Experimental Investigation on Thermal Conductivity of Teak Wood Dust Reinforced Epoxy Composites Using Forced Convection Apparatus

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***Abstract - In the present investigation the Thermal conductivity in particulate filler filled (teak wood dust) epoxy composites at different volume fractions (6.5%, 11.3%,26.8% and 35.9%) have been determined experimentally by using Forced Convection apparatus. The composites of teak wood dust particles of 150 micron size have been prepared by using hand-lay-up technique. The experimental results show that the incorporation of pine wood dust results in reduction of thermal conductivity of epoxy resin and there by improves its thermal insulation capability. Experimental results (22mm pipe diameter) are also compared with theoretical models such as Rule of mixture model, Maxwell model, Russell model and Baschirow & Selenew model to describe the variation of thermal conductivity versus the volume fraction of the filler. All these models exhibited results close to each other at low dust filler content. On comparison, It has been found that the errors associated with all the above four models with respect to experimental ones (22mm Dia.) lie in the range of* 7.32 to 23.39%, 11.46 to 30.90%, 14.22 to 33.33% and 2.30 to 26.25% respectively.**

Keywords*: *Forced Convection Apparatus, Epoxy-Pine wood dust composite, Thermal conductivity, Error analysis.

1. INTRODUCTION

Increased environmental awareness and consciousness throughout the world has developed an increasing interest in natural fibres and its applications in various fields. Natural fibres are now considered as serious alternative to synthetic fibres. Natural organic fibers can be derived from either animal or plant sources. The majority of useful natural textile fibers are plant derived with the exceptions of wool and silk. The advantages of natural fibres over traditional reinforcing materials such as glass fibre, carbon fibre etc are their specific strength properties, easy availability, light weight, ease of separation, enhanced energy recovery, high toughness, non-corrosive nature, low density, low cost, good thermal properties, reduced tool wear, reduced dermal and respiratory irritation, less abrasion to processing equipment, renewability and biodegradability. Wood dust (teak wood dust) is an insulating material that retards the conduction and convection of heat. When this wood dust is reinforced with epoxy it forms a composite whose sole effect is to retard the heat transfer rate and hence it's insulation capability can be improved.

2. REVIEW OF LITERATURE

Thermal conductivity is an important thermal property of materials and plays an important role in determining their heat conduction/insulation properties.Numerous theoretical and experimental approaches have been developed to determine the precise value of this parameter.

Russel [1] developed the thermal conductivity model assuming that the dispersed thermally conducting particles are isolated cubes in polymer matrix. Maxwell [2] studied the effective thermal conductivity of heterogeneous materials. The effective thermal conductivity of a random suspension was determined for sphere within a continuous medium by solving Laplace's equation. Baschirrow and Selenewo [3] developed the equation for the case when the particle are spherical and two phases are isotropic. Stein hagen [4] reviewed the thermal conductivity of wood from -40^0C to 100^0C and found that thermal conductivity of wood increases in a linear manner with temperature and density. Little difference was found between its value in tangential and radial directions. Suleiman et al. [5] investigated the thermal conductivity of wood in both longitudinal and transverse directions in the temperature range of 20^0C to 100^0C. Their results showed that thermal conductivity is about 1.5 times more in the longitudinal direction than in the transverse direction due to non-homogenous nature of wood. Fu and mai [6] predicted the effective thermal conductivity of short fibre reinforced polymer composites. It was observed that the thermal conductivity of the composites increases with mean fibre length but decreases with mean fibre orientation angle with respect to the measured direction. Abdul Razak et al.[7] studied the electrical and thermal properties of epoxy-carbon black composites. It was observed that the epoxy-carbon black composites have better thermal properties than the neat epoxy. Alam et al.[8] prepared an experimental set up to determine and analyze thermal conductivities of insulating materials and compared with the literature values. Lee's and Charlton's apparatus were used to measure this property of insulating materials by steady state technique. The thermal conductivities obtained by this apparatus were 0.797W/m-^{0}K, 0.3023W/m-^{0}K and 0.057W/m-^{0}K for borosilicate glass, styrene butadiene rubber and polyolefin foam faced aluminum foil respectively. The experimental results were found to deviate around 9 to 30 % from the literature values. Prisco [9] investigated experimentally the thermal conductivity of wood flour(WF) filled high density polyethylene composite (Wood plastic composite, WPC). Experimental results showed that the WPC thermal conductivity decreases with increase in WF content. Mohapatra et al. [10] prepared the palm fibre reinforced polyester composites (PFRP) by using hand- lay- up technique. The thermal conductivity of the palm fibre reinforced polyester composites at different volume fractions of the fibre were found experimentally by using Lee's apparatus. The experimental results showed that the thermal conductivity of the composite increases with increase in fibre percentage.

