

This article was downloaded by: [Soongsil University]

On: 09 January 2014, At: 17:07

Publisher: Taylor & Francis

Informa Ltd Registered in England and Wales Registered Number: 1072954 Registered office: Mortimer House, 37-41 Mortimer Street, London W1T 3JH, UK



## Journal of Adhesion Science and Technology

Publication details, including instructions for authors and subscription information:

<http://www.tandfonline.com/loi/tast20>

### Preparation of epoxy resin using n-hexadecane based shape stabilized PCM for applying wood-based flooring

Su-Gwang Jeong<sup>a</sup>, Sumin Kim<sup>a</sup> & Wansoo Huh<sup>b</sup>

<sup>a</sup> Building Environment & Materials Lab, School of Architecture, Soongsil University, Seoul 156-743, Republic of Korea

<sup>b</sup> Department of Chemical Engineering, Soongsil University, Seoul 156-743, Republic of Korea

Published online: 10 Dec 2013.

To cite this article: Su-Gwang Jeong, Sumin Kim & Wansoo Huh (2014) Preparation of epoxy resin using n-hexadecane based shape stabilized PCM for applying wood-based flooring, Journal of Adhesion Science and Technology, 28:7, 711-721, DOI: [10.1080/01694243.2013.865331](https://doi.org/10.1080/01694243.2013.865331)

To link to this article: <http://dx.doi.org/10.1080/01694243.2013.865331>

PLEASE SCROLL DOWN FOR ARTICLE

Taylor & Francis makes every effort to ensure the accuracy of all the information (the "Content") contained in the publications on our platform. However, Taylor & Francis, our agents, and our licensors make no representations or warranties whatsoever as to the accuracy, completeness, or suitability for any purpose of the Content. Any opinions and views expressed in this publication are the opinions and views of the authors, and are not the views of or endorsed by Taylor & Francis. The accuracy of the Content should not be relied upon and should be independently verified with primary sources of information. Taylor and Francis shall not be liable for any losses, actions, claims, proceedings, demands, costs, expenses, damages, and other liabilities whatsoever or howsoever caused arising directly or indirectly in connection with, in relation to or arising out of the use of the Content.

This article may be used for research, teaching, and private study purposes. Any substantial or systematic reproduction, redistribution, reselling, loan, sub-licensing, systematic supply, or distribution in any form to anyone is expressly forbidden. Terms &

Conditions of access and use can be found at <http://www.tandfonline.com/page/terms-and-conditions>

## Preparation of epoxy resin using *n*-hexadecane based shape stabilized PCM for applying wood-based flooring

Su-Gwang Jeong<sup>a</sup>, Sumin Kim<sup>a\*</sup> and Wansoo Huh<sup>b</sup>

<sup>a</sup>Building Environment & Materials Lab, School of Architecture, Soongsil University, Seoul 156-743, Republic of Korea; <sup>b</sup>Department of Chemical Engineering, Soongsil University, Seoul 156-743, Republic of Korea

(Received 11 October 2013; final version received 6 November 2013; accepted 10 November 2013)

Epoxy resin has excellent characteristics of moisture, low toughness, solvent and chemical resistance, low shrinkage on cure, superior electrical and mechanical resistance properties, and good adhesion to many substrates. In this experiment, we prepared epoxy resin with shape stabilized phase change material (SSPCM) to enhance the thermal properties of epoxy resin. The SSPCM was prepared through the vacuum impregnation method, and the SSPCM/epoxy resin composites were prepared through the shear stirring process and curing process. In the preparation process, the epoxy resin and hardener were mixed in a beaker at a one-to-one ratio. Then, 5, 10, 15, and 20 wt.% of the SSPCM was added to the mixture. The thermal properties and chemical properties of epoxy resin with SSPCM were analyzed from scanning electron microscopy, differential scanning calorimetry, thermal gravimetric analysis, and universal testing machine analyzer. From the analysis, we determined that the prepared epoxy resin with SSPCM has heat storage capacity and high thermal conductivity, compared with the epoxy resin.

**Keywords:** epoxy resin; SSPCM; xGnP; heat storage; thermal properties

### 1. Introduction

The latent thermal energy storage system (LTES) using phase change materials (PCMs) is one of the most preferred forms of energy storage, which can provide high energy storage capacity, and isothermal operating characteristics.[1–4] In the LTES, PCMs are used to balance temporary temperature alternations, and to store energy in several practical application areas, from electronics to the automobile industry, and also buildings.[5–7] Latent heat storage material has a higher heat storage density than sensible heat storage material.[8] PCMs have received attention for various applications in solar heating systems,[9–11] and building energy conservation systems,[12–14] and the PCMs provide high amounts of thermal energy, without the large structural mass associated with sensible heat storage.[15–17] Also, PCM can reduce building energy consumption, through reducing heating and cooling peak load, and it has a positive effect on the indoor temperature.[18] PCM is divided into three kinds, which are organic PCM, inorganic PCM, and eutectic PCM. These are used as storage media in latent thermal energy storage, which can be classified into two major categories: organic and inorganic compounds. Inorganic PCMs include salt hydrates, salts, metals, and alloys; whereas organic PCMs are comprised of hexadecane, octadecane, paraffin

