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Experimental Investigation on Thermal Conductivity Analysis of Bahunia Racemosa/Glass Fiber Reinforced Polymer Composites

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Abstract—*In India, thermal insulation products are manufactured from fiber glass, mineral wool or polyurethane foams. Although these materials have low thermal conductivity, they can be hazardous to human being as well as environment. Small particle of fiber glass or mineral wool can make skin irritation and respiratory problem. Over the past few years, there is an increase of energy utilization throughout world. To reduce the energy consumption, one of the focus area of research is production of energy saving eco-friendly composite panels by using natural fibers. In this paper, the influence of the fiber content on the thermal properties of short randomly oriented Bauhinia racemosa (BR) Lam/glass fiber (GF) vinyl ester composite (BRGVEC) was carried out. The results show that thermal conductivity of composites decreases with increase of fiber ratio. The experimental thermal conductivity value of composite is in good agreement with theoretical model. Thermal conductivity obtained from the series conduction model was shown better results compared to the experimental value.*

Keywords*: Bahunia Racemosa, Thermal conductivity, Series model, Composites.*

1. INTRODUCTION

The use of natural fiber reinforced composites under different environmental conditions has become popular in recent years. Many naturally occurring fibers have been used as effective reinforcement in polymer matrices. The interaction of thermal energy (i.e. heat) with the atoms which constitute a material determines some of the most important physical properties of the material. The properties describing this interaction at the most fundamental level are often called thermophysical properties which include heat capacity, thermal diffusivity, thermal conductivity, etc. In India, thermal insulation products are manufactured from fiber glass, mineral wool or polyurethane foams. Although these materials have low thermal conductivity, they can be hazardous to human being as well as environment. Small particle of fiber glass or mineral wool can make skin irritation and respiratory problem [1]**.** Over the past few years, there is an increase of energy utilization throughout world. To reduce the energy consumption, one of the focused area of research is production of energy saving eco-friendly composite panels by using natural fibers. Fiber reinforced polymer composites are considered as attractive material for the household appliances such as air coolers and air conditioners etc. to reduce energy consumption.

Natural fibers are added with polymers to reduce the thermal conductivity of composites. The hollow structure of natural fibers gives excellent insulation against heat. A number of mathematical model have been developed to predict the thermal conductivity of short fiber composites [2, 3]. Thermophysical properties of natural fiber reinforced polyester composites are discussed by Idicula et al. [4]. The thermal conductivity of sodium hydroxide treated fiber composite is 43% higher than the untreated fiber composite. The thermal conductivity and thermal diffusivity of flax reinforced polypropylene composites were determined at room temperature by John et al. [5]. Chemical modification in the form of a biodegradable zein coating was applied to the flax nonwovens. The effect of fiber loading and chemical modification on the thermo-physical properties was investigated. The increase of fiber content in polypropylene matrix resulted in a decrease of thermal conductivity and thermal diffusivity of the composites. Ramanaiah et al. [6] developed partially bio degradable sansevieria fiber reinforced polyester composites. The thermal conductivity of composite decreased with increase in fiber content. There was a decrease in thermal conductivity with increase of temperature.

However the reported research on thermal properties of bahunia racemosa Lam (BR)/glass fiber (GF) in composite is limited. Hence, a complete characterization of thermal studies of BR/GF reinforced composites is needed to study their utility. The influence of the fiber content on the thermal properties of short randomly oriented (BR) Lam/ (GF) vinyl ester composite (BRGVEC) was analyzed here.

2. MATERIALS AND METHODS

2.1 Materials

In this work, Bauhinia racemosa (BR) fiber and glass fibers (GF) are used for fabricating the composite specimen. The BR fiber collected from Hogenakkal, Krishnagiri district, Tamilnadu, India. Isophthalic vinylester resin and the catalyst Methyl Ethyl Ketone Peroxide (MEKP) are obtained from the open market. The accelerator used for the investigation is Cobalt Napthanate and is added as 1% with the resin and the catalyst. The GF used for the fabrication is of unidirectional mat having 300 GSM.