3. THERMAL CONDUCTIVITY MODEL

The thermal conductivity of a composite material depends on the fiber, resin materials, fiber volume fraction, orientation of the fiber, direction of heat flow and operating temperature. Many theoretical and empirical models have been proposed to predict the effective thermal conductivity of two phase mixtures.

Series Model (Rule of Mixture):

$$\frac{1}{K_c} = \frac{1-\phi}{K_m} + \frac{\phi}{K_f} \quad \text{.................................(1)}$$

Where subscript, c- composite, m- matrix, f-filler and Φ- volume fraction

Maxwell model:

Maxwell [3] is the one who developed first theoretical model for two phase system. The derived equation is given by Eqn. 2

$$K_c = K_m \left[\frac{K_f + 2K_m + 2\phi(K_f - K_m)}{K_f + 2K_m - \phi(K_f - K_m)} \right] \quad \text{...........(2)}$$

Russel model:

Russel[1] derived an equation for the thermal conductivity of the composite using a series parallel network. The derived equation is in Eqn. 3

$$K_c = K_m \left[\frac{\phi^{\frac{2}{3}} + \frac{K_m}{K_f}(1-\phi^{\frac{2}{3}})}{\phi^{\frac{2}{3}} - \phi + \frac{K_m}{K_f}(1+\phi-\phi^{\frac{2}{3}})} \right] \quad \text{........(3)}$$

Baschirow and Selenew model:

Baschirow and Selenew [12] developed the following equation for the case when the particles are spherical and two phases are isotropic. The model has been given in Eqn. 4

$$K_C = K_m \left[1 - \frac{a^2\pi}{4} + \frac{a\pi p}{2} \left\{ 1 - \frac{p}{a} \ln\left(1 + \frac{a}{p} \right) \right\} \right] \quad \text{....(4)}$$

4. EXPERIMENTAL INVESTIGATION

4.1 Matrix material

The low temperature curing epoxy resin (Araldite LY 556) and the corresponding hardener (HY 951) are mixed in a ratio of 10:1 by volume as recommended. The epoxy resin and the hardener are supplied by Hindustan Ciba Geigy India Ltd. Epoxy is chosen primarily because it happens to be the most commonly used polymer and because of its insulating nature (low value of thermal conductivity, about 0.363 W/m-^{0}K).

4.2 Teak wood dust

Teak wood dust collected from a local vendor has been chosen as the filler material mostly for its light weight and low thermal conductivity (0.085W/m-^{0}K) .

4.3 Composite Preparation

To prepare the composite samples for measurement of thermal conductivity using Forced Convection apparatus a mould was prepared as shown in the Fig.1 The diameter of solid pipe 22mm and inner diameter of outer pipe 37mm with length 300mm and thickness 7.5mm respectively. The low temperature curing epoxy (LY 556) resin and the corresponding hardener (HY 951) were mixed in the ratio of 10:1 by weight supplied by Hindustan Ciba Geigy (India) Ltd. The mixture (epoxy filled with Pine wood dust) was slowly powered into the respective mould. Convectional Hand lay-up technique was used to cast the composite in the respective mould so as to get composite pipe.

