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THERMAL ENERGY STORAGE PROPERTIES OF FORM-STABLE PARAFFIN/RECYCLE BLOCK CONCRETE COMPOSITE PHASE CHANGE MATERIAL

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Abstract

In this research, the form-stable composite phase change material was developed by incorporating paraffin on recycle block concrete (RB) through the vacuum impregnation method. The compatibility and thermal properties of RB impregnated with paraffin ranging from 0-35 wt% were characterized by Fourier transform infrared spectroscopy (FTIR) and differential scanning calorimetry (DSC). Results revealed that paraffin was uniformly absorbed in RB with a good physical compatibility. The optimum adsorption ratio of paraffin in RB was 25 wt% which produced phase transition temperature of 52.85 ^{O}C and latent heat of 30.98 J/g. The obtained form-stable paraffin/RB composite PCM had proper latent heat and phase transition temperature and can be applied for thermal energy storage applications such as solar heating and cooling in buildings.

Keywords: Phase change material (PCM), Paraffin, Recycled block concrete; Thermal energy storage.

1. Introduction

Thermal energy storage is one of the most crucial energy storage that can improve energy conservation, management and utilization [1-3]. Thermal energy can be

Nomenclatures

ΔH	Latent Heat (J/g)

Abbreviations

DSC	Differential Scanning Calorimetry
FTIR	Fourier Transform Infrared Spectroscopy
PCM	Phase Change Material
RB	Recycle Block Concrete

stored as latent heat, sensible heat and thermochemical heat. Among these, latent heat storage by using phase change materials (PCMs) is a promising method due to high amount of absorb and release latent heat during a phase change process between solid-solid or solid-liquid phase over a narrow temperature range [1, 4].

PCMs have been applied in various applications such as energy efficient building materials [5, 6] and solar energy storage [7]. However, leakage of PCMs during solid-liquid phase change process limits its application. To overcome this problem, many researchers have opted to prepare form-stable composite PCMs by compounding PCMs with porous materials [1, 8]. PCMs can be divided into two types i.e. inorganic and organic PCMs. The inorganic PCM such as salt hydrate provided high energy storage and high thermal conductivity. However, they have some limitation for applications i.e. large super cooling degree, segregation during phase change under thermal cycling and strong corrosion [9]. Compared with inorganic PCMs, organic PCMs have been widely used due to their outstanding properties such as non toxicity, low or no super cooling and good thermal reliability [10].

Recently, the form-stable composite organic PCM prepared by impregnation of paraffin based organic PCMs into porous materials has attracted attention [9, 11-13] due to the outstanding properties of paraffin i.e. high latent heat capacity, chemically inert, noncorrosive and inexpensive. Sun et al. [9] prepared paraffin/calcined diatomite form-stable composite PCM and reported that the latent heat and phase transition temperature of composite PCMs were 89.54 J/g and 33.04 ^{o}C, respectively. Li et al. [14] investigated the thermal storage and thermal reliability of expanded perlite impregnated with paraffin composite. The form-stable composite PCM showed a good thermal stability and reliability suitable for thermal energy storage in building applications. A number of building materials such as diatomite [12, 14, 15], expanded perlite [16], expanded graphite [16], silica fume [17], vermiculite [16] and kaolin [18] have been used as a support for producing a form-stable PCMs. Recently, the recycling of waste from building structure for use as building materials is receiving a lot of attention. Posi et al. [19] used RB to produce lightweight geopolymer concrete. The compressive strength and density were in the range of 1.0–16.0 MPa and 860–1400 kg/m^3, respectively. It could be used as lightweight geopolymer concrete for wall and partition.

Currently there is no information about using building material waste as a support for shape stabilized PCMs. In this research, the RB impregnated with paraffin was prepared as a novel form-stable composite PCMs. The microstructure, thermal properties and compatibility of the prepared form-stable composite PCMs were characterized

2. Experimental Works

2.1. Materials

Paraffin wax was supplied from Chemipan Co. Ltd, Thailand. Recycle block concrete (RB) were crushed and passed through a 3.36 mm sieve. The average size of RB was 2.38 mm. The chemical compositions of RB were characterized by X-ray fluorescence (XRF, Bruker model, S8 Tiger) before using and summarized in table 1.