2.2 Composite preparation

The composite materials used for the present investigation is fabricated by hand layup process. Chopped Bauhinia racemosa (BR) fiber of 30 mm length were used to prepare the specimen (150x150x30 mm). The composite consists of total three layers in which glass fiber (GF) layers are fixed in top and bottom of the specimen. Middle layer is filled by BR fiber. Initially, BR fiber is dried in sun light to remove the moisture. The GF mat is filled with vinylester resin. The second layer of BR fiber is placed over the GF before the resin gets dried. The processed composite is pressed hard and the excess resin is removed and dried for 24 hours. The composites were prepared by keeping the overall fiber volume fraction (40 vol.%) constant and the volumetric ratio between BR/GF are varied by 40:0, 37:3, 33:7, 11:29 and 15:25.

2.3 Thermal Properties of Composites

Thermo physical properties such as thermal conductivity and thermal diffusivity of bahunia racemosa/glass fiber composites are determined by following methods.

Thermal Conductivity (k)

The thermal conductivity of composites are measured by using guarded heat flow meter, Unitherm model 2022, ANTER Corporation, USA as per ASTM: E1530-11. In each case, five specimens were tested to obtain average value. Circular test specimens of 50 mm diameter and 3 mm thickness are cut from the composite panel. This sample is held under a uniform compressive load between two polished surfaces controlled at a different temperature. The lower surface is part of a calibrated heat flow transducer. The heat flows from the upper surface to the lower surface through the sample so that an axial temperature gradient is established in the stack. After reaching thermal equilibrium, the temperature difference across the sample is measured along with the output from the heat flow transducer. Thermal conductivity (k) can be determined using the following equations (1):

$$Q = kA(T_1 - T_2) / x \tag{1}$$

where

Q - heat flux (W)
k - thermal conductivity (W/m-K)
A_c - cross sectional area (m^2)
(T_1-T_2) - difference in temperature (^0C)
x - thickness of the sample (mm)

The thermal resistance of a sample can be given as (2):

$$R = \frac{T_2 - T_1}{(Q / A_c)} \tag{2}$$

where

R - resistance of the sample between hot and cold surfaces (m^2-K/W)

From Equations 1 and 2 we get

$$k = \frac{x}{R} \tag{3}$$

Specific Heat Capacity (C_p)

The specific heat capacity (C_p) of composites are determined using a differential scanning calorimeter analyzer NETZSCH, STA 449 F3. Composite specimen is put into the aluminum pan and covered with aluminum cover.

Thermal Diffusivity (a)

Thermal diffusivity (a) is the time dependent non-steady state aspect of heat flow. It is a measure of the material to allow the heat into it. Thermal diffusivity can be calculated by the following equation (4) [7]

$$a = \frac{k}{\rho C_p} \tag{4}$$

where

a- thermal diffusivity of composites
ρ- density of composites
C_p - specific heat capacity

2.4 Theoretical Thermal Conductivity

There are several theories to model the thermal properties of polymer composite materials [8, 9]. In general, when the ratio between the thermal conductivity values of the resin matrix and the fibers is less than 10, a first order model is used to determine the thermal conductivity of composites [10]. These models are represented in the equation (5, 6):

Parallel model [11]

$$k = Vk_2 + (1 - Vk_1) \tag{5}$$

Series model [11]

$$\frac{1}{k} = \frac{V}{k_2} + \frac{1-V_2}{k_1} \tag{6}$$

Where

k_1 - thermal conductivity of polymer

k_2 - thermal conductivity of fibers

k - thermal conductivity of composite

V - Volume content of fibers

3. RESULTS AND DISCUSSION

3.1 Effect of Fiber Content on Thermal Properties

The thermal conductivity values of composites at different fiber loading are given in Table 1. The values of thermal diffusivity and specific heat are also given in the table. It can be understand that glass fiber contribute more than bahunia racemosa fiber for thermal conductivity. So, addition of glass fiber increase the thermal conductivity of composites. However, experimental results show different trend (Table 1). BR fiber composite shows higher thermal conductivity values compared to the hybrid composites. It is due to the presence of waxy layer on the BR surface which reduce the bonding of the fiber and resin [12]. But the glass fiber surface is smooth so there is less possibility for adhesion with resin. It was reported that fiber- matrix adhesion play vital role in the performance of the composite [13, 14]. Also, initial increase in the thermal conductivity of the composite is due to the partial replacement of resin by fibers (Fig. 1). Especially, in the beginning volume percentage of BR fiber is greater than glass fiber in the composites. The decreasing in thermal conductivity by increasing volume fraction 3% V_f to 11% V_f is due to fiber matrix debonding, fiber pullout and resin fracture. But, increase of thermal conductivity in 15% V_f is mainly due to change in energy dissipation mechanism.

