Thermal Characterization of Sugar Cane Fiber Reinforced Composite

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***Abstract* - The main focus of this study is on thermal conductivity characterization of Sugar cane fiber reinforced composite. Thermal conductivity is tested by varying the volume fraction and by treating fibers with chemicals such as NaOH and Acetone. Cane fibers are extracted from its stem using retting and mechanical extraction procedure. The thermal conductivity characterization of composites is investigated experimentally by a guarded heat flow meter method and the experimental results of composites at different volume fractions were compared with two different theoretical models (E-S Model and Rule of Mixture Model). Moreover, results show Acetone treated fiber reinforced composite showed decreased thermal conductivity then untreated fiber reinforced composite. On the other hand, NaOH treated fiber reinforced composite showed increased conductivity when compared with untreated fiber reinforced composite. The results of this study indicate that the developed composite is an insulating material. Therefore, this composite can be used in building and automotive industry to save energy by reducing rate of heat transfer.**

Keywords: sugar cane, thermal conductivity, composite

I. INTRODUCTION

In the fast developing society there is a requirement of materials with unusual combination of properties, which cannot be met by conventional metal alloys, ceramics, and polymeric materials. Many of our modern technologies demand not only the strength, but also high performance, specific service materials. In order to fulfill the above requirements lot of research work has been done in the area of material science. At last, Composite materials are chosen as one of the best engineering materials. The flexibility that can be achieved with composite materials is immense. Merely by changing the composition, variety of properties can be obtained thus making the composites versatile and reliable substitutes for the conventional structural materials.

Composite materials have a long history of usage. Their beginnings are unknown, but all recorded history contains references to some form of composite material. More recently, fiber reinforced resin composites that have high strength - to - weight and stiffness - to - weight ratios have become important in weight sensitive applications such as aircraft and space vehicles.

In the composites industry, natural fibers refer to wood fiber and agro based bast, leaf, seed, and stem fibers. These fibers often contribute greatly to the structural performance of the plant and when used in plastic composites, can provide significant reinforcement. Natural fibers are complex and three-dimensional polymer composites, which are made up of cellulose, pectin, hemicellulose and lignin. Recent advances in the use of natural fibers in composites have been reviewed by several authors. Currently natural fibres form an alternative for glass fiber, the most widely applied fiber in the composite technology. The advantage of the natural fibers over synthetic fibers like aramid, carbon or glass fiber are low densities, non abrasive, non-toxic, high filling levels possible resulting in high stiffness and specific properties, biodegradable, low cost, good thermal and acoustic properties, good calorific value and enhanced energy recovery. The environmental impact is smaller since the natural fiber can be thermally recycled and fibers come from a renewable resource.

O.L.S. Alsina et al. [1] focused on thermal properties such as thermal diffusivity, thermal conductivity and specific heat of jute, sisal and ramie hybrid fabric reinforced polyester composites and noticed that the thermal behavior of sisal fabrics differs from the behavior of jute and ramie fabrics. Sherely Annie Paul et al. [2] worked on the periodical method, which is used to estimate the thermal conductivity, thermal diffusivity and specific heat of polypropylene (PP) banana fiber commingled composites at room temperature. It was found that the thermal conductivity and thermal diffusivity of the composites decrease with fiber loading [3]. But the density, specific heat of the fiber composites does not show a significant change [4]. The use of chemically treated banana fibers caused an increase in the thermophysical properties of the composites irrespective of the nature of the chemical treatments.

Xue Li [5] focused on flax fiber-reinforced HDPE bio composites with various fiber fractions were prepared and their thermal properties were investigated. In this study, the thermal conductivity, thermal diffusivity, and specific heat of flax fiber–high density polyethylene (HDPE) bio composites were determined in the temperature range of 170–200C. The fiber contents in bio composites were 10%, 20%, and 30% by mass. Using the line-source technique, the instrumental setup was developed to measure the thermal conductivity of bio composites. It was found that the thermal conductivity, thermal diffusivity, and specific heat decreased with increasing fiber content, but thermal conductivity and thermal diffusivity did not change significantly with temperature in the range studied. The specific heat and density of the bio composites increased gradually with temperature.

Maries Idicula [6] worked on thermal conductivity, diffusivity and specific heat of mixed banana/sisal hybrid fibre reinforced polyester composites were investigated as function of fiber concentration and for several fibre surface treatments. The thermophysical behaviour of hybrid pineapple leaf fibre (PALF)[7] and glass fibre reinforced polyester composites has been also evaluated for a constant total fibre loading of 0.40 Vf by varying the ratio of PALF and glass.