---

\*Corresponding author. Email: [skim@ssu.ac.kr](mailto:skim@ssu.ac.kr)

and fatty acids/esters, etc. Also, eutectic PCMs mean mixtures of PCM which are made by composition of organic-organic, organic-inorganic, and inorganic-inorganic PCMs. Because organic PCMs have various advantages, most researchers have studied organic PCM in their research. Among the investigated PCMs, organic PCMs have been widely used in thermal energy storage applications, due to their large latent heat, and proper thermal characteristics, such as little or no super cooling, low vapor pressure, good thermal and chemical stability, and self-nucleating behavior.[19–21]

However, PCM has a problem, which is liquid leakage, after the change from solid state to liquid state. In order to overcome the leakage of liquid, PCM usually needs to be encapsulated in containers that increase the extra cost. In recent years, microencapsulated PCMs [22,23] and shape-stabilized PCMs [24] have been studied, to solve the liquid leakage problems in the solid–liquid phase change process.[25] Also, this kind of PCM is not easy to be directly used in practical solar thermal applications, because of their low thermal conductivity, etc. As a result, many microencapsulated PCMs have been developed to overcome these difficulties.[2,3] Therefore, in previous research, we prepared *n*-hexadecane based shape stabilized phase change material (SSPCM) with Exfoliated graphite nanoplatelets (xGnP) by the vacuum impregnation method, to prevent the leakage of liquid state of PCM, and enhanced the low thermal conductivity of PCM. The xGnP, usually produced from graphite intercalated compounds, are particles consisting of several layers of graphene sheets. They have a very high aspect ratio, comparable to that of carbon nanotubes. Drzal et al. successfully developed a microwave exfoliation and ultrasonic grinding process to prepare exfoliated graphite nanoplatelets of different sizes and surface areas. These particles have been incorporated into different thermoplastic, thermoset materials, and PCMs, to improve the electrical, thermal, and mechanical properties of nanocomposites.[26,27]

Recently, wood flooring is mainly used in the radiant floor heating system, because of its hardness, durability, fire stability, and good appearance. Epoxy resins are used when these wood floors are installed in a building.[28] In the modern polymer industry, epoxy resins have been widely applied industrially for surface coatings, adhesives, painting materials, potting, composites, encapsulants for semiconductors, insulating materials for electric devices, laminates, etc.,[29–31] because of their excellent characteristics of moisture, low toughness, solvent and chemical resistance, low shrinkage on cure, superior electrical and mechanical resistance properties, and good adhesion to many substrates.[32] This paper deals with how the *n*-hexadecane based SSPCM with xGnP and sodium lauryl sulfate (SLS) affects the thermal properties and chemical properties of epoxy resin, using scanning electron microscopy (SEM), differential scanning calorimetry (DSC), and thermal gravimetric analysis (TGA). Also, we analyzed the bonding strength of SSPCM/epoxy resin composites through universal testing machine (UTM) analysis. Finally, we evaluated the effect of xGnP in SSPCM/epoxy resin composites, through thermal analysis and mechanical analysis. In addition, we evaluated the applicability of using composite epoxy resin in wood-based flooring using SSPCM. Also, we evaluated the applicability of using composite epoxy resin in wood-based flooring, using *n*-hexadecane based SSPCM with xGnP, for energy saving in building.

## 2. Experimental

### 2.1. Materials

In the experiment, we used *n*-hexadecane, which has a latent heat capacity of 254.7 J/g and melting point of 20.84 °C. This *n*-hexadecane was purchased from the Celsius

Korea Company in South Korea. The xGnP used was prepared from sulfuric acid intercalated expandable graphite (3772), and it was obtained from Asbury Graphite Mills, NJ in USA, by applying a cost and time effective exfoliation process initially proposed by Drzal's group.[33] The SSPCM was prepared from the above mentioned two materials by the vacuum impregnation method. The epoxy resin and hardener were purchased from SamChang Tech Co. Ltd in South Korea. A kind of amine is used as hardener in this experiment. The epoxy resin consists of a base with a hardener, and the mixture ratio is 1:1. This mixture ratio has been used in the actual construction filed. The SLS was obtained from DaeJung Chemicals & Metals Co. Ltd in South Korea.

