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Thermophysical properties of a novel copper reinforced oil palm shell (OPS) composite: Effect of copper volume fraction and temperature

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HIGHLIGHTS

- Addition of copper increased thermal stability by more than 100 °C.
- Thermophysical properties are dependent on temperature & copper volume fraction.
- Thermal conductivity of OPS-copper composite is twice to that of OPS.
- Thermal conductivity and thermal diffusivity reduced with increase in temperature.
- Specific heat capacity of composite lowered with increase in copper volume fraction.

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ABSTRACT

Thermophysical properties of novel oil palm shell (OPS)-copper composite with different copper volume fractions at varying temperatures, ranging from 30 °C to 100 °C have been reported in this work. Thermophysical properties of composites have been determined by using 'KD2 Pro' instrument based on transient hot wire method. Thermo-gravimetric analysis of composites show that the thermal stability increases by more than 100 °C on increasing the copper volume fraction from 0.0 to 0.2 in the composite. Addition of copper in OPS has increased thermal conductivity and thermal diffusivity while reduced the specific heat capacity of the composite significantly. At room temperature, thermal conductivity, thermal diffusivity and specific heat capacity of the composite with copper volume fraction 0.2 is found to be 0.408 W/m-K, 0.221 mm^2/s and 1.309 kJ/kg-K respectively as compared to 0.202 W/m-K, 0.142 mm^2/s and 1.152 kJ/kg-K respectively for pure OPS (with no copper). Increase in the temperature resulted in the reduction in thermal conductivity & thermal diffusivity while specific heat capacity is found to increase with the rise in temperature for all the composites.

1. Introduction

Knowledge of thermophysical properties of material is very important because it provides detailed information of the materials regarding the transportation and storage capacity of the heat within it. This information is crucial in numbers of applications related to heat flow through the material or designing the material processing equipment [1,2].Composite materials in the last few decades have secured their place in almost each industry. Being it aviation, manufacturing, electronics, construction, transportation or any other industry, composite materials are being used with a great success. One of the most important features of composite materials is that by selecting an appropriate matrix-filler combination in proper matrix-filler ratio we can alter the material property and we can achieve the desired material property.

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Thermal conductivity of various kinds of composite materials with the study of effect of various parameters like filler fraction, moisture content, particle size, sintering process temperature etc. have been studied and reported [3–7]. Forecasting the growing need to understand thermal conductivity behavior of the composite materials, several studies have been conducted on the development of theoretical models to predict the thermal conductivity of composite material [8–11].

Biomass based materials are now used to form composites to utilize them in various applications. Several studies are available on the mechanical and thermal properties of the biomass based composite materials [12–15]. Qi et al. [14] made a composite of High Density Polyethylene (HDPE)-sorghum and investigated the thermal conductivity of sorghum-HDPE composite to understand the heat flow mechanism and model the heat transfer phenomenon in the bio-composite materials. The study found that the thermal conductivity of sorghum-HDPE composite increases linearly on increasing the temperature and density of the composite while the increase in the HDPE content in composite enhances thermal conductivity non-linearly. Li et al. [15]synthesized a as natural fiber based bio-composite as it is more environment friendly as compared to glass-fiber based composite and measured thermal conductivity of fiber-HDPE bio-composite and reported that the increase of fiber content in bio-composite enhances the thermal conductivity of the bio-composite. Fasima&Sokhansanj [16]studied the effect of moisture content on thermal conductivity of alfalfa to design a pellet cooler and selection of ventilating and cooling equipment pellets using the plane heat source method and reported that increase the moisture content from 0.0% to 8.5%, increased the thermal conductivity of alfalfa from 0.112 W/mK to 0.204 W/mK. Alegngaram et al. [17]investigated thermal conductivity of oil palm shell (OPS) foamed concrete as a function of density and established that the thermal conductivity increased from 0.40 W/m-K to 0.57 W/m-k on increasing the density of OPS foam concrete from 1196 kg/m^3 to 1594 kg/m^3.