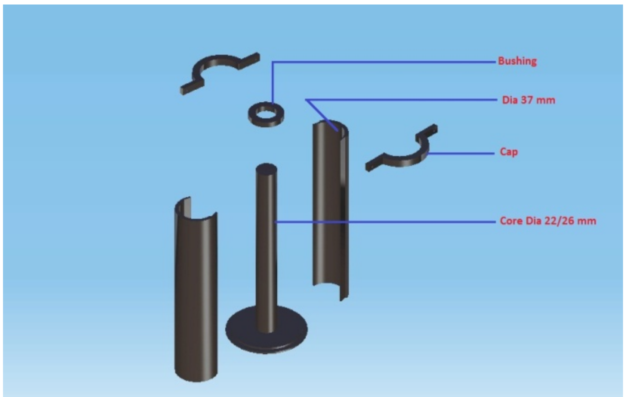

Fig.1 Mould to cast specimens for forced convection method

Composites of four different compositions with (6.5, 11.3, 26.8 and 35.9 Vol. % of Pine wood dust were made.

Silicon spray was used to facilitate easy removal of the composite from the mould. The cast of each composite was cured under a load of about 50 kg for 24hours before it was removed from the mould. Then this cast was post cured in air for another 24hours after removing out from the mould. All these tests were carried out for epoxy/wood dust composites.

4.4 Experimental set up

The thermal conductivity test is carried out with Forced convection Apparatus shown in Fig.2. The Apparatus consists of a blower, orifice meter and thermally insulated composite pipe heated over approximately 30 cm. of its length and provided with thermocouples, selector switches, Manometer: U- Tube as Mercury as working fluid, Dimmer stat: 230V, 2A, Digital Voltmeter of Range 0-300V a.c, Digital Ammeter of Range 0-5A a.c., Heater [Externally Heated, Nichrome Band Type (250W)] and Digital Temperature Indicator. To hold the composite pipes in place with the inlet and the outlet portions two adapter sockets were designed such that they fit over the inlet and outlet pipe. Here the pipes are a perfect fit and the Joint between the inlet/outlet and composite pipes are sealed with epoxy bond *(m-Seal)* for rendering it air tight and not let the air from blower leak to the surrounding. The nichrome heating element was used over the composite pipe and was press fitted longitudinally over it. Thus after being set over the designated pipe it left a small strip of uncovered portion along the axis of the pipe. Hence the pipe was made such that the holes or the perforations for the thermocouples are in a straight line and the pipe is fit in such a manner so as to keep the holes uncovered so that the thermocouples may be inserted into them. Thermocouples were inserted into the pipes for measurement of temperatures. After the above setup was complete the whole assembly of composite pipe and nichrome element was insulated by winding asbestos coated ropes of course by taking into account the projecting thermocouples. A blower was fitted with a test pipe.

Fig.2 Experimental set up of Forced convection Apparatus

Four thermocouples were embedded in the test section. Out of 4 thermocouples, the two thermo couples were placed in the air stream at the entrance and exit of the test section to measure inlet and outlet temperature of air. The rest two were placed in between the entrance and exit of the test section to measure surface temperature (average value of temperature measured by these two thermocouples). The readings were taken when the steady state was reached.

4.5 Thermal conductivity measurement

The thermal conductivity of a material can be defined as a rate at which heat is transferred by conduction through a given unit area of a given material, when the temperature gradient is normal to the cross sectional area.

Rate of heat gain by air (Q_a)

$$Q_a = m_a C_{pa} (T_1 - T_2) \quad \text{................ (5)}$$

Where, C_{pa} = Specific heat of air (J/Kg- ^{0}K)

T_1 = Inlet temperature of air in ^{0}C

T_2 = Outlet temperature of air in ^{0}C

Rate of convective heat transfer (Q_c) of air

$$Q_c = h_a A_i (T_s - T_1) \quad \text{................ (6)}$$

Where, h_a = Convective heat transfer coefficient

A_i = Inner area of cross section of pipe (mm^2)

T_s = Surface temperature in ^{0}C

Inner area of cross section of pipe

$$A_i = \pi D_i L \quad \text{..................................(7)}$$

Where, D_i = Inner diameter of pipe

L = Length of pipe

Comparing equation (5.10) and (5.11)

$$h_a = \frac{m_a C_{pa} (T_1 - T_2)}{A_i (T_s - T_1)} \quad \text{.................................(8)}$$

