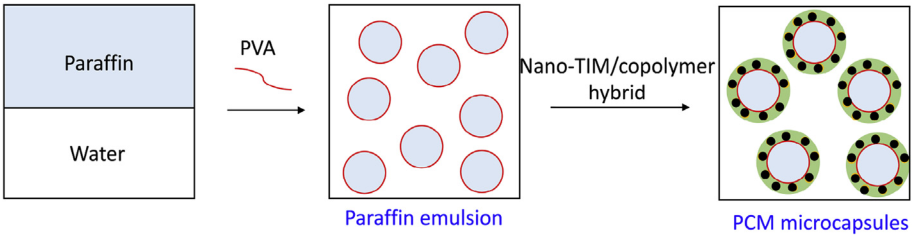
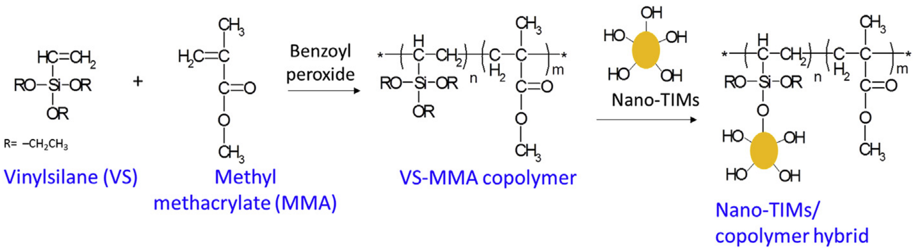


Fig. 1. Photographs of battery module.



Scheme 1. Schematic illustration of synthesis of PCM microcapsules.



Scheme 2. Synthesis of Nano-TIMs/copolymer hybrid.