Thermal Conductivity Characterization Of Areca Palm Fiber Reinforced Polymer Composites

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Abstract-
The main scope of our work is to investigate the thermal conductivity characterization of Areca Palm fiber reinforced polymer composites. The results are explicated by varying the volume fraction, temperature and also the fiber angles (0°,45°,90°). Areca Palm fibers were extracted from its stalk using the retting process. Those extracted fibers were reinforced with polymer composites in polyester resin matrix in order to form bio-degradable green composites. The Thermal conductivity characterization is experimentally explored with the help of Direct thermal conductivity meter method. The outcome included that the variation of thermal conductivity with the fiber volume fraction and also with the temperature variation. There is discrepancy in thermal conductivities with the fiber orientation. At maximum volume fractions, the Areca Palm FRPC attained the values of 0.175W/m.K, 0.181W/m.K, 0.188W/m.K for the fiber angles of 0°,45°,90° respectively. The low values of these natural composites indicate that this can be used as an insulating material and also in internal components of automobiles and shipbuilding industry.

Key words: Areca Palm, Natural fiber, Thermal conductivity, Fiber orientation, Direct Thermal conductivity.

I. INTRODUCTION

In recent days, the usage of the natural composites is increased due to their availability and the cheaper cost. These composites are bio-degradable green composites and their characteristics are attractive. The reason for the focus on the natural composites is increased and they can replace the place of synthetic fibers. Almost all the natural fiber composites are used in the light weight applications. They can be used as insulators because of their low thermal conductivity. Natural fiber reinforced composites are advantageous over the metals and metalloids when excellence corrosion resistance is required [1]-[3]. Natural composites can easily adaptable in the light weight applications because of its divergent characteristics. Almost most of the natural fibers are abundantly available and their preparation is simpler.

Research work was done on the exploration of mechanical properties of the natural fiber reinforced composites such as kenaf, betel nut, bamboo, coconut, pine apple, hemp, mother tree fiber etc. These can be investigated to estimate the strengths of different fibers which can be used in various real time applications.

The recent works on Areca Palm fiber is to explore its tensile, impact and flexural strengths. When the fiber is exposed to alkali treatment, its strength increases ultimately. Sherely Annie Paul et al had worked on the method of estimating the thermal conductivity, thermal
diffusivity of polypropylene (PP)/ banana fiber commingled composites at 240°C temperature. It is observed that thermal conductivity and diffusivity decreases when the fiber loading decreases. Also he experimentally investigated the thermal conductivity values of the reinforced composites at the temperatures ranging from 170°C-200°C using the linear regression method[4].

C.L.Choy, W.P.Leung was worked on the estimation of thermal properties of metallic glasses at the various temperatures. Their results indicate that the metallic glasses possess higher thermal conductivity values when compared to the natural fiber reinforced composites. Thermal conductivity values imparted for the fiber composites shows that their usage in the electrical conducting devices and also in the places of circuit boards [5].

Captivatingly, various types of natural fibers which are generously available like areca sheath, oil palm, banana, bamboo, sisal, jute, flax straw, sugarcane, cotton, wheat, silk, and coconut have proved to be good and efficient reinforcement in the thermo-set and thermoplastic matrixes.

The Areca Palm is a clustering palm that grows in tropical to many moderate climate zones, gets a full-grown height of fifteen to forty feet, and has stalk diameters of two to four inches. All mature stalks are more or less the same diameter with no dominant trunk when trunks are mature. Clumps seen in most areas usually have about a dozen stalks or less, although mature specimens of just one trunk and as many as sixty are known to exist [6].

An excellent review by Pinku Poddar on mechanical and thermal properties of Areca Palm covers a variety of reasons that result in problems associated with composite properties falling short of their true reinforcing potential. Adding the polar and hydrophilic fibers with non-polar and hydrophobic matrix can result in difficulties associated with the dispersion of fibers in the matrix[7].

In recent trends, environmental policies of developed countries are increasing the pressure on manufacturers to consider the enviroweight of their products. Therefore, the need in using fibers as reinforcement in composites is nurturing mainly because of its renewability.