Table 1. Chemical Compositions of Recycle Block Concrete (RB) (%wt).

SiO_2	CaO	SO_3	Al_2O_3	Fe_2O_3	K_2O	MgO	Na2O	TiO_2	Other
45.10	26.10	3.72	3.14	1.20	0.90	0.40	0.14	0.13	19.17

The RB was firstly cleaned by methyl alcohol for 24 hr. After that it was dried at 120 °C for 1 hr to remove solvent. The form-stable composite PCMs paraffin/RB was prepared using impregnation method. The vacuum impregnation set up is shown in Figure 1. The paraffin wax and RB particles at different weight ratios of 15:85, 20:80, 25:75, 30:70, 35:65 were placed inside a flask equipped with vacuum pump and overhead stirrer. The vacuum pump was used to evacuate air from porous material. The evacuation process at the vacuum pressure of 80 kPa was continued for 30 min. The flask containing paraffin and RB were heated at 80°C for 30 min. The melted paraffin was impregnated in RB by continuous mixing with overhead stirrer at 120 rpm for 30 min. Finally, the vacuum pump was turned off and air was allowed to enter the flask again to force paraffin to penetrate into the pore space of RB. The obtained form-stable composite PCMs were cooled down to room temperature for characterization.

2.2. Testing and characterizations

The thermal properties of paraffin/RB samples were examined by differential scanning calorimetry (Pyris Diamond, DSC Perkin Elmer). The non-isothermal scanning experiments were performed at a heating rate of 10 ºC/min. A full temperature scan was performed between 25 ºC and 100 ºC under nitrogen atmosphere at a flow rate of 50 ml/min. The optimal mix proportion of paraffin and RB was characterized by adapted method from literature work [13]. The form stable PCM was heated at a temperature slightly higher than the melting point of PCM. The samples were placed on glass substrate and heated at 80 ^{o}C for 4 hr in order to observe the leakage of melted paraffin on substrate. No leakage of PCM indicated that the ratio of PCM and support material was suitable. The no leakage of PCM indicated that the ratio of PCM and support material was suitable. The morphology of paraffin/RB samples after heated at 80 ^{o}C for 4 hr was recorded by a digital camera (Power shot SX10IS, Canon). Attenuated total reflection infrared (FTIR-ATR) spectra of all samples were acquired by Bruker Tensor 27 spectrometer. All spectra were taken with 64 scans at a resolution of 4 cm^{-1} and a spectral range of 4000–650 cm^{-1}.

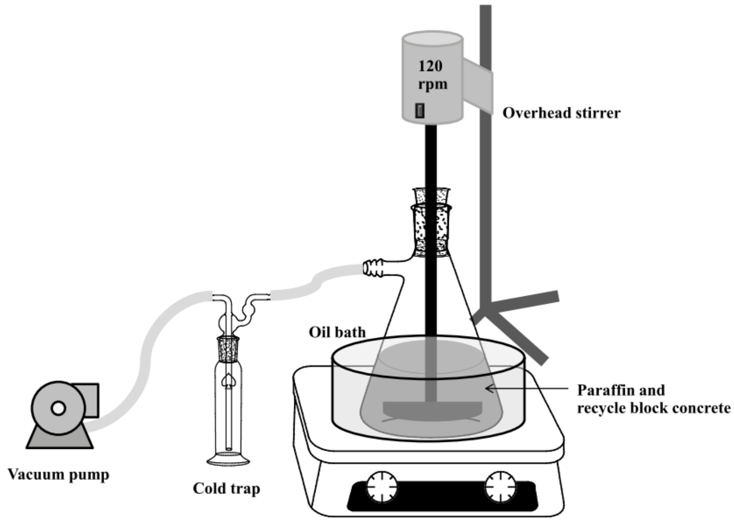

Fig. 1. Schematic of vacuum impregnation system.

