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Utilization of waste glass powder for latent heat storage application in buildings

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ABSTRACT

The feasibility of using soda–lime waste glass powder for latent heat storage application was investigated. n-Octadecane was loaded into glass powder (GP). The surface morphology, chemical compatibility, phase change behavior, thermal stability and reliability were determined using Scanning electron microscope (SEM), Fourier transformation infrared spectrum analysis (FT-IR), Differential scanning calorimetry (DSC), Thermo gravimetric analyzer (TGA) and thermal cycling test. The thermal performance of cement paste composite PCM was also evaluated.

The maximum mass percentage of n-octadecane retained by GP was found to be 8. FT-IR results showed that the interaction between the components of composite PCM is physical in nature. The melting and freezing temperatures of the composite PCM were found to be 26.93 °C and 25.03 °C while the latent heat of melting and freezing were 18.97 J/g and 18.95 J/g. TGA and thermal cycling results confirmed that the composite PCM is thermally stable and reliable. Thermal performance test showed that the cement paste panel with composite PCM reduced the indoor temperature by 3 °C. It can be concluded that the composite PCM can be used for thermal energy storage applications in buildings. Its usage will provide sustainable solution to reuse the waste glass. Thus, landfills can be saved for useful applications.

1. Introduction

Discarded waste glass is one of the major contributors of solid waste. It has become a significant burden on the landfills throughout the world. United Nation estimates the volume of yearly disposed glass waste to be 14 million tons [1]. In Hong Kong, around 100,000 tons of glass containers are disposed in landfills every year [2]. Moreover, glass is not biodegradable. Therefore landfills do not offer environmental friendly solution to its disposal. In addition, due to the lack of a local manufacturing industry to serve as a possible recycling outlet, disposal and recycling of waste glass have become a major challenge for Hong Kong [2,3]. In order to save landfills for useful applications, it is vital to find a sustainable solution to reuse waste glass.

The increase in the growth of industrialization and urbanization have resulted in several energy concerns such as supply difficulties, exhaustion of energy resources, climate change and environment pollution [4]. Moreover, the conventional fossil energy sources are depleting, and their usage is related to emission of harmful gases making people worried about environment issues and shortage of energy resources. To deal with this demanding situation, energy resources should be used proficiently. Latent heat thermal energy storage using PCM is a simple and effective technique for application to building envelops to enhance the energy efficiency of buildings. This, in turn, reduces the environmental impact related to energy use [5].

The idea of improving the thermal comfort of buildings by the application of PCM began to receive attention during the 1950s [6]. PCM is based on heat absorption or release when it goes change in state from solid to liquid or liquid to gas or vice versa [5,7,8]. However, solid liquid transition is found to be economically visible [7]. The properties of PCM would have direct impact on the human comfort. The PCM to be used for latent heat storage purpose should have desirable thermal, physical, kinetic and chemical properties [9,10]. Ideally, the PCM should have high storage density, good heat transfer, small volume change, low vapor pressure, no super cooling, long term chemical stability, non-toxic, non-flammable and self-nucleating behavior [9,10]. In order to be used in building envelope, target PCM materials shall have phase change temperatures in the human comfort zone [11,12]. In addition, they should have high latent heat storage capacity. n-Octadecane has attracted researchers [4,13] because it has phase change temperature in the human comfort zone and has high latent heat storage capacity.

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Table 1
Composition of soda lime glass powder.

Chemical composition	%
Silicon dioxide (SiO_2)	72.1
Sodium oxide (Na_2O)	12.3
Calcium oxide (CaO)	9.82
Aluminum oxide (Al_2O_3)	3.41
Potassium oxide (K_2O)	1.63
Sulfur trioxide (SO_3)	0.17
Magnesium oxide (MgO)	0.12
Iron oxide (Fe_2O_3)	0.09
Titanium oxide (TiO_2)	0.064
Zirconium dioxide (ZrO_2)	0.025
Strontium oxide (SrO)	0.012

In the present work, form-stable composite PCM was developed by utilizing waste glass powder as container for n-octadecane. The PCM was incorporated in GP using vacuum impregnation method. The chemical compatibility between the components of form-stable composite PCM was evaluated using FT-IR analysis. DSC, TGA and thermal cycling test were used to determine the thermal properties, thermal stability and reliability of the composite PCM. The thermal performance of cement paste panel prepared with n-octadecane-GP composite PCM was also evaluated.

2. Experimental program

2.1. Materials selection and characterization

The selection of PCM suitable for incorporation in building materials as latent heat storage material was a difficult task. This is especially true when choosing PCM which has phase change temperature in the human comfort zone. In addition, the PCM should have high latent of fusion. n-Octadecane, which has phase transition temperature in the human comfort zone and has high latent heat of fusion, was therefore selected as a PCM.

