Thermal Conductivity and Bending Strength of Coconut Fiber/Paraffin/Graphite Composite Phase Change Materials

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Abstract. The use of composite materials for panel boards, building construction, vehicle accessories, and household furniture is growing. Coconut coir fiber-reinforced composites can be applied as panel boards for building and furniture construction, which can also be used as heat storage systems. The coco fiber composite's low energy storage capacity can be increased by incorporating PCM material into it, forming a PCM composite material. Heat absorption and release performance depend on the material's thermal conductivity, which can be increased by adding additives such as graphite. This paper presents a performance test of PCM composites to obtain bending strength and thermal conductivity. The research materials were coconut coir fiber, polyester, paraffin, and graphite. The weight fractions of coco fiber and polyester were 30 and 50%, respectively. Variation of paraffin weight fraction 15 and 20% and variation of graphite weight 0 and 5%. The method of mixing materials is direct incorporation and forming of PCM composites using a press molding process. The tests carried out include the bending test (ASTM D790-03) and the thermal conductivity test using the Heat Transfer Experiment Base Unit test kit. The results show that the use of 15 wt% paraffin with 5 wt% graphite increases thermal conductivity by 23.27% and increases bending strength by 36.71%.

Keywords: Bending Strength, Coconut Fiber, Composite PCM, Graphite, Paraffin, Thermal Conductivity

I. Introduction

A composite material is a material composed of two or more primary elements which from the macro side differ in shape and/or composition, combined to produce new materials with different properties compared to the basic material properties before being mixed and surface bonding occurs between each of the constituent materials [1], [2]. The advantages of composite materials are that they are light, strong, not affected by corrosion, and can compete with metal and the ability of these materials to be designed so that their strength can be adjusted only in specific directions, which are called tailoring properties [3].

The use of composite materials is growing, such as for various components in vehicles and panel boards for building construction [4]. The use of composites in building structures has experienced rapid growth in recent years, especially polymer-based composites. Fiber-reinforced composites are materials that can be used as fences, walls, windows, door frames, and furniture. These composites consist of a polymer matrix, usually polyethylene, reinforcing fibers, and other additives. Composites reinforced with coconut coir fibers are one of the materials that can be applied as panel boards for furniture and building construction [5]. One of the essential mechanical properties of composite materials used as panel boards or furniture is the bending strength. Bending strength is the greatest bending stress that can be received by a material due to external loading without experiencing major deformation or failure [6].

Fiber-reinforced composites, like composite materials, generally have a low thermal mass. There are various methods for increasing the storage capacity of thermal energy in lightweight construction. The latent heat thermal energy storage (LHTES) can provide a high energy storage density and an almost constant operating temperature. The method applied is to incorporate PCM material into the construction material or structure to form a PCM composite [7] - [9]. A construction material containing PCM in its compartment can absorb heat energy when there is a surplus and release it back when it is in deficit. This passive heat release and absorption cycle will reduce temperature fluctuations inside buildings, which leads to a reduction in energy consumed [10].

Some researchers have proposed incorporating PCM in building compartments such as walls, floors, ceilings, windows, or wall coverings using panel boards [11], [12]. The incorporation of PCM material into a building material or construction can be done by (1) direct incorporation [13], [14], (2) immersion [15], [16], and (3) encapsulation which can be in the form of micro encapsulation [17] - [19], and in the form of macro encapsulation [20]. The easiest and simplest method is the direct incorporation method.

An essential factor of the material used as an absorber and heat storage is its thermal conductivity. In general, fiber-reinforced composites have a low thermal conductivity, which will limit the kinetics of heat absorption and release [21] – [23]. Various studies have been conducted to overcome the limitations of thermal conductivity, and mostly by adding materials that have high thermal conductivity such as graphite [24], metal foam [25], copper foam [26], and perlite [27].

Based on the above explanation, in this study, tests were carried out to obtain the mechanical and thermal characteristics of PCM composites made of coconut coir fibers, polyester, paraffin, and graphite. The purpose of this research is to prepare PCM composites in the form of panel boards that can be applied to building construction or furniture, which also functions as a heat storage system.