3. Results and Discussions

3.1. Thermal properties of form-stable paraffin and RB composite PCMs

DSC is an accepted as suitable method for measuring the thermal energy storage properties of a PCM since it prevents uncertainty about phase change temperatures and latent heat [1]. Figure 2 shows DSC thermograms of paraffin and form-stable paraffin/RB composite PCMs. The phase change temperatures of all samples were evaluated from the endothermic peaks between 50.54 to 53.10 ^{o}C. The phase change temperatures of form-stable paraffin/RB composites PCM were slightly shifted. This was probably due to the physical interaction between paraffin and RB. The latent heat of samples was observed from the area under endothermic peaks which ranged from 17.13 to 39.37 J/g. The latent heat increased with increasing paraffin content. The enhancement of latent heat implied the increasing performance of thermal energy storage [5].

3.2. The optimum proportion of form-stable paraffin and RB composite PCM

Generally, the higher the mass ratio of paraffin to support material, the larger the latent heat of paraffin composite PCMs [20, 21]. However, excess of paraffin mixture impregnated in support material may cause the leakage during the melting process. The experiment defined the maximum adsorption ratio without any leakage occurring during the process of melting as the optimum adsorption ratio [9]. The optimum of paraffin impregnated in RB were evaluated following Eq. (1).

$$\Delta H_{Paraffin/RB} = \%\ \text{Paraffin contained} \times \Delta H_{Paraffin} \qquad (1)$$

where $\Delta H_{Paraffin/RB}$ is the latent heat of form-stable paraffin/RB composite PCM (J/g), % Paraffin is the ratio of paraffin in form-stable paraffin/RB composite and $\Delta H_{Paraffin}$ is latent heat of pure paraffin (J/g). The latent heat of all samples are shown in Figure 3. The theoretical latent heat increased as a function of paraffin content. The experimental results at paraffin contents range of 15-25 wt% showed a linear relationship between the latent heat value and the paraffin loading. The actual latent heat values of form-stable paraffin/RB composite PCM were slightly lower than theoretical values. It is due to the physical interaction between the PCM and inner surface of support. The similar observation was reported by Karaipekli and Sari [8]. This suggested that the paraffin content at 25 wt% was optimal for preparing form-stable composite PCM without leakage. The latent heat of the RB impregnated with 25 wt% paraffin was 30.98 J/g. This was in the same range with previous reports about the form stable PCM i.e. xylitol penta palmitate ester/gypsum (37.14 J/g), and xylitol penta stearate ester/cement (24.01 J/g), capric and myristic/vermiculite (27 J/g) [16] and erythitol tetra palmitate/cement (38.1 J/g) [8].

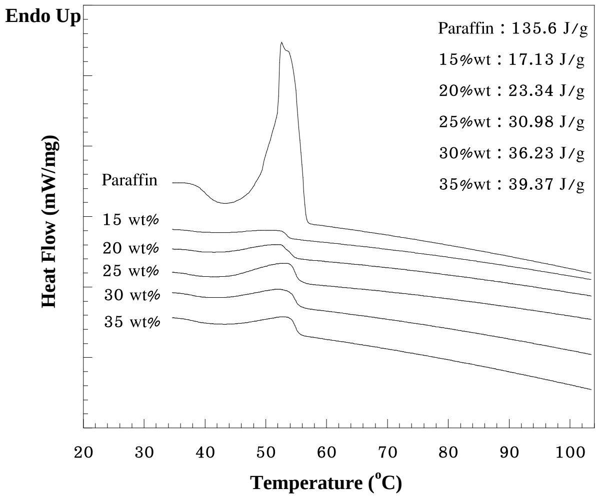

Fig. 2. DSC curves of form-stable paraffin/RB composite PCM at paraffin contents: (a.) 15 wt% paraffin, (b.) 20 wt% paraffin, (c.) 25 wt% paraffin, (d.) 30 wt% paraffin and (e.) 35 wt% paraffin.

