



# Dual-level packaged phase change materials – thermal conductivity and mechanical properties



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## ARTICLE INFO

### Keywords:

Phase change materials  
Dual-level packaging  
Thermal conductivity  
Mechanical properties

## ABSTRACT

Phase change materials (PCMs) which possess high thermal conductivity and excellent mechanical property have been prepared in this work according to a dual-level packaging technology. Porous graphite foam with bulk density of 0.25 g/cm<sup>3</sup> which is derived from worm-like expanded graphite is infiltrated by liquid paraffin. The as-infiltrated graphite foam is ball milled into small spheres with diameter of 1–3 mm. Then the spheres are sprayed with a pre-polymer composed of epoxy resin and its curing agent. These spheres are finally hot-pressing at 30 °C for 6 h under 1 MPa to obtain the PCMs. Correspondingly, porous graphite works as the first-level packaging (core) while epoxy resin film acts as the second-level packaging (shell) of paraffin. The thermal conductivity of PCM composites reach to 4.98 W/m K. Meanwhile, the compressive strength of PCM composites keeps a very stable value of 19.50 MPa when temperature increases from 25 to 90 °C. The excellent shape-stability of PCM is attributed to its dual-level packaging structure in which porous graphite prevents the leaking of liquid paraffin from the core and epoxy resin provides a strong polymer network at high temperature.

## 1. Introduction

Thermal-energy storage system based on phase change materials (PCM) are attractive in various fields such as solar heating system, energy-saving buildings, and thermal management of electronic devices.[1–3] PCM can absorb/release a large amount of energy with small temperature fluctuation according to solid/liquid or liquid/solid phase change.[4] The thermal conductivity and shape stability of PCM at high temperature are most concerned when they are utilized in a thermal-energy storage system.

Paraffin is widely used PCM due to its large latent heat, non-toxicity, non-corrosive and low cost. However, paraffin possess inherent drawbacks of low thermal conductivity (0.1–0.3 W/m K) and poor shape stability at high temperature which limit its applications. Many research works which focus on enhancing the thermal conductivity of paraffin have been reported in this decade.[5–7] These works can be concluded as a “filling method” because conductive fillers (carbon fiber, metallic powders, etc) are dispersed in paraffin matrix. Meanwhile, encapsulating technology (or packaging technology) is utilized to improve the shape stability of PCM at high temperature by packaging the micro-sphere of PCM with a polymer shell.[8] However, encapsulating make little contribution to thermal conductivity of PCM because polymer shells usually possess low thermal conductivity. Therefore,

there is always a dilemma for preparing PCM with enhanced thermal conductivity and elevated shape stability at high temperature either using a simple “filling” method or using a traditional encapsulating technology.

We propose a dual-level packaging method for obtaining PCM composites with high thermal conductivity and excellent shape stability at high temperature. Porous graphitic foam is firstly infiltrated with liquid paraffin. Then the as-infiltrated graphite foam are machined and ball milled into spheres with diameters of 1–3 mm. subsequently, the spheres are sprayed with an ethanol solution of epoxy resin and its curing agent. After rapidly removing the solvent of ethanol, a thin film composed of epoxy pre-polymer is formed at surface of the spheres. Finally, the spheres with epoxy pre-polymer are hot-pressed in a steel module. The thermal conductivity and mechanical properties of final PCM composites are measured. The effect of dual-level packaging on the mechanical properties at high temperature is also investigated.

## 2. Experimental

### 2.1. Raw materials

Refined paraffin which is composed of hydrocarbon (C<sub>22–28</sub>H<sub>46–58</sub>) are purchased from ShangHai Joule wax Co.,Ltd( China) whose proper-

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**Table 1**  
Properties of paraffin.

Bulk density (g/cm <sup>3</sup> )	Melting point (°C)	Latent heat (J/g)	Thermal conductivity (W/m·K)	Compressive strength (MPa)	
				25 °C	50 °C
0.90	51.4	245.1	0.22	3.01	~0.10

ties are listed in Table 1.

Epoxy resin (E51) and its curing agent are supplied by China national Blue-star Co.,Ltd. Expanded graphite derived from natural graphite flake is supplied by Ruisheng new-energy Co.,Ltd (China).

## 2.2. Preparation of PCM composites

Worm-like expanded graphite is compressed into porous graphite foam with bulk density of 0.25 g/cm<sup>3</sup> under mechanical pressure without external binder in a steel module. The porous graphite foam is infiltrated with liquid paraffin at 90 °C under 10 KPa for 4 h. Then the as-infiltrated graphite foam is machined and ball milled into spheres (labeled as PCM-FP) with diameters of 1–3 mm. A pre-polymer solution composed of epoxy resin base and its curing agent (3:1) in ethanol is sprayed on the surface of PCM-FP spheres. After removing the solvent of ethanol, the PCM spheres with pre-polymer film at surface are hot-pressed at 30 °C for 6 h with applied pressure of 1 MPa in a steel module. The optimized weight ratio between paraffin, graphite and epoxy resin is 3:1:1. The size of final PCM composites (labeled as PCM-DP) is 150 × 60 × 30 mm.