## 2.2. Preparation

Firstly, the SSPCM was prepared through the vacuum impregnation method. The preparation process was as follows. One hundred grams of dried xGnP was put inside a filtering flask, and the air in the pore space of the xGnP was drawn out, by using a pump. Two hundred grams of liquid PCM was flowed into the flask, to fill the pore structure of xGnP. The vacuum process was continued for 90 min. After the penetrating process, the excess PCM remaining in the flask was removed through filtering process. Finally, the filtered samples were dried in a vacuum drier at 80 °C for 48 h. As the next process, the SSPCM/epoxy resin composites were prepared. The epoxy resin and hardener were mixed in a beaker at a one-to-one ratio. Then, 5, 10, 15, and 20 wt.% of the SSPCM were added to the mixture. Then, the SLS was added into the composite epoxy resin with SSPCM, and at this time, the amount of SLS was 10 wt.% of SSPCM. In fact, the SSPCM which was prepared by vacuum impregnation method may be occurred leakage of PCM during stirring process. Therefore, we used the SLS as surfactant for enhancing compatibility with epoxy resin and SSPCM. This mixture was continuously stirred at a rate of 1000 rpm for 10 min with a shearing stirrer at room temperature. Table 1 shows the contents of the mass ratio of SSPCM/epoxy resin composite. The composites were then cured in the mold for two days at room temperature.

## 2.3. Characterization techniques

The morphology and microstructure of SSPCM/epoxy resin composites were observed by means of scanning electron microscopy (SEM: JEOL JSM-6360A; [www.jeol.co.kr](http://www.jeol.co.kr)) at room temperature. A SEM with an accelerating voltage of 12 kV and working distance of 12 mm was used to collect the SEM images. The latent heat capacity and melting and freezing temperature of the composites were measured using differential

Table 1. Contents mass ratio of SSPCM, Epoxy resin, Hardener, and surfactant for the preparation of epoxy resin with SSPCM.

SSPCM wt.% of samples	SSPCM	Epoxy resin (g)	Hardener (g)	Surfactant (g)
0/wt.%	0	50	50	0
5/wt.%	5	47.5	47.5	0.5
10/wt.%	10	45	45	1
15/wt.%	15	42.5	42.5	1.5
20/wt.%	20	40	40	2

scanning calorimetry (DSC: Q 1000; [www.tainstruments.com](http://www.tainstruments.com)). Measurements were performed at a 5 °C/min heating and cooling rate, and a temperature range of -20 to 50 °C and 50 to -20 °C. The thermal durability of the prepared sample was determined using thermogravimetric analysis (TGA: TA Instruments, TGA Q 5000; [www.tainstruments.com](http://www.tainstruments.com)). Finally, the thermal conductivity of the prepared composites was measured, using a TCi thermal conductivity analyzer. The TCi developed by C-Therm ([www.ctherm.com](http://www.ctherm.com)) Technologies Ltd is a device for conveniently measuring the thermal conductivity of a small sample, by using the modified transient plane source method. Also, the tensile shear adhesive strength of samples were examined by means of a universal testing machine (UTM: WL2100; [www.tasatec.com](http://www.tasatec.com)), according to ASTM standards D 1002.

### 3. Results and discussion

#### 3.1. Microstructure analysis of epoxy resin with SSPCM

Figure 1 shows SEM images of the epoxy resin and its composites with SSPCM. Figure 1(a) shows the epoxy resin, and its microstructure shows that the epoxy resin has a solid surface, as compared with the others. We confirmed that the epoxy resin with SSPCM has xGnP nanoparticles in the SEM images. This means that the xGnP