Glass is a transparent material formed by melting several inorganic mineral raw materials at high temperature followed by controlled cooling to become a hard, homogeneous, stable, inert, amorphous and isotropic material [14]. Soda–lime glass, which comprises of more than 80% by weight of waste glass [15], received in powdered form was used as a container for PCM. It was sieved through 150 μm sieve and dried at 105 °C for 24 h before use. The chemical composition of GP analyzed by X-ray fluorescence (XRF) technique is given in Table 1. It can be seen that GP mainly comprises of silicon dioxide, sodium oxide, calcium oxide, aluminum oxide and potassium oxide while sulfur trioxide, magnesium oxide, iron oxide, titanium oxide, zirconium dioxide and strontium oxide are present in trace amounts. The energy spectrum of particles of GP (Fig. 1) also shows that it is mainly composed of silicon, sodium, oxygen, calcium, aluminum and potassium. In addition, the cumulative pore volume of GP in 17,000 Å to 3000,000 Å diameter range was determined by TriStar 3000 surface area and porosity analyzer and was found to be 0.0076 cm^3/g.

2.2. Preparation of form-stable composite PCM

The composite PCM was prepared by using vacuum impregnation method (Fig. 2) [16,17]. The procedure started by placing GP with different mass fraction of n-octadecane ranging from 6 to 30 wt% in the beaker kept inside the vacuum chamber. Vacuum pump was then used for 90 min to evacuate air from GP sample while vacuum pressure, monitored through vacuum meter, was maintained at 65 kPa [18]. In the next step, the melted PCM was allowed to enter the beaker so that the melted PCM covers the whole surface area of the GP sample. After that the vacuum pump was switched off and air was allowed to enter the system for 30 min so as to force the PCM to penetrate into pores of GP. During the impregnation process, the composite was kept above the melting temperature of PCM so as to check the exudation of PCM from GP sample. The n-octadecane-GP composite was then put in air conditioned laboratory below the melting point of PCM for 24 h so as to make sure that PCM becomes solid. The maximum absorption ratio was determined by performing leakage test. In this test, the n-octadecane-GP composite PCM was placed in an oven for 30 min above the melting point of PCM so as to observe the PCM leakage in the melted state. The maximum percentage of n-octadecane retained by the GP was found to be 8% (Fig. 3) and was named as form-stable composite PCM.

2.3. Characterization of the form-stable composite PCM

The surface morphology of the form-stable composite PCM was analyzed through XL30 ESEM FEG operated in secondary electron detection mode with low vacuum and an accelerating voltage 15 kV. For chemical compatibility of form-stable composite PCM FT-IR spectra, in transmittance mode, were taken on KBr pellets with resolution of 4 cm^{-1} in the frequency range of 4000–400 cm^{-1} using Perkin-Elmer FT-IR spectrophotometer.

The phase change behavior, i.e. phase change temperatures and latent heat storage capacities were determined using TA instrument MDSC2910 under nitrogen atmosphere (50 ml min^{-1}) in the temperature range 0–40 °C and at a heating/cooling rate of 5 °C min^{-1}. Temperature and heat flow calibrations were done using indium. A known weight of sample was placed in sealed aluminum pan for measurement while an empty pan was used for reference. Thermal properties were determined using TA

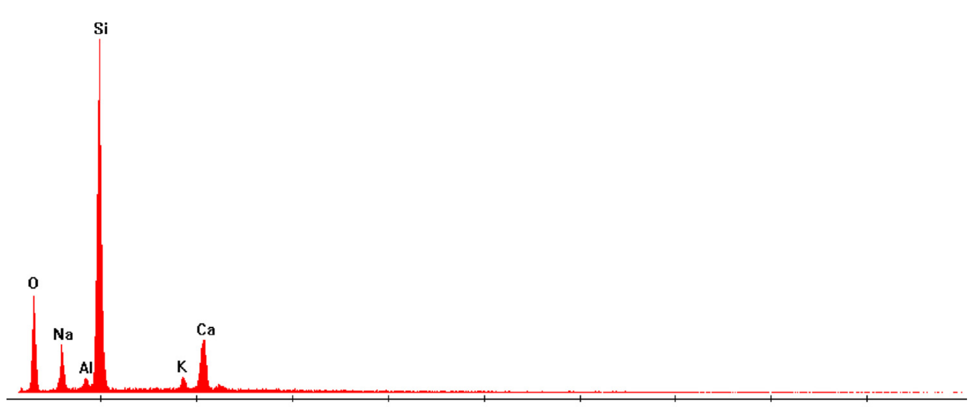

Fig. 1. Energy spectrum analysis results of soda lime glass powder.