II. EXPERIMENTAL

2.1. Materials

The materials used in this research are coconut fiber, polyester, paraffin, and graphite. Coconut coir fiber is taken from the old coconut fruit, comes from the Tabanan Regency with the density of coconut coir ρ = 1.44 gr/cm^3. Yucalak 157 BQTN-EX type of polyester is used with a density of 1.21 gr/cm^3 with hardener type MEXPO. Both materials were purchased from PT. Mufasa Specialties Indonesia (http://www.mufasaspecialties.biz/jual-yukalac-157-bqtn-ex/). Graphite with density ρ = 2.267 gr/cm^3 is purchased online via https: // www. lazada.co.id/products/ graphite-powder-bubuk-grafit-500-gram. Paraffin with characteristics, namely: density ρ = 0.89 g/cm^3, melting temperature 54.38 ^{0}C, latent heat 142.72 kJ/kg and thermal conductivity 0.356 w/mK purchased online via https: // www. tokopedia.com/chemposite/paraffin-wax.

2.2. Composite Preparation

The manufacture of PCM composites uses the direct incorporation method with the composition of the raw materials, as shown in Table 1. PCM composites are molded into boards or sheets for bending tests and cylindrical for thermal conductivity tests (Figure 1). Two types of PCM composites were made using additional graphite and without graphite to compare their thermal conductivity tests. Specimens for the bending test with dimensions of 120 mm × 15 mm × 5 mm and thermal conductivity tests with dimensions of 30 mm (diameter) x 20 mm (thickness), as illustrated in Figure 2.

Table 1. Composition of composite PCM materials

No	Coconut fiber (wt%)	Polyester (wt%)	Paraffin (wt%)	Graphite (wt%)
1	30	50	20	0
2			15	5

Fig. 1. Composite PCM.

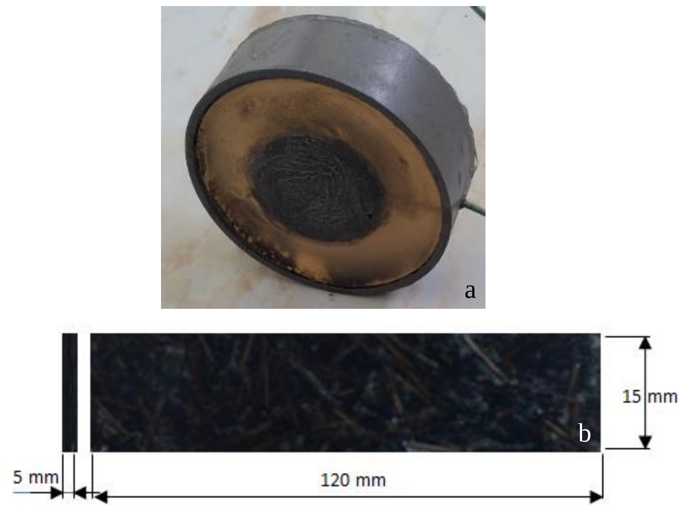

Fig. 2. Specimen of composite PCM a) thermal conductivity, b) bending

2.3. Composite Test

Testing to obtain mechanical properties, namely bending strength, is carried out by the three-point bending method using the ASTM D-790 standard. The three-point bending schematic is shown in Figure 3, and the testing process is presented in Figure 4. The schematic and testing process obtains thermal conductivity using the Heat Transfer Experiment Base Unit test tool, as shown in Figures 5 and 6.