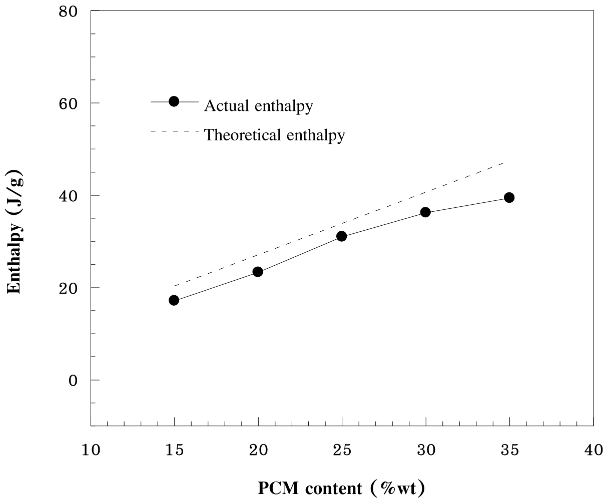

Fig. 3. Latent heat of form-stable paraffin/RB composite PCM.

3.3. Morphologies of form-stable paraffin/RB composite PCM

The maximum ratio of paraffin and RB was also confirmed from morphology. Figure 4 shows the images of form-stable paraffin/RB composite PCMs after heated at 80 ^{o}C for 4 hr.

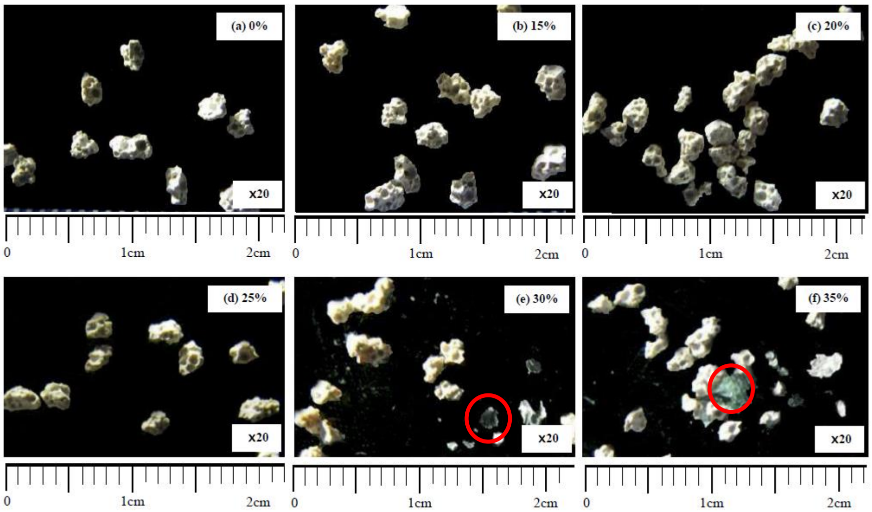

Fig. 4. Images of RB impregnated with paraffin at various paraffin contents.

For RB impregnated with 30-35wt% paraffin, there were excess paraffin adhered to the glass substrate indicating the leakage of paraffin during melting process. Based on the results, it was concluded that the optimum adsorption ratio of paraffin in RB was 25 wt%. This result was consistence with calculated latent heat from DSC.

3.4. Compatibility of Form-Stable Paraffin/RB Composite PCM

The form stable PCMs were characterized by FT-IR spectroscopy to observe the chemical compatibility between the paraffin and RB. FTIR transmission spectra of the paraffin, RB and form stable paraffin/RB composite are illustrated in table 2 and Figure. 5 (a-c). For RB's spectra depicted in Figure 5(a), the peaks at 1413, 1621 and 3552 cm^{-1} were assigned to carbonate group (CO_3^{2-}) and O-H group, respectively. Two characteristic peak regarding to S-O and Si-O groups were found at 1141 and 957, respectively [8, 22]. The characteristic peaks of paraffin at 723, 1462, 2843 and 2911 cm^{-1} were attributed to CH2 and CH3 groups [8] as shown in Figure 5(b). The characteristic peaks of both paraffin and RB were found in form-stable 25 wt% paraffin/RB composite PCM spectra, as shown in Figure 5(c), and no new peak was observed, indicating no chemical interaction between paraffin and RB. When compared the FTIR results of the paraffin, RB and form-stable composite PCM, some little shifted of characteristic peaks were observed. These results implied the physical interactions such as capillary and surface tension forces between the components of composite PCM preventing the leakage of the paraffin during the heating process. The similar results were reported for form-stable PCMs based building materials [1], montmorillonite-based composite PCMs [23], granular PCM composites [24].