Kalaraprasad worked on the exploration of thermal conductivity and diffusivity of sisal reinforced polyethylene composites. The thermal conductivity values are estimated from cryogenic temperatures to higher temperatures[8]. Kanagaraj results conclude that the thermal properties enhanced at cryogenic temperatures achieve the lower values when compared to other temperatures. Also he measured the values of thermal expansion at lower temperatures [9]. The aim of our research is development of bio-degradable composites and characterization of Areca Palm natural fiber composites on its thermal properties. The investigative study also covers orientation effect of fiber in composite.

II. MATERIALS AND METHODS

A. Materials

Unsaturated polyester resin of grade ECMALON 4413 having the density of 1.38 gm/cc, MEKP (methyl ethyl ketone peroxide) and cobalt naphthanate were supplied by Bindu Agencies., Andhra Prades, Vijayawada, India.

B. Fiber Extraction

The retting process is implemented in order to extract the fibrous material from areca palm stem. This method involves the exploit of fungus and moisture on dried out areca palm stem strips by immersing them so that it will remove all cellulose content that enclosures the fibrous material in the strips. The soaking process loosens the fibrous material so that extrication process will be easy. Then it is allowed to dry at room temperature for 5-7 days.
C. Preparation of Composites.

Composites were made according to the ASTM E-1530 standards[10]. The mould is prepared on ceramic tile with rubber shoe sole to the required size. Initially the ceramic tile is cleaned with shellac (NC thinner), a spirituous product to ensure clean surface on the tile. Then mould is prepared keeping the rubber sole on the tile. The gap between the rubber and the tile is separated with 100 microns OHP sheet. A slight coating of PVA(poly vinyl alcohol) is applied on the contact surface of the specimen, using a brush. The resulting mould is cured for 19 hours.

Hand lay-up technique is adopted to fill the equipped mould with common purpose polymer resin. The blend was made from unsaturated polyester with methyl ethyl ketone peroxide catalyst & cobalt naphthenate accelerator and were mixed thoroughly. Multidirectional composites were arranged, using polyester matrix to assess the reinforcing capacity of Areca palm fibers. The quantity of accelerator and catalyst added to resin for curing was 1.5% by amount of resin each at room temperature. The composites are left alone for 1-2 days for the completion of molding of composites.

D. Measurement of Thermal Conductivity

Thermal conductivity of the composites as a function of volume percentage and fiber direction was measured using the direct thermal conductivity meter (Model: DTC-300, Make:
According to ASTME 1530-99, the test samples of size 50mm in diameter and 10mm thickness were prepared. The following equations represent the calculation of thermal conductivity:

\[ q = \frac{k(T_1 - T_2)}{L} \]

\[ R = \frac{(T_1 - T_2)}{q} \]

\[ k = \frac{L}{R} \]

Where \( q \) is the heat flux (W/m²), \( k \) is the thermal conductivity (W/m.K), \((T_1-T_2)\) is the difference in temperature (K), \( L \) is the “thickness” of the sample (m), and \( R \) is the “thermal resistance” of sample(m².K/W).

III. RESULTS AND DISCUSSION

A. Measurement of Thermal Conductivity

Thermal conductivity of Areca Palm fiber reinforced polymer composites with varying fiber volume fraction and fiber and fiber angles are listed in the below table. It is observed that the thermal conductivity decreases when the volume fraction increases.

B. Theoretical measurement of Thermal Conductivity

The thermal conductivity of fiber and matrix can be evaluated by using the regression analysis of the composite. The thermal conductivity values of the composite to 100% fiber and 0% fiber are found to be 0.05W/mK and 0.2371W/mK respectively. The etiquette of the thermal conductivity of the composites can be evaluated[12] and can be compared with the theoretical models: Rule of mixture(1) and E-S model(2). The expressions for these two models are as follows:

Series Model:

\[ \frac{1}{k_c} = \frac{v_f}{k_f} + \frac{1-v_f}{k_m} \]  \hspace{1cm} (1)

Series Expansion Model:
\[ K_e = \frac{k_c}{k_m} = 1 - \frac{1}{c} + \frac{\pi}{2d} - \frac{c}{d\sqrt{d^2 - c^2}} \ln \left( \frac{d + \sqrt{d^2 - c^2}}{c} \right) \]