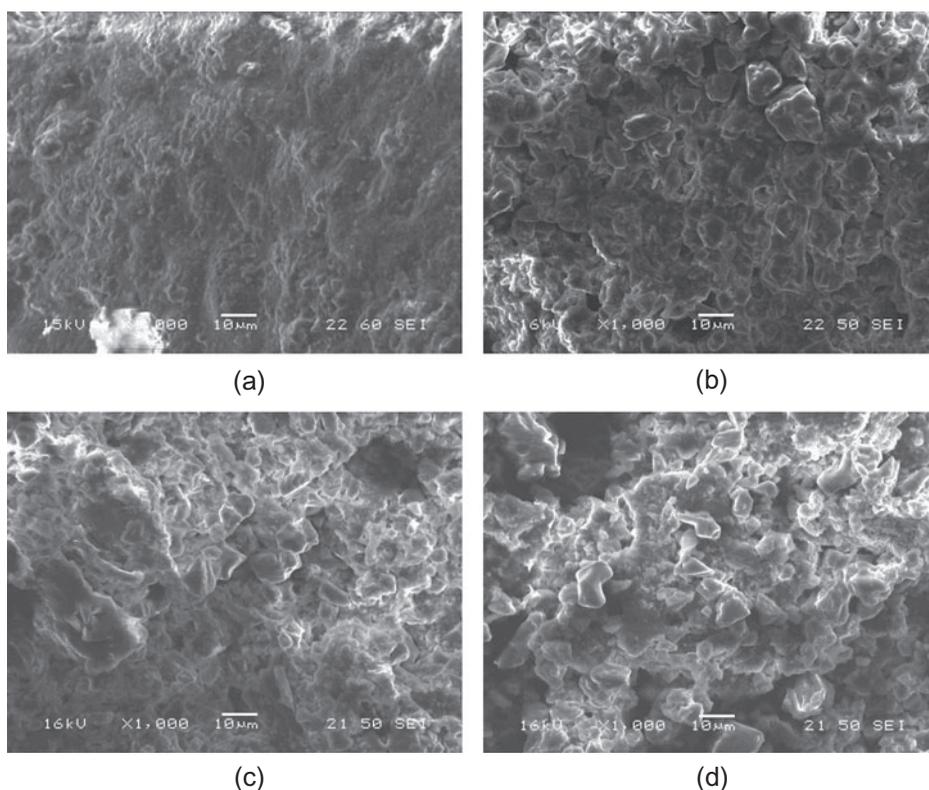


Figure 1. Microstructure of (a) epoxy resin and epoxy resin, with (b) 5 wt.%, (c) 10 wt.%, and (d) 20 wt.% of SSPCM.

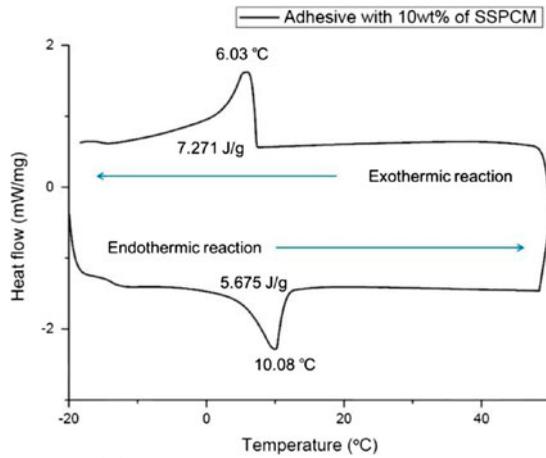
was well dispersed into the structure of the epoxy resin. However, the epoxy resin with more xGnP had weak cohesiveness among the xGnP of SSPCM, because the epoxy resin with low content of SSPCM had more solid surface, in comparison with the other adhesive composites with high SSPCM content. It means that the adhesives with lower loaded SSPCM have more bonding strength. Through SEM analysis, we confirmed that the SSPCM that contained *n*-hexadecane and xGnP was well dispersed into the structure of epoxy resin, and it led the heat performance of the epoxy resin.

### 3.2. Thermal properties analysis of epoxy resin with SSPCM

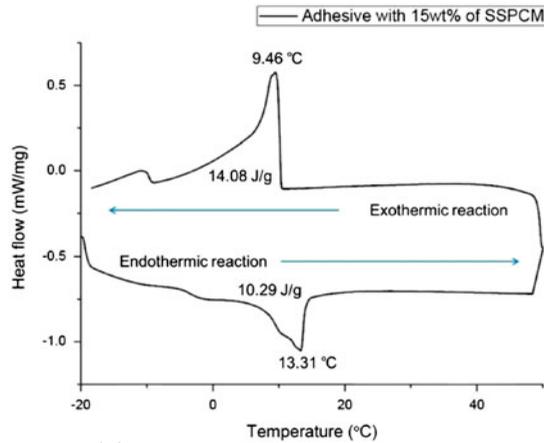
The DSC curves of epoxy resin and its composites with SSPCM, and thermal properties analysis during heating and freezing are shown in Figure 2 and Table 2. In the DSC graphs, the epoxy resin with 5, 10, 15, and 20 wt.% of SSPCM melts at 5.75, 10.08, 13.31, and 14.07 °C, respectively and these samples freeze at 1.92, 6.03, 9.46, and 10.12 °C, respectively. This shows that the adhesive composite more loaded with SSPCM has a higher phase change temperature, in comparison with adhesive composites with low-loaded SSPCM. The prepared hexadecane based SSPCM has 21.8 °C of melting temperature, and 14.6 °C of freezing point. Its latent heat capacity is 96.4 J/g at heating, and 94.8 J/g at freezing. In comparison with SSPCM, the prepared adhesive composites have lower phase change temperature, due to the influence of epoxy resin and surfactant. Also, the phase change temperature of adhesive with SSPCM is lower than in previous research, in which research was carried out on the composition of pure *n*-hexadecane and epoxy resin. This shows that adhesive composite with high amounts of *n*-hexadecane has the higher phase change temperature. The epoxy resin with 5, 10, 15, and 20 wt.% of SSPCM have 1.565, 5.675, 10.29, and 18.25 J/g at heating, and 2.965, 7.271, 14.08, and 16.07 J/g at freezing. Therefore, to acquire more heat storage properties and a higher phase change temperature, more loaded SSPCM has to combine with the epoxy resin. And, we analyzed the enthalpy of the adhesives with SSPCM. Its graph is shown as Figure 3. As shown in the graph, we confirmed that the enthalpy slope is steep at the phase change range because of the effect of latent heat capacity of SSPCM in the samples. In case of the adhesive with 20 wt.% of SSPCM showed highest steep curve in the enthalpy graph compared to others. However, all samples exclude the adhesive with 20 wt.% of SSPCM showed linear graph. It means that loading more 20 wt.% of SSPCM influence the effective thermal performance to the sample. Also, we determined that the adhesive with high-loaded SSPCM showed high total enthalpy. As a result, the adhesive composite with high-loaded SSPCM shows a high latent heat storage property. However, the latent heat capacities of each epoxy resin with SSPCM are lower than its calculated latent heat capacity. This is caused by bonding of the epoxy resin, SSPCM, and SLS. After study, we needed to prepare the adhesive with high latent heat capacity.