A. Benazzouk [8] focused on the effect of inclusion of rubber particles on the thermal insulating performance and S.R. Hostler [9] put his effort on aerogel materials. Many others [10] estimated the transverse thermal conductivity of continuous fiber reinforced composites containing a random fiber distribution with imperfect interfaces was performed using finite element analysis. FEA results[11] were compared with the classical solution of Hasselman and Johnson to determine limits of applicability Hasselman-Johnson model compared to the analysis of unit cell models. J.L. Bailleul [12] worked on the thermal conductivity of a thermosetting polymeric matrix-based composite material is a thermophysical parameter, which varies significantly during the transformation of the matrix

Aleksandra Lazarenko [13] did study to measure the thermal diffusivity of different types of nanocarbon composites[14]. Thermoexfoliated graphite (TEG), ultrasonically dispersed TEG, and multiwalled carbon nanotubes were used as fillers in epoxy polymer matrixes. The nanocarbon filler content was 1–10 wt%. The temperature dependence of the thermal conductivity and the heat capacity were extensively characterized in the temperature range between 150 and 425K. C.M. Lin and C.W. Chang [15] worked on various products containing bamboo charcoal are popular.P.L. Teh, , has worked on Nanocomposites containing natural rubber (NR) as matrix, epoxidized natural rubber (ENR) as compatibilizer[16]

Extensive work has been carried out on natural fiber reinforced composites and when compared to the research on mechanical properties, the analysis and evaluation of thermal properties of natural fiber reinforced composite is left a step behind. Therefore the focus of the work is to investigate the thermal properties of composite whose natural fibers are extracted from agrowastes which are not explored so far. Finally, working with agrowaste based composite is two way beneficial i.e., the crop residues can be effectively utilized and a composite with attractive properties can be fabricated.

2. MATERIALS AND METHODS

2.1 Materials

Unsaturated polyester resin of grade ECMALON 4411, methyl ethyl ketone peroxide and cobalt naphthanate were purchased from NIkitha marketing associates, Opp. Stella college, Vijayawada-8.

2.2 Fiber extraction

To extract fiber from plant strips a process called retting is employed .This process involves the action of bacteria and moisture on dried sugarcane strips to dissolve and rot away cellular tissues that surround the fiber in the strips. And this soaking process loosens the fibers and can be extracted out easily. Finally, the fibers were washed again with water and dried at room temperature for about 5 days.

2.3 Preparation of composite

Composites are prepared as per the ASTM E-1530 standards. The foremost required resin mixture is prepared by adding accelerator and catalyst to resin at room temperature for curing which was 1.5% by volume of resin. The samples were prepared using Hand lay-up technique. Hand lay-up technique was adopted to fill up the prepared mold with an appropriate amount of polyester resin mixture and unidirectional fibers, starting and ending with layers of resin. Fiber deformation and movement should be minimized to yield good quality, unidirectional fiber composites. Therefore at the time of curing, a compressive pressure of 0.05MPa was applied on the mold and the composite specimens were cured for 24 h. The specimens were also post cured at 70^0C for 2 h after removing from the mold.

2.4 Thermal conductivity measurement

Thermal conductivity of the composites as a function of volume fraction (Fig. 1) was measured using guarded heat flow meter (Unitherm model 2022, ANTER Corp., Pittsburgh, PA).

In accordance with ASTME1530–99, the test sample of size 50 mm in diameter and 10 mm in thickness were prepared. Following equations correspond to the calculation of thermal conductivity :

Where q is the heat flux (Wm^{-2}), k is the thermal conductivity ($Wm^{-1}\ K^{-1}$), T_1-T_2 is the difference in temperature (K), L is the thickness of the sample (m), and R is the thermal resistance of sample (m^2KW^{-1}).

3.1 Measurement of thermal conductivity

According to the literature, the effective thermal conductivity of a composite or a blend depends upon the conductivity of the individual components [10]. Fiber length, fiber aspect ratio, relative modulus of the fiber and matrix, thermal expansion mismatch are all-important variables that controlthe performance of a composite [12,17].Thermal conductivity of the composites as a function of volume fraction was measured using guarded heat flow meter. In accordance with ASTME1530–99, the test sample of size 50 mm in diameter and 10 mm in thickness were prepared. Following equations correspond to the
Calculation of thermal conductivity:

$$q = \frac{k(T1 - T2)}{L}$$

$$R = \frac{(T1 - T2)}{q}$$

$$k = \frac{L}{R}$$

Where q is the heat flux (Wm^2), k is the thermal conductivity (W/mK), T1-T2 is the difference in temperature (K), L is the thickness of the sample (m), and R is the thermal resistance of sample (m^{2}K/W).

