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Theoretical Investigation of Thermal Behaviours of PU Foam Sandwich Structure with Curaua Fibers and E Glass Composites

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***Abstract*— A PU foam sandwich structure with Curauá fibers and E-glass exhibits good thermal insulation due to the low thermal conductivity of the PU foam core and the high thermal conductivity of the E-glass, while the Curauá fibers potentially improve the mechanical properties without significantly impacting the thermal properties. Simultaneous measurment of effective thermal conductivity (k) and effective thermal diffusivity (α) of pineapple leaf fiber reinforced phenolformaldehyde (PF) composites have been studied by transient plane source (TPS) technique. t is found that of effective thermal conductivity and effective thermal diffusivity of the composites decrease, as compared with pure PF as the fraction of fiber loading increases. Using Y. Agari, model thermal conductivity of pure fiber is evaluated and compared with the thermal conductivity of fiber determined by extrapolated experimental value of composite. Also, we have compared the results of thermal conductivity of composites with two models (Rayleigh/Maxwell and Meredith /Tobias model). Good agreement between theoretical and experimental result has been found.**

***Keywords*— Fiber reinforced polymer; Thermal conductivity; Thermal diffusivity; Transient plane source technique**

I.INTRODUCTION

The increase in cost and effect on environments due to synthetic fiber reinforced polymers have forced the scientists and engineers to synthesize new materials and composites which, besides having their needed specific physical properties [1-4] are cost-effectiveas well as environmentally friendly [5].Maintaining the Integrity of the Specifications. In this context, the use of inclusion of natural fiber over the synthetic fiber in polymers matrix has gained momentum during last decade [6-8]. The inclusion of natural fiber such as pineapple leaf (PALF), jute, sisal, palm and banana in some thermosetting polymer e.g. phenolformaldehyde (PF) has not only changed their brittle character and some other thermal properties but also brought reduction in cost and made the composite more environmentally friendly.

Thermal properties such as effective thermal conductivity and effective thermal diffusivity are of paramount importance for the scientists and engineers for specific use of a particular composite for a specific purpose. So the present study is aimed at observing the variation in these thermal properties by reinforcing varying volume fraction of pineapple leaf fiber [9-12] in PF matrix at room temperature and normal pressure using transient plane source (TPS) technique. Polyurethane foam (PUF) exhibits excellent thermal insulation due to its closed-cell structure. Research explores incorporating Curauá fiber (CF) as a filler in rigid PUF composites, potentially influencing thermal behavior. The studies evaluate the impact of CF on these composites, likely assessing thermal conductivity and stability. While E-glass is not explicitly mentioned, the focus is on the thermal properties of PUF and the effect of Curauá fiber reinforcement. These morphological features were responsible for the gains in mechanical properties, in both parallel and perpendicular rise directions, and better viscoelastic characteristics. Despite the gains, higher thermal conductivity and lower flammability were reported for the developed RPUF composites, related to the high content of cellulose and hemicellulose on the bleached CF chemical composition. This work shows the possibility of using a Brazilian vegetable fiber, with low exploration for the manufacturing of composite materials with improved properties. The developed RPUF presents high applicability as enhanced cores for the manufacturing of structural sandwich panels, mainly used in civil, aircraft, and marine industries. For instance, they are being considered for the fuselage structures of commercial aircraft [13]. The design of hinge-less & bearing-less helicopter rotor hubs also employs laminated composite materials, which experience both centrifugal loads and bending in the flapping flexural region. In order to meet the demand for improved performance of these structural materials, it becomes necessary to evaluate them under multi-axial loading. His research has focused on developing of the composite material considering improvised electrical & thermal property. His research focuses on the integration of functional materials into polymer matrices to achieve tailored

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properties, including the utilization of polyethylene fibers as material for reinforcement structures [14],[15]. The extracted fibers are then subjected to drying under sunlight for ten hours to eliminate residual moisture. The fibers which are extracted will be then dried & washed under broad sunlight for removing the excess moisture. A metal brush was used to comb the surface of the fibre for the removal of the waste particles [16].

II. MATERIAL SELECTION

As a solution, natural fibers are increasingly being used due to their low cost, biodegradable nature, availability, and renew-ability. The present study fabricates hybrid composite laminates is to used sisal & fibers made of glass that too being reinforced using polyester & epoxy material for studying the mechanical and physical property [17]. The stacking sequence and weight %age of matrix & fibre were varied to fabricate the composite laminates.