### 3.3. Thermogravimetric analysis

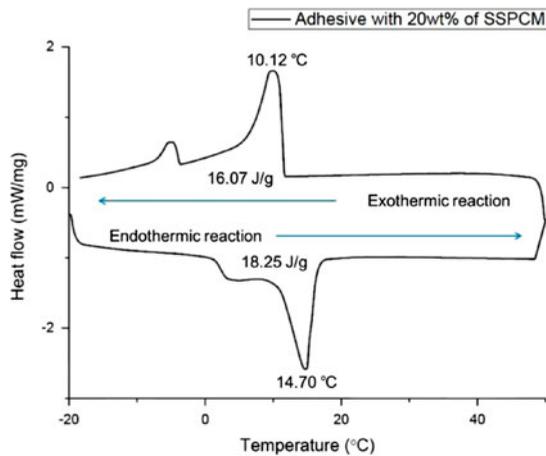
Figure 4 shows thermogravimetric analysis of the epoxy resin with hexadecane based SSPCM. In the graphs, the main peak of the epoxy resin occurred at 339.60 °C. The first peak of derivative weight of epoxy resin with 5, 10, 15, and 20 wt.% of SSPCM occurred at 163.78, 152.09, 141.60, and 144.01 °C, respectively. This result shows that the adhesive composite with high-loaded SSPCM has a lower first peak temperature. It shows the oxidation peak of the *n*-hexadecane in SSPCM, because the used



(a) DSC graph of adhesive with 10wt% of SSPCM.



(b) DSC graph of adhesive with 15wt% of SSPCM.



(c) DSC graph of adhesive with 20wt% of SSPCM.

Figure 2. DSC graph of epoxy resin, with (a) 10 wt.%, (b) 15 wt.%, and (c) 20 wt.% of SSPCM.

Table 2. Heat storage properties of epoxy resin with SSPCM.

PCM samples	Melting point (°C)	Freezing point (°C)	Latent heat (J/g)	
			Solid-liquid melting	Liquid-solid freezing
Epoxy resin with 5 wt.% of SSPCM	5.75	1.92	1.565	2.965
Epoxy resin with 10 wt.% of SSPCM	10.08	6.03	5.675	7.271
Epoxy resin with 15 wt.% of SSPCM	13.31	9.46	10.29	14.08
Epoxy resin with 20 wt.% of SSPCM	14.70	10.12	18.25	16.07

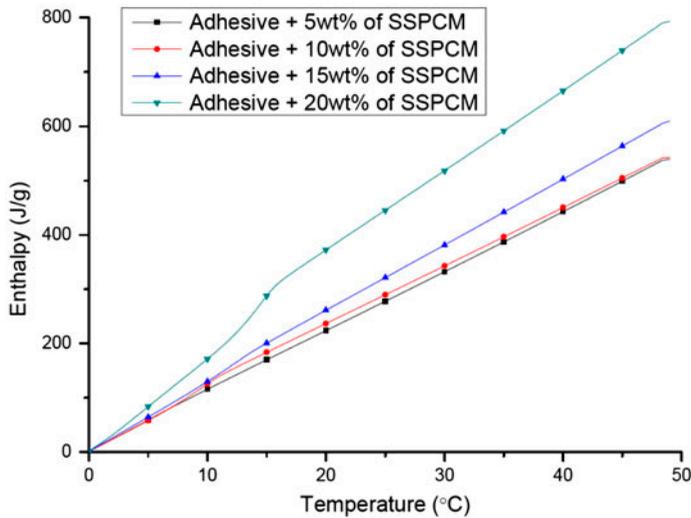


Figure 3. Enthalpy graph of epoxy resin with SSPCM.

*n*-hexadecane has lower thermal resistant properties, compared with epoxy resin. Also, we confirmed that the high loaded xGnP helped heat absorption of the adhesive composites, due to its high thermal conductivity. From the result of the second peak of derivative weight, epoxy resin showed 339.60 °C and adhesive with 5, 10, 15, and 20 wt.% of SSPCM showed 346.75, 354.25, 350.16, and 353.47 °C, respectively. In this graph, epoxy resin with SSPCM has a higher second peak temperature, compared with adhesive composite without SSPCM. We determined also that xGnP affected the thermal durability of samples. However, the final mass loss of the adhesive composites with SSPCM is higher than epoxy resin, because the *n*-hexadecane in SSPCM has low-thermal durability properties. Therefore, the adhesive composites with high-loaded SSPCM have high-mass loss. This result is shown in Table 3.