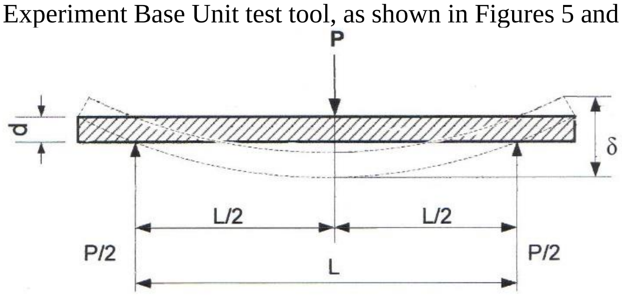

Fig 3. Schematic of three-point bending

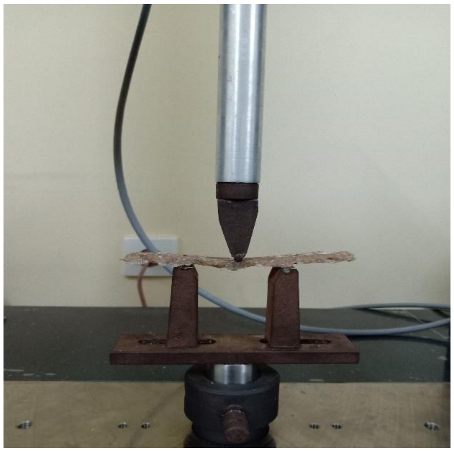

Fig. 4. Bending test of composite PCM

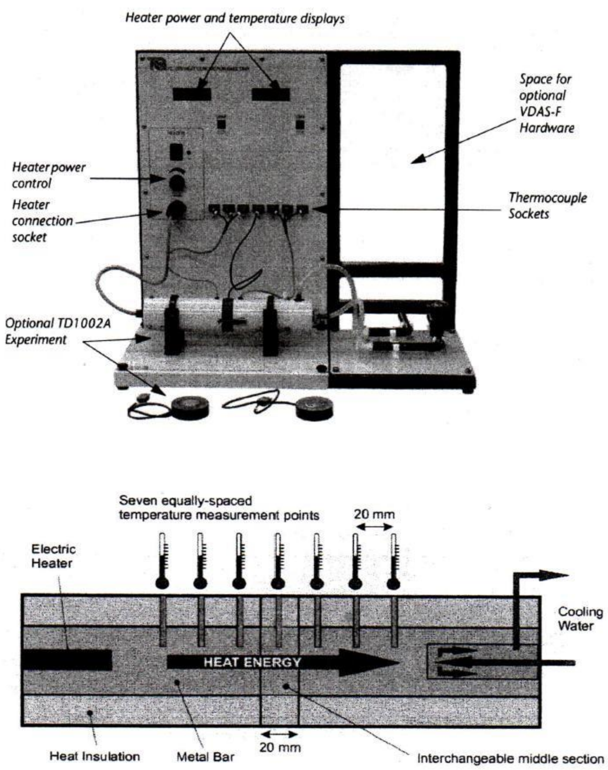

Fig. 5. Schematic of thermal conductivity apparatus test

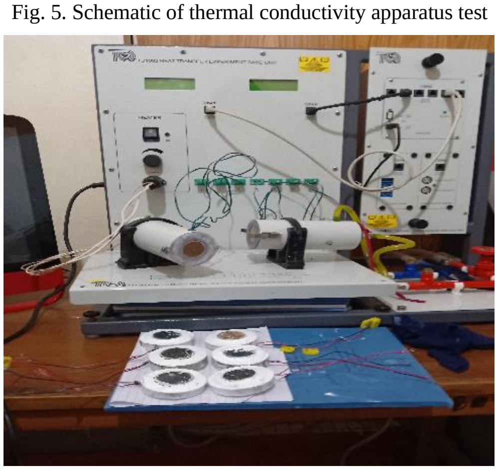

Fig. 6. Thermal conductivity test of composite PCM

III RESULT AND DISCUSSION

3.1. Thermal conductivity

The thermal conductivity of PCM composites is presented in Table 2 and Figure 7. The addition of 5% graphite to the PCM composite resulted in 3.33 W/mK thermal conductivity. Increased by 23.27% compared to PCM composites without graphite. Compared with pure paraffin, the addition of graphite to this PCM material can increase the thermal conductivity by 56%. The trend of the same results was reported by [28], who examined PCM materials, namely paraffin with carbon additive material is nano graphite, and the fraction of additive is 10 wt% where there is an increase in thermal conductivity of 7.41 times. Reference [29] also reported that there was an increase in thermal conductivity by 41.4% on PCM material, namely paraffin, with 2 wt% expanded graphite.

Graphite is a material with a carbon-based material that has high thermal conductivity. The use of graphite as an additive will be useful for increasing the thermal conductivity of PCM materials.

Table 2. Thermal conductivity of composite PCM

No	Coconut fiber (wt%)	Polyester (wt%)	Graphite (wt%)	Paraffin (wt%)	Thermal Conductivity (W/m.K)
1	30	50	0	20	3.3168
2			5	15	3.3274

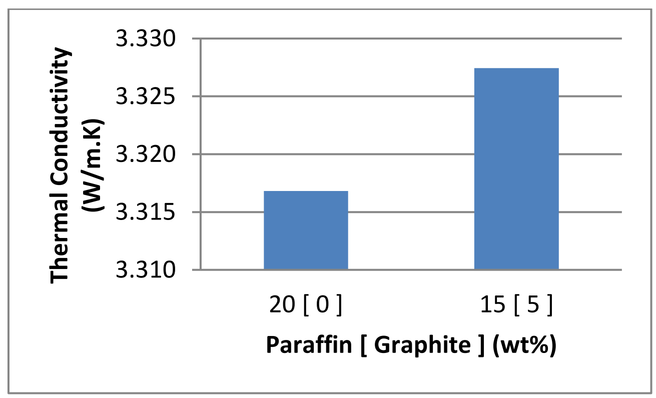

Fig. 7. Thermal conductivity of composite PCM

Heat absorption and storage of PCM composites is shown in Figure 8. Heat absorption and storage in PCM composites without graphite (Figure 8a) is deficient, as seen from the graph where the temperature of the PCM composites (T4) is almost constant, but in PCM composites with an additional .5 wt% graphite shows that heat absorption and storage occurs as seen from the increasing temperature of T4 with increasing testing time (Figure 8b).