Composite with metallic fillers with the advantage of isotropic properties, improved mechanical strength, better thermal conductivity, higher electric conductivity, ease of synthesis have always attracted the researchers. Different filler-matrix combinations have been synthesized and studied as electronic packaging material, wear resistance materials, fire retardants and phase change materials [1,2,18–20]. Metallic composites have also been found advantageous in heat transfer, automobile, construction and many other applications [21–23]. Among the various inorganic metallic fillers, Cu, Al, Si, Ni, TiO_2, AlN, BN, SiO_2, and iron oxides are the most studied fillers because of their high thermal conductivity, high mechanical strength, high electrical properties, high thermal stability and relatively low cost [24,25]. Various studies have been made on the thermal conductivity measurement of the metal-matrix composites revealing that the metal-matrix composite has a higher thermal conductivity as compared to the matrix material [26,27]. OPS is a waste material generated during the production of palm oil from the palm trees. Many research articles have been published on the effective and efficient utilization of OPS [28–32]. A closer analytical look into the available literature has revealed that most of the studies on the OPS has been focused upon its thermochemical conversion into char [33,34]and bio-oil or as adsorber or in the construction industry. Few studies have discussed its utilization in agriculture for soil procurement. Based on the literature review, the authors have found that although researchers have studied the thermal conductivity of different biomass based materials but to the best knowledge of the authors the thermophysical properties of OPS-metal composites have not been reported yet. Studies have revealed that Inorganic fillers have increased the thermal conductivity, electrical conductivity and mechanical strength of the composite materials significantly and composite with inorganic particulate fillers have been found to perform well in real operational conditions [7,18,35]. Biomass based metal composites have never been tested for their thermal and mechanical properties. A metal based OPS composite prepared by the incorporation of metal powder to OPS is expected to improve thermal conductivity of OPS.

In the present study, a novelOPS-copper composite with different copper volume fractions ranging from 0.0 to 0.2 has been synthesized and the effect of copper loading and temperature on the thermophysical properties of novel OPS-copper composite has been investigated. Copper has been used as filler in numerous composites, because of its high mechanical strength, high thermal conductivity, high electrical conductivity, better thermal stability. Moreover, composites with copper are considered to be one of the efficient and most commonly used heat sinks [36,37].The study will try to explore any possibility to use OPS as electronic packaging material. Thermophysical properties of OPS-metal composite will provide us the information regarding the heat flow through the OPS and OPS-copper composite which will be helpful for the designing and development of equipment for the heat treatment of OPS and OPS based composite materials [16,38]. Besides, the information related to the thermophysical properties of the material may be important to model the complex heat transfer phenomenon in the metal based bio-composite materials [38,39]. Knowledge of thermal conductivity of OPS will also be helpful for the utilization of OPS in construction industry [17].

2. Experimental work

2.1. Materials

The oil palm shell (OPS) used in the present study was supplied by Seri Ulu Langat Palm Oil Mill Dengkil, Selangor, Malaysia. The OPS supplied by the mill were brown coloured granular particles. Copper powder was supplied by MarckKGaA, Germany. The copper particles size was< 63 μm and density was 8.96 g/cm^3 as claimed by the supplier.

2.2. Sample preparation

The OPS supplied by the mill was washed by normal water to remove water soluble impurities present in it (if any). Washed OPS was then dried in an electric furnace at 80 °C for 24 h. Once the OPS was dried it was taken out of the electric furnace. The dried OPS was grinded using a Fritsch Pulverisette-6 planetary high energy ball mill which contains a tungsten carbide (WC) vessels and Zirconium oxide (ZrO_2) balls. The OPS was fed to the vessel and ball-to-powder weight ratio (BPR) was kept to be 4:1. Ball mill was programed to rotate for 24 h and the rotation speed of ball mill was set to 300 rpm. The continuous rotation of the ball mill may produce excess amount of heat and to avoid this problem the ball mill was programmed to rotate for 20 min and then a stoppage time of 12 min was given. After 24 h the machine stopped and the powdered OPS was taken out of the ball mill.

Calculated amount of copper powder for different volume fraction of composite was added to appropriate amount of powdered OPS. Amount of copper powder and OPS was calculated on the basis of Eq. (1) [18]. OPS and copper powder was mixed mechanically for 30 min so that copper powder gets mixed uniformly to the OPS matrix. A small amount of xylene was then added to the mixture of OPS and copper powder. Xylene was used as a solvent which helps in preparing a homogeneous and uniform mixture of OPS and copper. The used amount of OPS, copper, xylene for the preparation of composite and the density of each sample is