### 3.4. Thermal conductivity analysis

The thermal conductivity analysis of epoxy resin composites with SSPCM is shown in Figure 5. In the analysis, the thermal conductivity of epoxy resin shows 1.092 W/mK, and adhesive composites with 5, 10, 15, and 20 wt.% of SSPCM show 1.099, 1.133, 1.409, and 1.612 W/mK, respectively. As the amounts of xGnP in SSPCM increased,

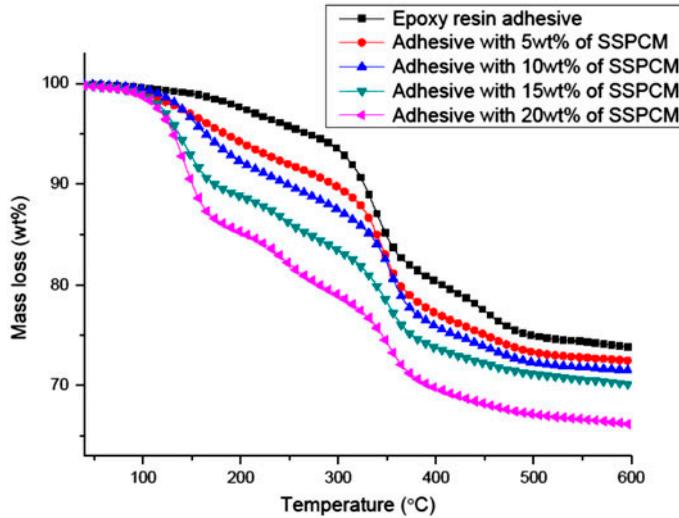


Figure 4. Thermogravimetric analysis of epoxy resin with SSPCM.

Table 3. Thermogravimetric analysis of the epoxy resin with SSPCM.

PCM samples	First peak of derivative weight (°C)	Second peak of derivative weight (°C)	Mass loss (wt.%)
Epoxy resin	—	339.60	26.19
Epoxy resin with 5 wt.% of SSPCM	163.78	346.75	27.54
Epoxy resin with 10 wt.% of SSPCM	152.09	354.25	28.54
Epoxy resin with 15 wt.% of SSPCM	141.60	350.16	29.85
Epoxy resin with 20 wt.% of SSPCM	144.01	353.47	33.79

the thermal conductivity of samples also increased. This means that xGnP led to an enhancement of thermal conductivity. Finally, the adhesive composite with 20 wt.% of SSPCM has a nearly 150% increase of thermal conductivity, compared with epoxy resin. Through the thermal conductivity analysis, we determined that the thermally enhanced adhesive composite is more useful, than previous applied in its field.

### 3.5. Analysis of tensile shear adhesive strength

To measure the tensile shear adhesive strength of epoxy resin with SSPCM bonding strength, we performed a test with a UTM (WL2100), which satisfied the ASTM D 1002 (Standard Test Method for Apparent Shear strength of Single Lap Joint Adhesively Bonded Metal Specimens by Tension Loading). Specimen for analyzing tensile shear adhesive strength is presented in the following sentence. Stainless steel plates with dimensions of 101.6 mm × 25.4 mm were used to perform the single lap shear test for two different composites. The thickness of the composites layer was 1.2 mm because the adhesives were installed normally at a 1.0–1.5 mm thickness. The acrylic plastic was used to form a uniform adhesives layer. Figure 6 shows the change of the tensile shear adhesive strength with increasing loading contents of SSPCM. The tensile

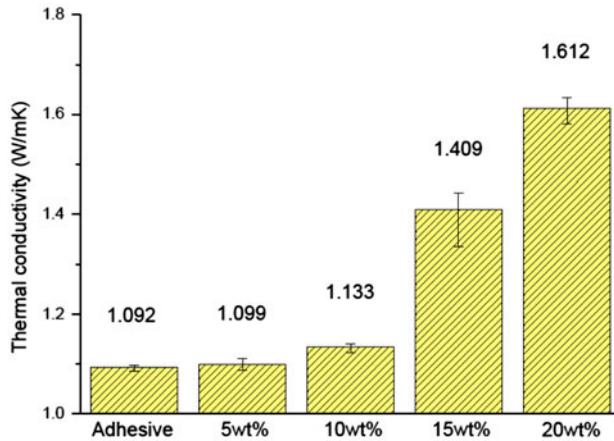


Figure 5. Thermal conductivity of adhesive composites with SSPCM.