These results indicate that graphite can increase thermal conductivity so that PCM composites can absorb and store energy, mainly heat energy.

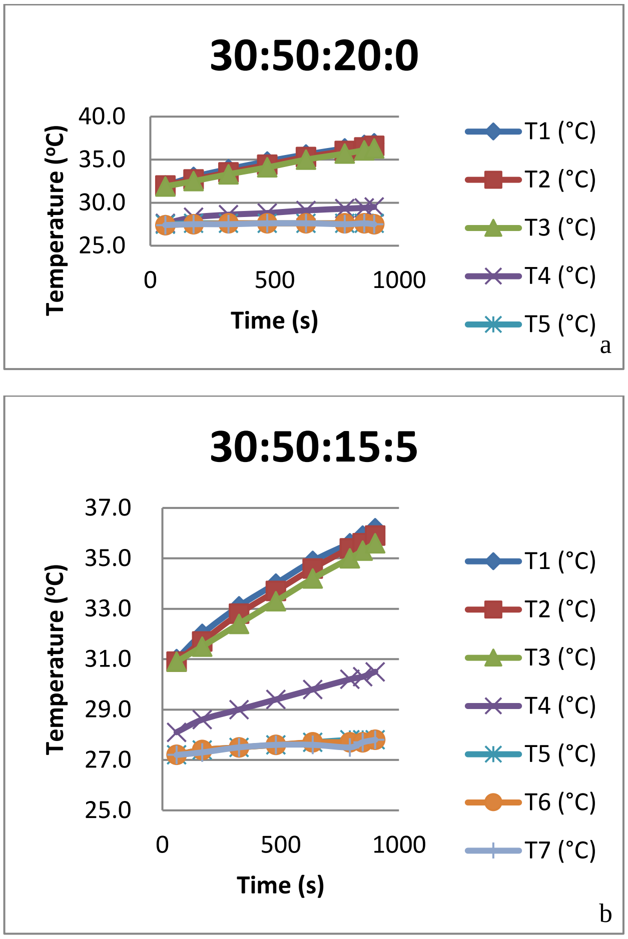

Fig. 8. Heat absorption of composite PCM a). 0 wt% graphite, b).5 wt% graphite

3.2 Mechanical Test

The results of the three-point bending test for PCM composites are presented in table 3. PCM composites with 15 wt% incorporated PCM and 5 wt% aggregate graphite, the coating material is a polyester resin and obtained a bending stress of 10.65 MPa, an increase of 36.71% compared to bending stress of PCM composites without graphite, which has a bending stress of 7.79 MPa. The bending strain and bending elasticity modulus were also increased with the addition of graphite to the PCM composites with an increase of 66.67 and 37.63%, respectively. The trend of the same results was reported by [30], who used paraffin as a PCM material with aggregate expanded clay, the coating material was epoxy coating graphite, and the percentage incorporated PCM was 50%, getting the strength of 15 MPa. Reference [31] reported the results of their research using PCM material, namely paraffin with 20% percentage incorporated PCM, with aggregate expanded clay, the coating material is a polyester resin adhesive where the strength obtained is 12.5 MPa.

Graphite in the form of granules also functions as reinforcement in the composite and will fill in the fibers and matrices' gaps to increase the strength of the composite. Figure 10a presents SEM photos of PCM composites without graphite, which show less dense morphology, in contrast to Figure 10b, which shows denser morphology due to additional graphite in the composite material. This condition causes the bond between the fiber and the matrix to be stronger so that the composite's strength is higher.

Table 3.Bending strength of composite PCM

No	Coconut fiber (wt%)	Polyester (wt%)	Graphite (wt%)	Paraffin (wt%)	Bending Strength		
					σ (MPa)	ε (MPa)	E (MPa)
1	30	50	0	20	7.79	0.03	261.81
2			5	15	10.65	0.05	360.33