Where \( c = \frac{\pi\rho}{v_f} \), \( d = \rho (1/\beta - 1) \), \( \beta = \frac{k_f}{k_m} \), and \( v_f \) is the volume fraction of fiber. \( k_c, k_f \) and \( k_m \) are the thermal conductivity of composite, fiber and matrix respectively. The procured theoretical values of thermal conductivity are listed in the below Table II. The difference between the theoretical values are due to some of the predictions in the theoretical models. They assumed that the fibers are perfectly aligned in the reinforced matrix. Also in the E-S Model (2), the cross-section of the fiber should be elliptical but the real composite cross-section is to be circular which leads to the variation in the thermal conductivity value. The thermal conductivity increases with increase in temperature (Fig.6) for all samples because in this condition, the phonons vibration is the thermal carrier and the moisture in the fiber and sample escapes completely. Areca palm fiber shows the least value of thermal conductivity when compared to glass FRPC, bamboo FRPC, polyester resin (Fig.7). These results indicated that areca palm FRPC have high thermal insulation properties due to porous structure of fibers and air entrapment. Hence these can be used to reduce heat transfer, in the building components of aircraft due to its light weight and also in the internal shipbuilding components.

<table>
<thead>
<tr>
<th>Volume fraction of the fiber(%)</th>
<th>Thermal Conductivity(W/m.K)</th>
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<tbody>
<tr>
<td></td>
<td>At 0° fiber angle</td>
</tr>
<tr>
<td>16.5</td>
<td>0.199</td>
</tr>
<tr>
<td>21.3</td>
<td>0.196</td>
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<tr>
<td>27.9</td>
<td>0.184</td>
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<tr>
<td>34.8</td>
<td>0.175</td>
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<tr>
<th>Volume fraction of the fiber(%)</th>
<th>Thermal Conductivity(W/m.K)</th>
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<tbody>
<tr>
<td></td>
<td>Experimental</td>
</tr>
<tr>
<td>16.5</td>
<td>0.199</td>
</tr>
<tr>
<td>21.3</td>
<td>0.196</td>
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Fig. 4. Thermal conductivity variation of fiber reinforced composite with fiber angle at specified volume fraction.

Fig. 5. Thermal conductivity variation of fiber reinforced composite with specified volume fraction.
In this work, bio-degradable green composites with varying volume fraction of areca Palm fiber were developed and their thermal conductivity values were investigated through experimental technique by using Direct thermal conductivity meter. Thermal conductivities of natural composites are explored with varying volume fraction and fiber angles\textsuperscript{[13]-\textsuperscript{[14]}}. From the procured results, the following conclusions are drawn:

1. The thermal conductivity of the composites had decreased when the volume fraction of the fiber increases. The highest fiber volume fraction composites attains least value of 0.175 W/m.K at 0\textdegree fiber orientation.
2. The thermal conductivity of the composites increases with the increases in the fiber angle and the value attained is 0.215 W/m.K at 90\textdegree fiber orientation.
3. The thermal conductivity values are explored in the range of 40\textdegree C-70\textdegree C temperature variation and the highest value is attained is 0.214 W/m.K.
4. Thermal conductivity of areca Palm fiber reinforced polymer composites increases with the increase in the temperature.
5. The highest thermal conductivity value achieved is 0.215 W/m.K at 90° fiber angle orientation.
6. The experimental values were compared with the theoretical values with the help of theoretical methods.
7. Our comparison slightly attains the greater values than the theoretical ones due to some of the predictable assumptions in the theoretical methods.
8. Areca Palm fiber composites shows slightly less thermal conductivity values than bamboo FRPC and glass FRPC which indicates that it can be used as an insulating material.
9. The results of thermal analysis shows that the areca Palm fiber composite’s stability increases.

The results of our work also concluded that areca palm fiber reinforced composites are light weight and possesses good thermal and mechanical properties[15]. These fiber reinforced composites can be used in the preparation of ship building, aircraft components, automobile interior parts, electronic goods etc.

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