A. Synethic Materials

Fiber reinforced polymer composites are often made with glass fibers due to their low cost, high tensile strength, chemical resistance, and insulating properties. There are two types of glass fibers commonly used in the industry: S-glass and E-glass. S-glass is known for its high tensile strength, greater modulus, and higher elongation at failure, and was originally developed for use in missile casings, aircraft components, and helicopter blades. However, it is more expensive due to its compositional difference and higher manufacturing cost. E-glass, on the other hand, is the least expensive reinforcing fiber available, and is therefore widely used in the FRP industry. For the purposes of this research, E-glass fibers were chosen to create Glass-Sisal hybrid composites. Plain woven fabric form was used to achieve uniform fiber distribution, minimize void formation, and ensure uniform laminate thickness [18]. For preparing these composites we need pineapple leaf fiber and PF. The resole type PF resin is obtained from Coast Polymers Pvt. Ltd., Kannur, Kerala, India while pineapple leaf fiber are supplied by South India Textile Research Association, Coimbatour. The pithy material of pineapple leaf is removed after retting process. The fibers were cut into 40 mm length and randomly oriented mats are prepared. Composites have been prepared by hand lay up method followed by compression moulding at 100 8C for about 30 min. Composites having weight percentages of 15-50% have been prepared.

B. Experimental technique and theory of transient plane source technique

Simultaneous measurements of thermal conductivity and thermal diffusivity of all the composites have been made at room temperature and normal pressure using TPS technique. The sample size used for the study is 1.9 /1.9 cm^2 . Thickness of the samples is approximately 0.3 cm. The TPS technique has proven to be a precise and convenient method for measuring the thermal transport properties of electrically insulating materials. The TPS method consists of an electrically conducting pattern (Fig. 1) in the form of a bifilar spiral, which also serves as a sensor of the temperature increase in the sample. In Fig. 1, K-4521 is the design No. of the sensor and K stands for kapton. The sensor is sandwiched between the thin insulating layers of kapton. Assuming the conduc- tive pattern to be in the Y/Z plane of a co-ordinate system, the rise in the temperature at a point Y/Z at time t due to an output power per unit area Q is given by [19].

$$\Delta T(y,\ z,\ t) = \frac{1}{8\pi^{3/2}c\rho} \int_0^t \frac{dt'}{\kappa^{3/2}(t-t')^{3/2}} \int_A dy'\, dz'$$
$$\times Q(y',\ z',\ t')\exp\left[\frac{-(y-y')^2-(z-z')^2}{4\kappa(t-t')}\right] \quad (1)$$

where r be the density of composite, 'c ' be the specific heat and k be the thermal diffusivity. If one of the integration variables in Eq. (1) is transformed by assuming k (t-t')=$\sigma^2 a^2$, Eq. (1) can be written as:

$$\times Q\left(y',\ z',\ t'-\frac{\sigma^2 a^2}{\kappa}\right)\exp\left[\frac{-(y-y')^2-(z-z')^2}{4\sigma^2 a^2}\right] \quad (2)$$

$$\Delta T(y,\ z,\ \tau) = \frac{1}{4\pi^{3/2}a\lambda}\int_0^\tau \frac{d\sigma}{\sigma^2}\int_A dy'\, dz'$$

For our experimental work, the approximate solution of Eq. (2) assuming that the disc consist of certain number (m) of concentric ring sources, the average increase in temperature:

$$\kappa = \frac{\lambda}{\rho c}$$

$$(3)$$

$$D_s(\tau) = [m(m+1)]^{-2}$$
$$\times \int_0^\tau \frac{d\sigma}{\sigma^2}\left[\sum_{l=1}^{m} l\left\{\sum_{k=1}^{m} k\, e\frac{(-l^2+k^2)}{2\sigma^2 m^2}\, L_0\left(\frac{lk}{2\sigma^2 m^2}\right)\right]\right.$$

$$\overline{\Delta T(\tau)} = \frac{P_0}{\pi^{3/2}a\lambda}\, D_s(\tau)$$

$$(4)$$

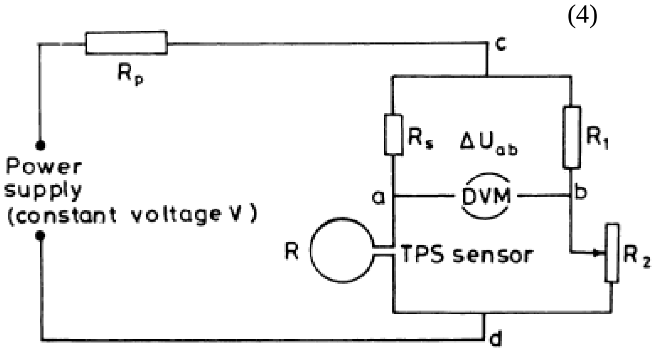

Fig. 2. Bridge circuit diagram for the TPS technique. R1 and R2 are the resistance, R is the effective resistance of the wires

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outside the arms of p bridge, R is the resistance of the TPS element and DVM is the digitals voltmeter. Uab is the potential difference between the point a and b in the bridge circuit.