Thermal conductivity of sugarcane fiber reinforced composites with different fiber loadings are presented in Table 1.The results show that thermal conductivity of composites decreases as fiber content increases. The thermal conductivity of fiber and matrix have been evaluated by extrapolating the linear regression of thermal conductivity values of the composite to 100% fiber and 0% fiber and are found be 0.07W/mK and 0.2386W/mK respectively. The behavior of the thermal conductivity of different composites can now be explained using thermal conductivity values of the fiber. Further, the measured thermal conductivity of composites was compared with series model (Rule of mixture) and E-S model. The expressions for these two models are:

Series model:

$$\frac{1}{k_c} = \frac{v_f}{k_f} + \frac{1 - v_f}{k_m}$$

E-S model:

$$k_e = \frac{k_c}{k_m} = 1 - \frac{1}{c} + \frac{\pi}{2d} - \frac{c}{d\sqrt{d^2 - c^2}}\, ln \frac{d\sqrt{d^2 - c^2}}{c}$$

The calculated and measured thermal conductivity of sugarcane fiber-polyester composites as a function of fiber content are presented in (Fig. 1). It is observed that the two theoretical models overestimate the value of thermal conductivity with respect to the experimental ones. This may be attributed to the fact that some of the assumptions taken for model are not practical. In E-S model, the cross section of the fibers was assumed to be elliptical, while in the present it is not perfectly elliptical. Further, in theoretical models, orientation of the fibers was assumed to be perfect, but in actual practice when liquid matrix is poured over the fibers some of the fibers may be misaligned. However, at higher volume fractions of fiber, the experimental values of thermal conductivity are in agreement with the predicted values (Fig. 2). Effect of volume fraction on thermal conductivity of composites with NaOH treated fiber and variation of thermal conductivity of NaOH treated fiber reinforced composite with theoretical values are shown(fig 3,4). In the same manner, effect of volume fraction on thermal conductivity of composites with Acetone treated fiber and variation of thermal conductivity of Acetone treated fiber reinforced composite with theoretical values are shown(fig 5,6). The thermal conductivity of all the samples decreases with the increase of volume fraction of fiber. The variation of thermal conductivity of fibers both treated and untreated with respect to change in their volume fractions is shown (fig. 7).

Sugarcane fiber reinforced composite showed least thermal conductivity when compared to polyester resin, glass composite and bamboo fiber reinforced composite (Fig. 8). The results indicate that the sugarcane fiber reinforced composites considered in this study have good thermal insulation properties. The core of the fibers is porous and air is entrapped. This may be the reason for higher thermal insulation properties of the composites. Hence; these materials may be considered as building components to reduce heat transfer in air conditioned buildings in order to decrease energy consumption.

Volume fraction of fiber	Thermal conductivity W/mk		
	Untreated	NaOH treated	Acetone treated
0.23	0.193	0.205	0.189
0.32	0.185	0.189	0.171
0.41	0.165	0.177	0.162

Table 1: Variation of thermal conductivities for varying volume fractions of different fibers

Volume fraction of fiber	Thermal conductivity W/mk		
	Experimental	Rule of mixture model	E-S Model
0.23	0.193	0.154	0.2
0.32	0.185	0.135	0.192
0.41	0.165	0.121	0.187

Table 2: Variation of thermal conductivities of untreated fiber for varying volume fraction

Volume fraction of NaOH treated fiber	Thermal conductivity W/mk		
	Experimental	Rule of mixture model	E-S Model
0.23	0.205	0.169	0.217
0.32	0.189	0.158	0.190
0.41	0.177	0.137	0.189

Table 3: Variation of thermal conductivities of NaOH treated fiber for varying volume fraction

Volume fraction of Acetone treated fiber	Thermal conductivity W/mk		
	Experimental	Rule of mixture model	E-S Model
0.23	0.189	0.150	0.192
0.32	0.171	0.133	0.181
0.41	0.162	0.121	0.179

Table 4: Variation of thermal conductivities of Acetone treated fiber for varying volume fraction

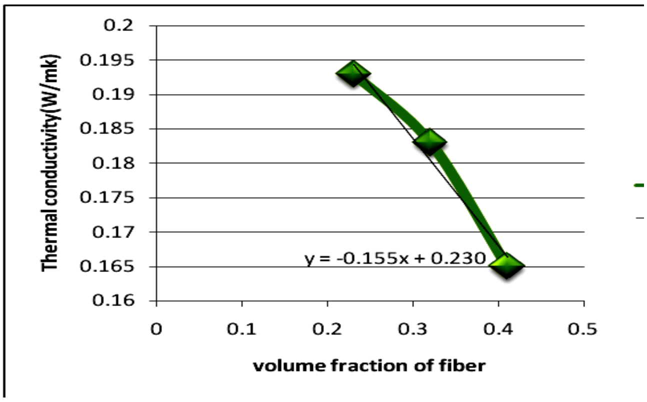

Fig. 1: Effect of volume fraction on thermal conductivity of composites with untreated fiber.