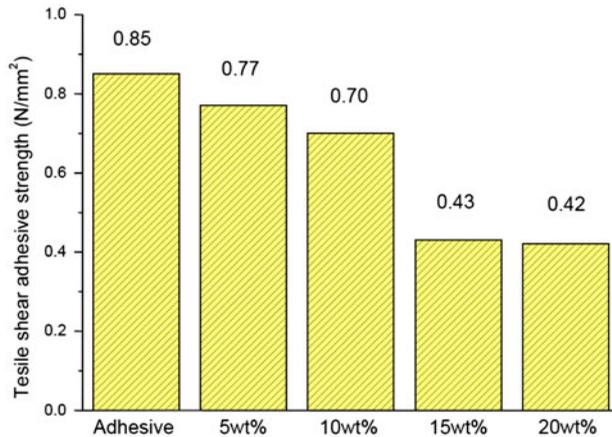


Figure 6. Tensile shear adhesive strength of epoxy resin with SSPCM.

shear adhesive strength of epoxy resin shows the value of  $0.85 \text{ N/mm}^2$ , whereas the tensile shear adhesive strength of the adhesive with 5, 10, 15, and 20 wt.% of SSPCM shows 0.77, 0.70, 0.43, and  $0.42 \text{ N/mm}^2$ , respectively. This shows that the adhesive with high loaded SSPCM has weak tensile shear adhesive strength. In the experiment, the reduction of tensile shear adhesive strength is small by the adhesive 10 wt.% of SSPCM; however, the samples with over 10 wt.% of SSPCM show nearly half the value of tensile shear adhesive strength, compared with pure epoxy resin. As a result, we determined that the reduction of tensile shear adhesive strength of epoxy resin with SSPCM was caused by the loading of SLS and *n*-hexadecane in SSPCM.

#### 4. Conclusion

Epoxy resins have been widely applied industrially for surface coatings, adhesives, painting materials, potting, composites, encapsulants for semiconductors, insulating materials for electric devices laminates, etc., because of their excellent characteristics of

moisture, low toughness, solvent and chemical resistance, low shrinkage on cure, superior electrical and mechanical resistance properties, and good adhesion to many substrates. In this experiment, we analyzed how the *n*-hexadecane based SSPCM with xGnP and SLS affects the thermal properties and chemical properties of epoxy resin, using SEM, DSC, TGA, and UTM analyzer. As a result, the SSPCM was well dispersed in the structure of epoxy resin, which was confirmed from SEM analysis. We confirmed from DSC analysis that the adhesive composite with high loaded SSPCM shows a high latent heat storage property. From the TGA analysis, we revealed that the xGnP gave thermal durability to the prepared samples; also the epoxy resin with SSPCM shows higher thermal conductivity, compared with pure epoxy resin, because of the xGnP effect. Finally, from the tensile shear adhesive strength analysis, the reduction of tensile shear adhesive strength of epoxy resin with SSPCM was caused by the loading of SLS and *n*-hexadecane in SSPCM. However, the difference of reduction is small. Consequently, we expect the prepared epoxy resin with SSPCM to be useful in applications in wood flooring system or other application fields, due to its high thermal properties, by the *n*-hexadecane and xGnP in SSPCM.

### Funding

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea Government (MEST) [grant number 2013-030588]; the Human Resources Development Program [grant number 20124010203160] of the Korea Institute of Energy Technology Evaluation and Planning (KETEP) grant funded by the Korea Government Ministry of Trade, Industry and Energy.

### References

- [1] Pincemin S, Olives R, Py X, Christ M. Highly conductive composites made of phase change materials and graphite for thermal storage. *Solar Energy Mater. Sol. Cells*. 2008;92:603–613.
- [2] Alkan C, Sari A, Karaipekli A, Uzun O. Preparation, characterization, and thermal properties of microencapsulated phase change material for thermal energy storage. *Sol. Energy Mater. Sol. Cells*. 2009;93:143–147.
- [3] Bayés-García L, Ventolà L, Cordobilla R, Benages R, Calvet T, Cuevas-Diarte MA. Phase change materials (PCM) microcapsules with different shell compositions: preparation, characterization and thermal stability. *Sol. Energy Mater. Sol. Cells*. 2010;94:1235–1240.
- [4] Pan L, Tao Q, Zhang S, Wang S, Zhang J, Wang S, Wang Z, Zhang Z. Preparation, characterization and thermal properties of micro-encapsulated phase change materials. *Sol. Energy Mater. Sol. Cells*. 2012;98:66–70.
- [5] Fan L, Khodadadi JM. Thermal conductivity enhancement of phase change materials for thermal energy storage: a review. *Renew. Sust. Energy Rev*. 2011;15:24–46.
- [6] Zalba B, Marin JM, Cabeza LF, Mehling H. Review on thermal energy storage with phase change: materials, heat transfer analysis and applications. *Appl. Therm. Eng.* 2003;23:251–283.
- [7] Ye W, Zhu D, Wang N. Fluid flow and heat transfer in a latent thermal energy unit with different phase change material (PCM) cavity volume fractions. *Appl. Therm. Eng.* 2012;42:49–57.
- [8] Li M, Wu Z, Chen M. Preparation and properties of gypsum-based heat storage and preservation material. *Energy Build.* 2011;43:2314–2319.
- [9] Saman W, Bruno F, Halawa E. Thermal performance of PCM thermal storage unit for a roof integrated solar heating system. *Sol. Energy*. 2005;78:341–349.
- [10] Ait Hammou ZA, Lacroix M. A hybrid thermal energy storage system for managing simultaneously solar and electric energy. *Energy Convers. Manage.* 2006;47:273–288.
- [11] Shukla A, Buddhi D, Sawhney RL. Solar water heaters with phase change material thermal energy storage medium: a review. *Renew. Sust. Energy Rev*. 2009;13:2119–2125.