P_0 is the total output power, and L0 is the modified Bessel function. This increase in temperature DT (t) gives rise a change in electrical resistance DR (t) which causes a potential difference DU (t) that can be measured by a voltmeter in the bridge in Fig. 2. For recording the DU (t), we havetoevaluate Ds(t) using a computer program. Therefore, by calculating potential difference DU (t) one can determine thermal conductivity, ,and thermal diffusivity, k. Thermal conductivity and ther- mal diffusivity of all the samples have been measured using the TPS method [14], which are reproducible within 2-2.5%.

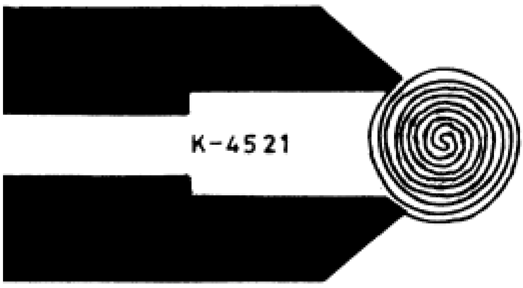

Fig. 1. Schematic diagram of the TPS sensor

III. SIMULATION RESULTS

The thermal conductivity Table 1 of the pineapple leaf fiber has been calculated using Y. Agari model [15-17]. According to the model the logarithm of the thermal conductivity of the composite is linearly related to the volume percentage of the filler as follows:

$$\log \lambda = A \cdot V + B \quad (5)$$

where $A = C_f \log(\lambda_f/(C_p\lambda_m))$; $B = \log(C_p\lambda_m)$.

Here lf χ_f and χm are the thermal conductivity of the filler and matrix, respectively. Cf and Cp are the constants and V is the volume percentage of the filler in the composite. The thermal conductivity of the matrix has been measured experimentally and has also been obtained by extrapolating the experimental values of thermal conductivity of composite to zero volume fraction of fiber. The logarithm of the experimental values of the thermal conductivity of composite has been plotted as a function of the volume percentage of the fiber and using Eq. (5) the thermal conductivity of the fiber has been evaluated. The effective thermal conductivity of two-phase composite has been explored by using two different theoretical approaches. In the first approach the effective thermal conductivity is evaluated by considering a random distribution of dispersed phase. Rayleigh and Maxwell [18,19] model, for effective thermal conductivity of a composite, for a two-phase dispersion of spherical particle in a continuous medium is given as:

$$\frac{\lambda_{eR}}{\lambda_m} = \frac{\{2 - 2V + (1 + 2V)(\lambda_f/\lambda_m)\}}{\{2 + V + (1 - V)(\lambda_f/\lambda_m)\}} \quad (6)$$

V is the percentage of the filler in the composite and lf is the thermal conductivity of the fiber. According to Meredith and Tobias [20] effective thermal conductivity (χ_m) of two-phase materials can be calculated by the following expression:

$$\lambda_{eM} = \frac{\lambda_m(A - 2V + 0.409BV^{7/3} - 2.133CV^{10/3})}{(A + V + 0.409BV^{7/3} - 0.906CV^{10/3})} \quad (7)$$

where $A = (2+K)/(1-K)$; $B = (6+3K)/(4+3K)$; $C = (3-3K)/(4+3K)$ and $K = \lambda_f/\lambda_m$.

IV.RESULTS & DISCUSSION

The volume percentage V of fibre has been deter- mined by using the formula:

$$V = \frac{w_1\rho_m}{w_2\rho_f + w_1\rho_m} \quad (8)$$

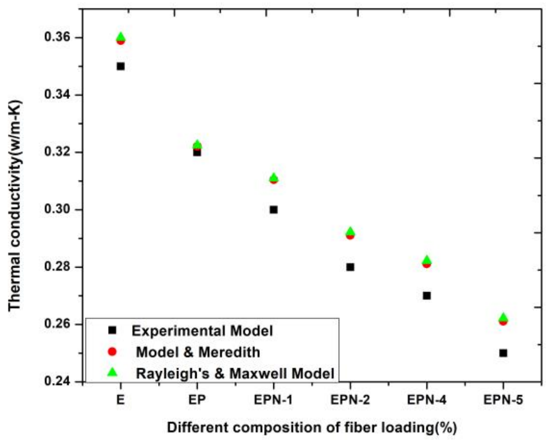

Fig.3 Thermal conductivity versus different composition of fiber loading

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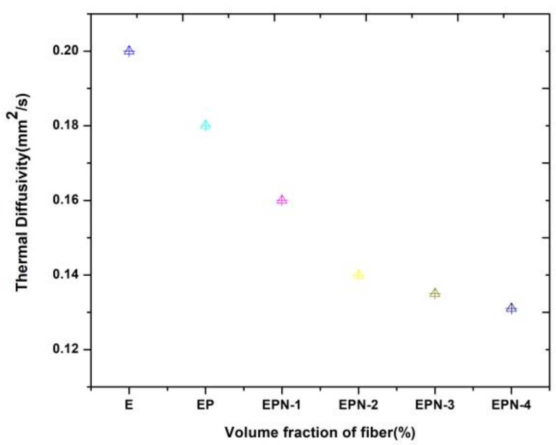