## 2.3. Characterization

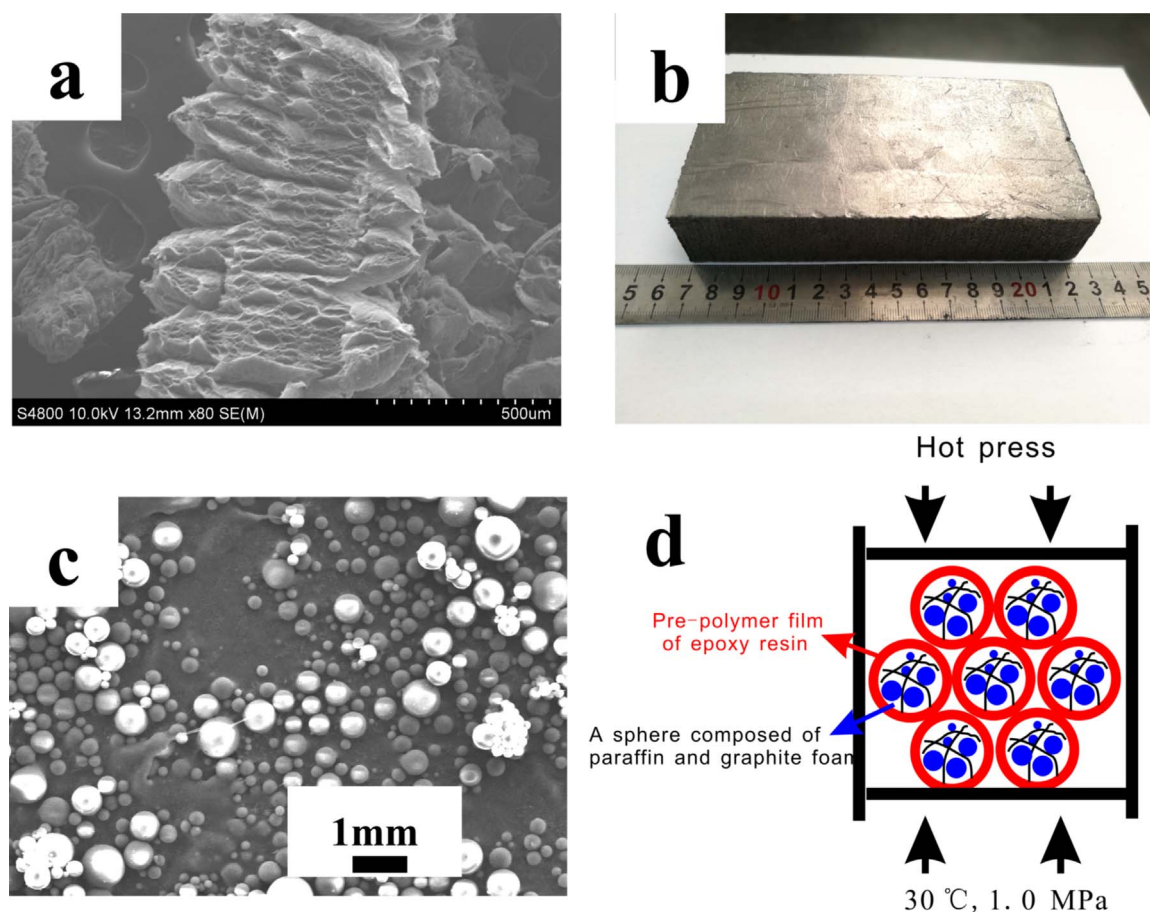
Differential scanning calorimetry (DSC) technology is employed to determine the melting point and latent heat of PCM composites which is conducted with a thermal analysis apparatus (200 F3 MAIA, Netzsch Germany). The specific heat of all PCMs are also determined by DSC technology which is operated from 25 to 40 °C using a sapphire (Al<sub>2</sub>O<sub>3</sub>) as reference samples.

A Netzsch system (LFA427, German) based on laser flash technique is employed to measure the thermal diffusivity ( $\alpha$ ) of the PCM composites which cut into squares of 10 × 10 × 2 mm.

The leakage of phase change materials (for instance: wax) is always concerned when phase change technology is used in an energy storage system. Therefore, we carried out the “weight loss” experiments by keeping all of the PCMs blocks at 90 °C for 100 h: The weight of these blocks before ( $M_1$ ) and after “weight loss” experiment ( $M_2$ ) are measured. Then weight loss ratio is defined as  $(M_1 - M_2)/M_1 \times 100\%$ .

PCM cubic with size of 1 × 1 × 1 cm are used to measure the compressive strength with a material testing machine (CMT-4304, MTS Industry System CO.,LTD. USA) according to the Chinese standard GB/T 1431–2009.

As mentioned above, the PCM call for mechanical stability when they are used in thermal-storage. So, the compressive strengths of PCM at different temperatures which range from 25 to 90 °C are measured. The variations of compressive strengths obtained at different temperatures are used to evaluate the mechanical stability. Field emission scanning electron microscopy (FESEM, JEOL JSM-7001F, Japan) was employed to observe the microstructure of PCM.



**Fig. 1.** Worm-like EG (a), porous graphite foam prepared by EG (b), spheres prepared with as-infiltrated graphite foam (c). Hot-pressing of spheres with pre-polymer of epoxy resin (d).

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