Table 1: Thermal conductivity, thermal diffusivity and specific heat of composites at different fiber loading

Volume ratio of the fiber			Thermal conductivity, k (W/m K)	Specific heat, C_p (J/kg K)	Thermal diffusivity, a (mm^2/s)
BR	GF	Vinyl ester			
Neat resin			**0.18**	**900**	**0.153**
40	0	60	0.196	800	0.196
37	3	60	0.186	850	0.197
33	7	60	0.183	1000	0.183
29	11	60	0.182	1150	0.159
25	15	60	0.188	1200	0.164

3.2 Evaluation of Thermal Conductivity using Theoretical Models

The comparison between the experimental thermal conductivity of the composites and some theoretical models as a function of different fiber loadings are given in Table 2.

Table 2: Theoretical and experimental thermal conductivity values

Volume ratio of the fiber			Thermal conductivity			Experimental Thermal conductivity	Theoretical Thermal conductivity	
BR	GF	Vinyl ester	Vinylester resin k_1 (W/mK)	BR k_2 (W/m K)	Glass k_3 (W/m K)	k (W/mK)	k_{low} (Series model) (W/m K)	k_{sup} (Parallel model) (W/mK)
Neat resin			0.3	0.233	0.374	0.18	0.3	0.3
40	0	60	0.3	0.233	0.374	0.196	0.2690	0.2732
37	3	60	0.3	0.233	0.374	0.186	0.2711	0.2752
33	7	60	0.3	0.233	0.374	0.183	0.2739	0.2778
29	11	60	0.3	0.233	0.374	0.182	0.2908	0.2926
25	15	60	0.3	0.233	0.374	0.188	0.2875	0.2899

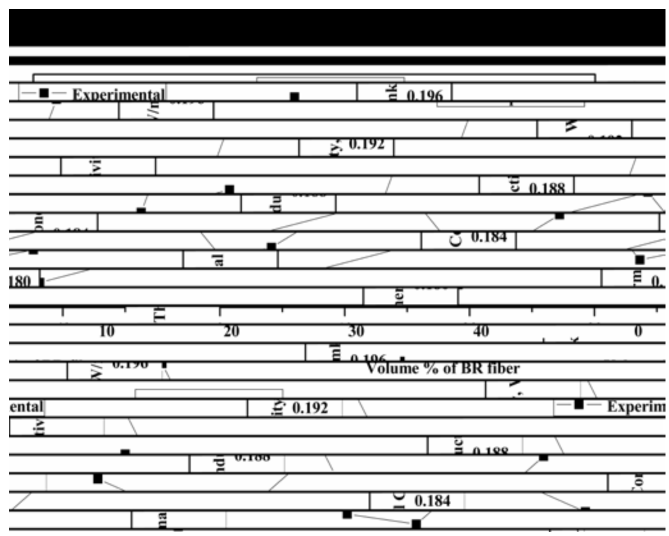

Fig. 1: Thermal conductivity of Composite with volume fraction of fiber

It can be seen the series model comes closer to the experimental results than other models. The reason for good agreement between experimental results and series model may be explained as follows: As the thickness of composite is less than the length of fiber used, there is no random packing in the direction of heat flow and the arrangement of fiber packing is transversal rather than random packing [10].

4. FURTHER SCOPE

A suitable technique has to be developed for the extraction of nanofibrils from bahunia racemosa fiber. High performance Nano composites can be developed using nanofibrils.

5. CONCLUSION

In this work, green composites with various volume fractions of Bahunia racemosa/glass fibers were successfully developed and their thermal properties were investigated. The thermal conductivity of the composites with increased in volume fraction of glass fibers decreases as compared to the composite of pure BR fiber. The variation of thermal diffusivity of composite with respect to fiber content is marginal. Series model gives results closer to the experimental value. Due to good thermal properties, the established composite material can be used for various applications such as automobile interior parts and building construction.

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