Fig.4 Thermal diffusivity versus different composition of fiber loading

In Fig. 3, the experimental results of effective thermal conductivity have been plotted as a function of volume percentage of pineapple leaf fiber. From the figure, it is clear that as the volume percentage of the pineapple leaf fiber increases the thermal conductivity of the composite decreases. To explain this behavior, thermal conductivity of the fiber has been evaluated using Y. Agari model. The plot is almost a straight line. The value of thermal conductivity of the fibre as obtained from the extrapolation of effective thermal conductivity value of the composite to 100% fiber comes out to be 0.21w/m-K. This value has also been obtained using Y. Agari model and is predicted equal to 0.203 w/m-K. Thermal conductivity of the pineapple leaf fiber is smaller than the thermal conductivity of the PF matrix (0.34w/m-K). However, the extrapolated value of thermal conductivity of PF matrix comes out to be 0.319w/m-K.

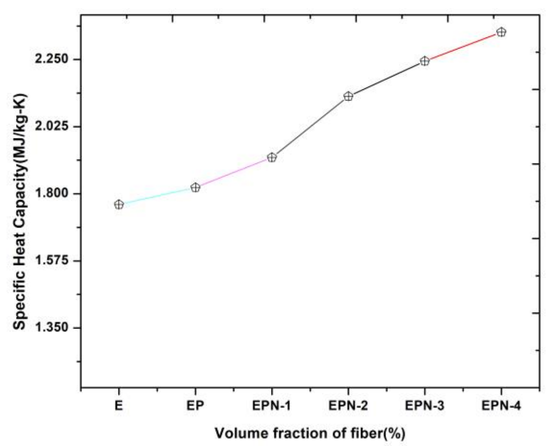

Fig.5 Thermal heat capacity versus different composition of fiber loading

The behaviour of the thermal conductivity of different composites can now be explained using thermal conductivity values of the fiber. As a small fraction (15% by weight) of the PF is replaced by the pineapple leaf fiber thermal conductivity value of the composite decreases from that of the matrix. Further increase of the fiber contents in the composites shows a decreasing trend of thermal conductivity as compared with thermal conductivity of PF matrix. This behaviour of the effective thermal conductivity of the fibre reinforced PF compo- sites seams to be justified because the fiber filled in the PF matrix has lower value thermal conductivity and effective thermal conductivity of composite becomes less as compared with the thermal conductivity of PF matrix.

Fig. 3 also shows the theoretical value of effective thermal conductivity of composites as obtained through the model calculations. Models used to predict the effective thermal conductivity are Rayleigh/Maxwell model and Meredith /Tobias model. Rayleigh /Maxwell considered the shape of the filler to be spherical, which however is not the case for our composites. As discussed earlier the composites have been prepared using the fibres having cylindrical shape. A departure from the spherical shape of the filler have not been taken into account in the models and they predict the value of the effective thermal conductivity in close agreement with the experimental values. In the early process of making composites from PF matrix and fiber mat, they assume some symmetric structures but when molten PF resin are poured over the mat of fibers, arranged initially in order, and composite is cooled down to their stable form, the fiber do not remain directionally symmetric and the random orientations of fibers are visible in the composites. This in fact tends to deviate the thermal conductivity values as compared with the composites obtained with uniform dispersion of the filler in all directions. Nevertheless, the model of Rayleigh/Max- well is applicable to entire range of filler concentration in the composites. Model of Meredith /Tobias does not consider the size and shape of the filler particles and found that the calculated values of thermal conductivity for quartz and diamond composites are in close agreement with experimentally observed values. Same analogy has been applied for our case and the values of effective thermal conductivity have been obtained. It is found that the obtained values of thermal conductivities are in close agreement with the experimentally measured values (Fig. 3). Variation of the effective thermal diffusivity with volume fraction of the filler is plotted in Fig. 4. Thermal diffusivity of the composite show the similar trend as obtained in the case of thermal conductivity, since it is directly proportional to conductivity. From the measured values of thermal conductivity and thermal diffusivity, the specific heat per unit volume have been obtained. These values have been plotted in Fig. 5.Itis found that the values of specific heat remain constant and show a weak dependence on filler concentration as also exhibited by effective thermal conductivity and thermal diffusivity of the composites under investigation.

V.CONCLUSION

Decrease in thermal conductivity and thermal diffusivity of the pineapple leaf fiber reinforced PF composite with the increase of fiber contents in the matrix is suggestive of the fact that fiber in any concentration could not provide the conductive path to the heat energy in the composite material.

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