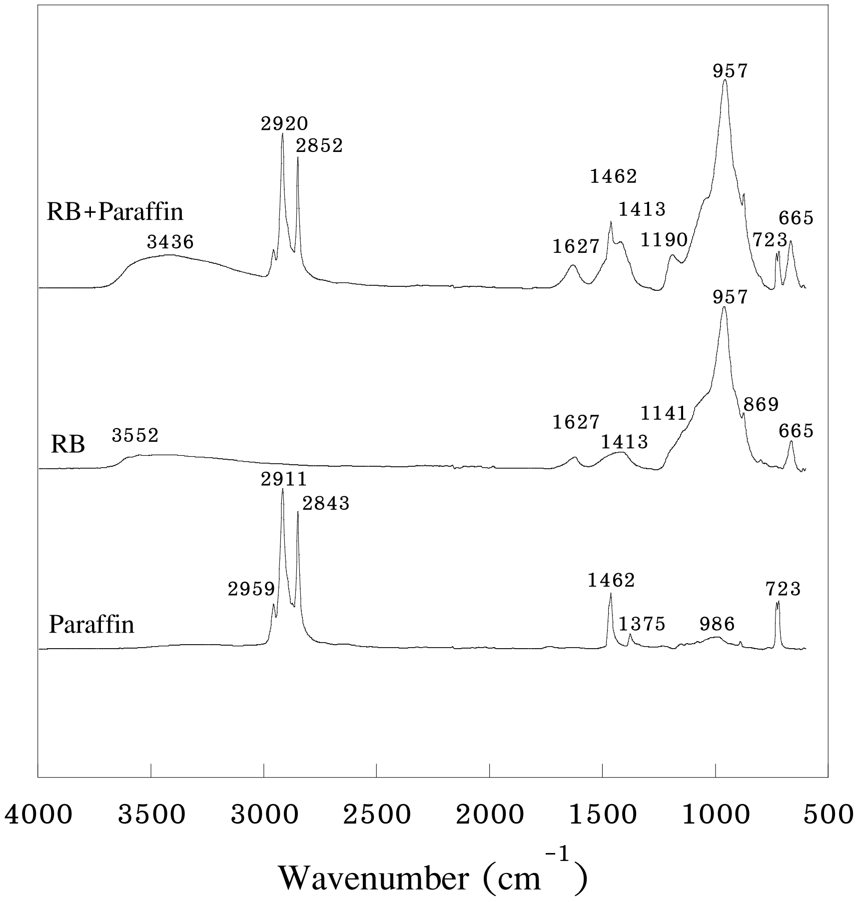

Fig. 5. FTIR spectra of samples: (a.) RB, (b.) paraffin and (c.) form-stable 25 wt% paraffin/RB composite PCM.

Table 2. FT-IR Absorption Bands of RB, Paraffin and Paraffin/RB.

Group	Wavenumber (cm^{-1})		
	RB	Paraffin	Paraffin/RB
OH (trace of water in concrete)	3552	-	3436
C-H vibration stretching	-	2911-2843	2920-2852
OH	1627	-	1627
C-H bending vibration	-	1462	1462
CO_3^{2-}	1413	-	1413
S-O	1141	-	1190
Si-O	957	-	957
CH_2 rocking vibration	-	723	723

4. Conclusions

The form-stable paraffin/RB composite PCM was prepared as a novel thermal energy storage material. The paraffin was confined in porous RB by mass fraction of 25% without melted of paraffin leakage from the sample. The phase transition temperature and latent heat of composite form-stable 25 wt% paraffin/RB were 52.85 ^{O}C and 30.98 J/g, respectively. FTIR results showed that the adsorption of paraffin in RB was physical. Based on the obtained results, it was concluded that form-stable paraffin/RB composite PCM can be considered as a promising phase change material for energy storage with ecological utilization of building waste as support material.

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