- [12] Dincer I. On thermal energy storage systems and applications in buildings. *Energy Build.* 2002;34:377–388.
- [13] Tyagi VV, Buddhi D. PCM thermal storage in buildings: a state of art. *Renew. Sust. Energy Rev.* 2007;11:1146–1166.
- [14] Zhang YP, Zhou GB, Lin KP, Zhang QL, Di HF. Application of latent heat thermal energy storage in buildings: state-of-the-art and outlook. *Build Environ.* 2007;42:2197–2209.
- [15] Stritih U. Heat transfer enhancement in latent heat thermal storage system for buildings. *Energy Build.* 2003;35:1097–1104.
- [16] Bentz DP, Turpin R. Potential applications of phase change materials in concrete technology. *Cem. Concr. Compos.* 2007;29:527–532.
- [17] Fang XM, Zhang ZG. A novel montmorillonite-based composite phase change material and its applications in thermal storage building materials. *Energy Build.* 2006;38:377–380.
- [18] Li H, Liu X, Fang G. Preparation and characteristics of *n*-nonadecane/cement composites as thermal energy storage materials in buildings. *Energy Build.* 2010;42:1661–1665.
- [19] Zhang Z, Fang X. Study on paraffin/expanded graphite composite phase change thermal energy storage material. *Energy Convers. Manage.* 2006;47:303–310.
- [20] Zhang Y, Ding J, Wang X, Yang R, Lin K. Influence of additives on thermal conductivity of shape-stabilized phase change material. *Sol. Energy Mater. Sol. Cells.* 2006;90:1692–1702.
- [21] Liu X, Liu H, Wang S, Zhang L, Cheng H. RETRACTED: preparation and thermal properties of form stable paraffin phase change material encapsulation. *Energy Convers. Manage.* 2006;47:2515–2522.
- [22] Cho JS, Kwon A, Cho CG. Microencapsulation of octadecane as a phase-change material by interfacial polymerization in an emulsion system. *Colloid Polym. Sci.* 2002;280:260–266.
- [23] Schossig P, Henning HM, Gschwander S, Haussmann T. Micro-encapsulated phase change materials integrated into construction materials. *Sol. Energy Mater. Sol. Cells.* 2005;89:297–306.
- [24] Ye H, Ge XS. Preparation of polyethylene–paraffin compound as a form-stable solid–liquid phase change material. *Sol. Energy Mater. Sol. Cells.* 2003;64:37–44.
- [25] Cheng W, Zhang R, Xie K, Liu N, Wang J. Heat conduction enhanced shape-stabilized paraffin/HDPE composite PCMs by graphite addition: preparation and thermal properties. *Sol. Energy Mater. Sol. Cells.* 2010;94:1636–1642.
- [26] Kalaitzidou K, Fukushima H, Drzal LT. Multifunctional polypropylene composites produced by incorporation of exfoliated graphite nanoplatelets. *Carbon.* 2007;45:1446–1452.
- [27] Xiang J, Drzal LT. Investigation of exfoliated graphite nanoplatelets (xGnP) in improving thermal conductivity of paraffin wax-based phase change material. *Sol. Energy Mater. Sol. Cells.* 2011;95:1811–1818.
- [28] Athienitis AK, Chen TY. Experimental and theoretical investigation of floor heating with thermal storage. *ASHRAE Trans.* 1993;99:1049–1057.
- [29] Wang CS, Liao JK. Synthesis of high purity *o*-cresol formaldehyde novolac epoxy resins. *Polym. Bull.* 1991;25:559–565.
- [30] Nakamura Y, Yamaguchi M, Okubo M, Matsumoto T. Effects of particle size on mechanical and impact properties of epoxy resin filled with spherical silica. *J. Appl. Polym. Sci.* 1992;45:1281–1289.
- [31] Kinjo N, Ogata M, Nishi K, Kaneda A. Epoxy molding compounds as encapsulation materials for microelectronic devices. *Adv. Polym. Sci.* 1989;88:1–48.
- [32] Sun D, Yao Y. Synthesis of three novel phosphorus-containing flame retardants and their application in epoxy resins. *Polym. Degrad. Stab.* 2011;96:1720–1724.
- [33] Kim S, Drzal LT. High latent heat storage and high thermal conductive phase change materials using exfoliated graphite nanoplatelets. *Sol. Energy Mater. Sol. Cells.* 2009;93:136–142.