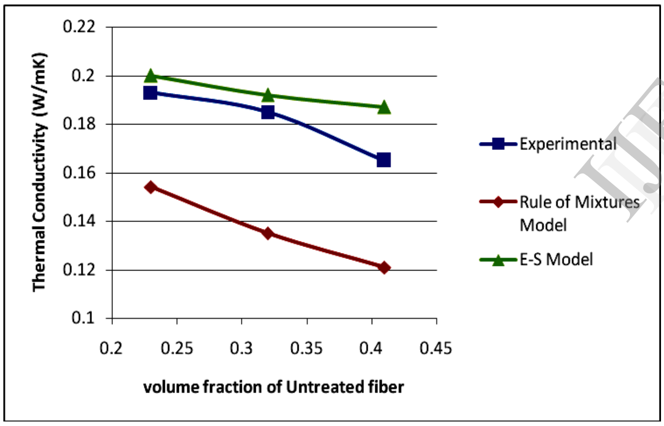

Fig 2: Variation of thermal conductivity of untreated fiber reinforced composite with theoretical values

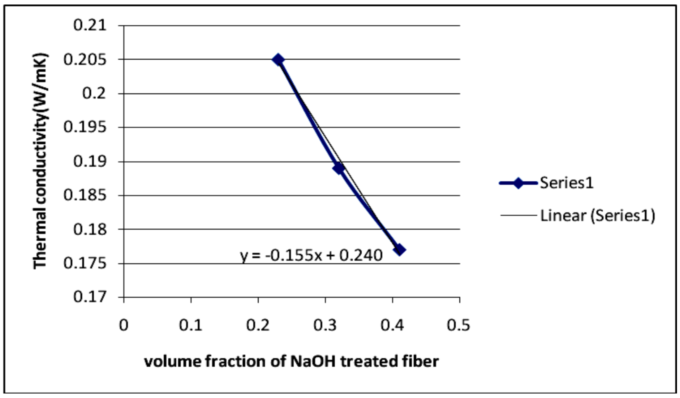

Fig. 3: Effect of volume fraction on thermal conductivity of composites with NaOH treated fiber

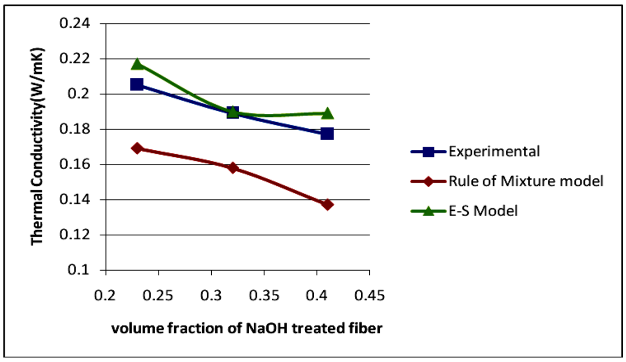

Fig 4: Variation of thermal conductivity of NaOH treated fiber reinforced composite with theoretical values.

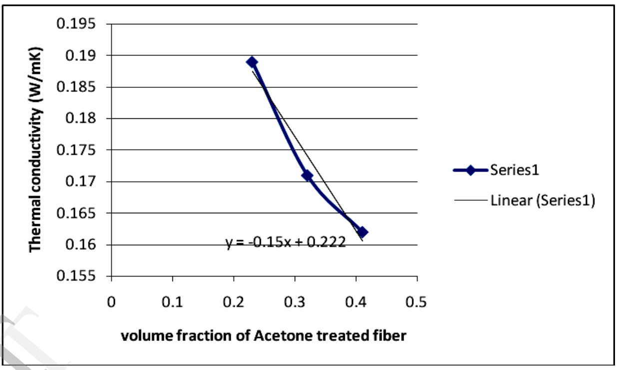

Fig. 5: Effect of volume fraction on thermal conductivity of composites with Acetone treated fiber

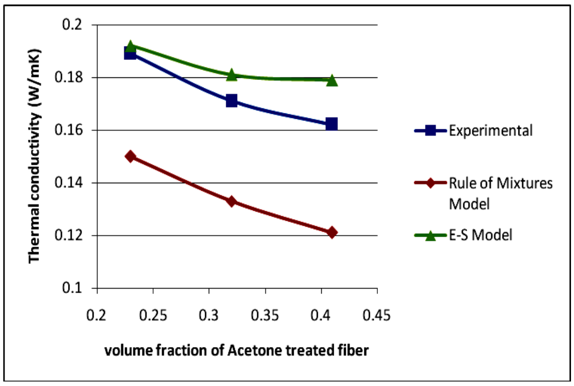

Fig 6: Variation of thermal conductivity of Acetone treated fiber reinforced composite with theoretical values.