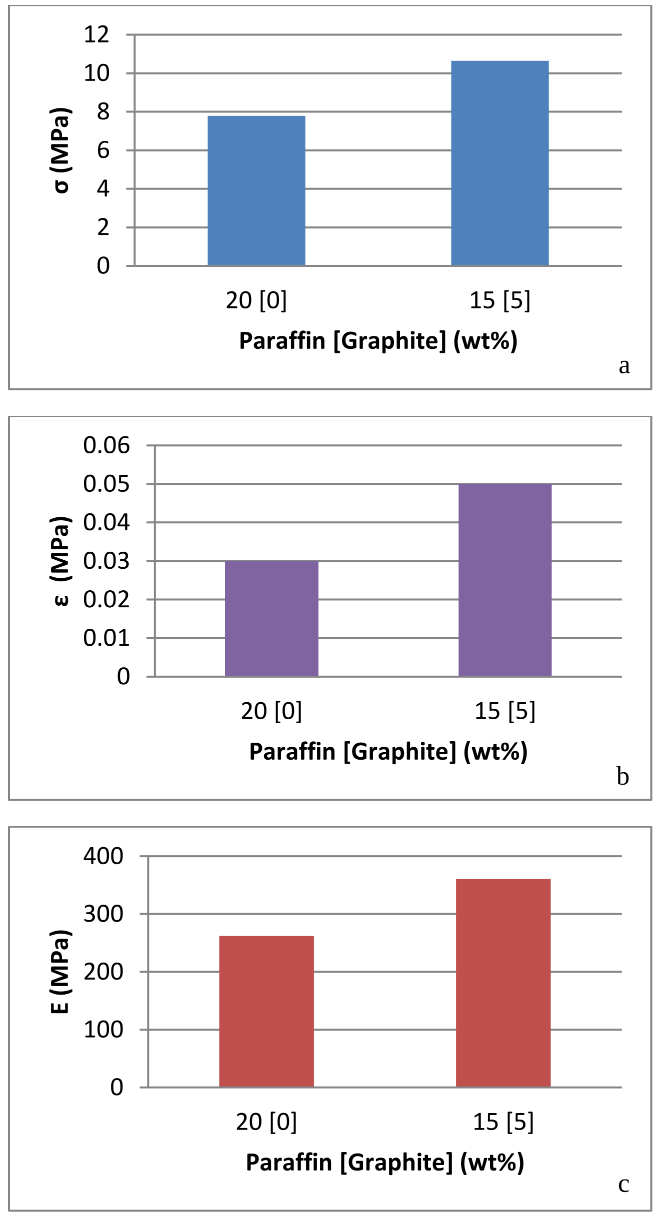

Fig.9. Bending strength of composite PCM a) bending stress (σ), b) bending strain (ε), c) bending elasticity modulus (E)

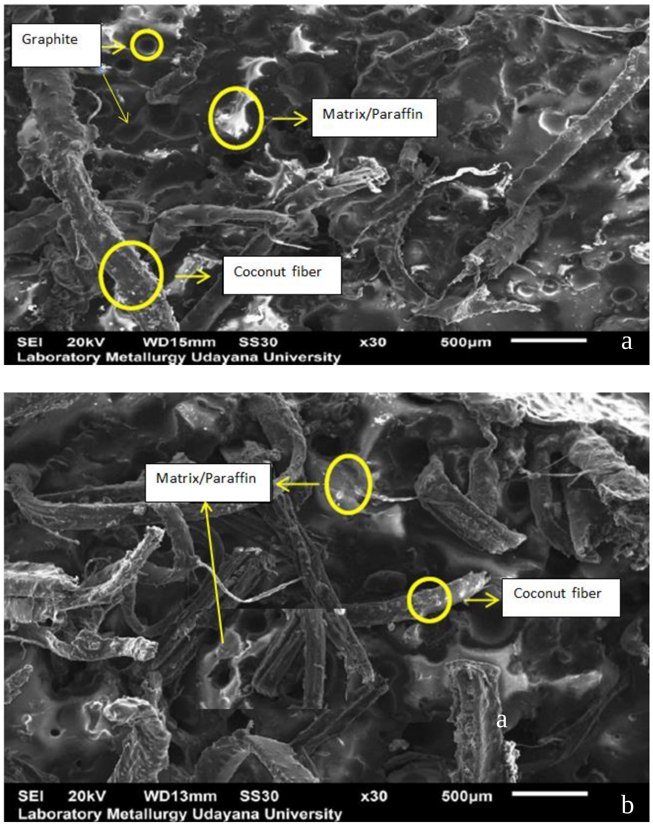

Fig. 10 SEM of composite PCM a) 0 wt% graphite, b) 5 wt% graphite

IV. CONCLUSION

PCM composites with coconut coir fiber reinforcement can be used as interior building materials such as panel boards and furniture materials, which also function as thermal energy storage. The results show that the use of 15 wt% paraffin with 5 wt% graphite increases thermal conductivity by 23.27% and increases bending strength by 36.71%.

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