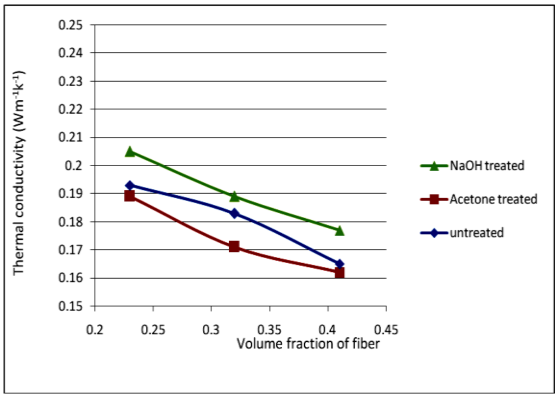

Fig 7: Variation of thermal conductivity of various fibers reinforced composite with temperature at specified volume fraction.

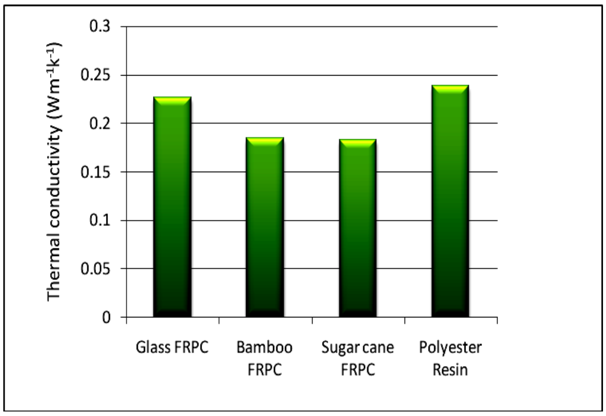

Fig 8. Comparison of thermal conductivities of various composites with polyester resin.

3.2 Density of Composite

The variation in density of composite with respect to volume fraction of fiber is presented in Fig. 9. It is clearly evident that the density of the composite decreased with fiber content. The porous nature of the fibers may be responsible for decrease in the density of the composites under study. This means that with increase in fiber content, composites become light in weight. Hence, it is an attractive parameter for design of light weight structures.

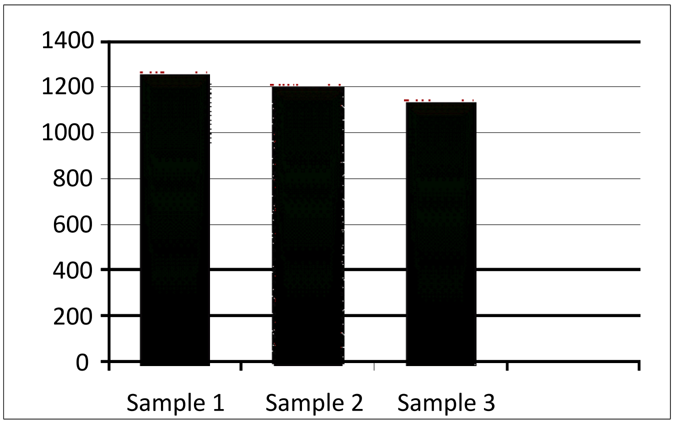

Fig 9: Variation of density of composite with volume fraction of fiber

CONCLUSIONS

Natural fiber reinforced polyester composites thermo physical properties are studied and the following conclusions are derived.

- The density of the natural fiber reinforced polyester composite decreases as fiber content increases.
- The incorporation of the Sugarcane fiber induces a decrease of the effective thermal conductivity of the composite with the increase of the fiber content. The low thermal conductivity of the natural fiber reinforced polyester composite will help to prevent heat transfer in to building and consequently to save energy.
- Thermal conductivity of NaOH treated fiber reinforced composite is higher when compared to untreated fiber reinforced composite & Acetone treated reinforced composite. Amongst these Acetone treated fiber reinforced composite showed least thermal conductivity values.

The results of this study indicate that the sugarcane treated reinforced composites are light in weight & exhibit good insulating properties. Hence newly developed composite material can be used for applications such as automobile interior parts, electronic packages, building construction & sports goods.

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