Thermal conductivity of composite material (K)

$$K = h_a x \quad \text{..(9)}$$

Where, x = Thickness of the composite material

$$x = \frac{(D_o - D_i)}{2} \quad \text{......................................(10)}$$

Where, D_o = Outer diameter of pipe

6. RESULTS AND DISCUSSION

The results obtained from Forced Convection Apparatus method are compared with Lee's Apparatus method for same size of teak wood dust (150μm) and same filler contents shown in fig.3. On comparison it is found that the thermal conductivities of neat epoxy calculated by the above two experimental methods are same i.e. 0.36 W/m-^{0}K. After that as the volume fraction of reinforcement increases the thermal conductivities are reduced but the distribution of thermal conductivities are higher in case of Forced convection apparatus method on comparison to Lee's apparatus. This is because of direction of heat flows through the composite and the basal plane formation along the axis. These basal planes are closely packed which helps transferring heat quickly. Wood dust filler contracts upon heat due to negative expansion coefficient further reducing the distance between the basal planes. In Forced convection apparatus, the heat transferred through the composite is in longitudinal (along the axis) direction where as in Lee's apparatus it is in Transverse direction. In transverse direction thermal conductivity is much lower due to lack of basal plane. In present comparison the range is 1.56 to 1.62 which is very close to results of Suleiman et al [5].

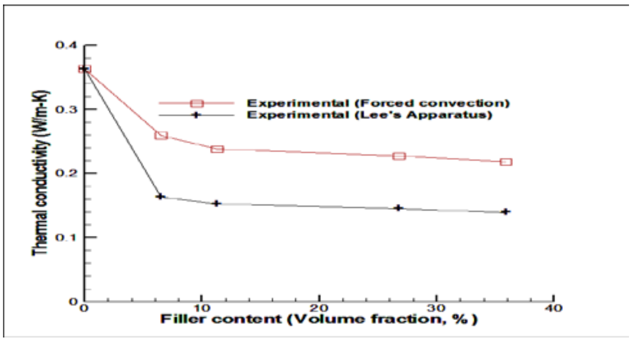

Fig. 3 Comparison of thermal conductivity of different methods with varying filler content (TWD)

Table 1Thermal conductivity comparison between two experimental methods (TWD)

Sample	Particulate content (Vol. %)	Thermal conductivity values (W/m-K)		Ratio of thermal conductivity with respect to Forced convection Apparatus method
		Lee's Apparatus method	Forced convection Apparatus method	
1	6.5	0.163	0.259	1.59
2	11.3	0.152	0.246	1.62
3	26.8	0.145	0.227	1.56
4	35.9	0.139	0.218	1.57

It is also found that the addition of teak wood dust results in reduction in thermal conductivity of epoxy resin and thereby improves its thermal insulation property. The values of thermal conductivity and their ratios associated with each method are shown in Table-1.

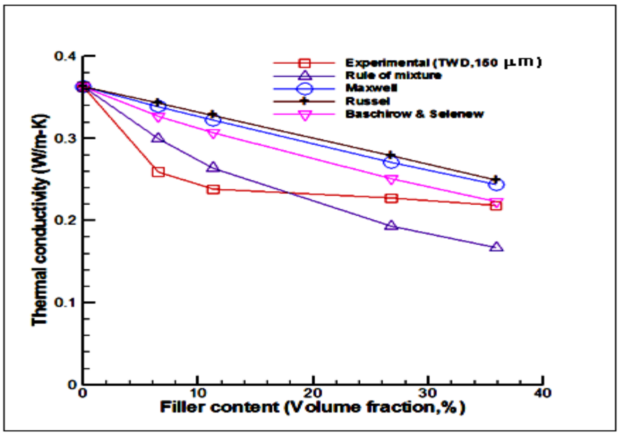

Fig. 4 Comparison of thermal conductivity of different models with experimental values and varying filler content (TWD)

In Fig.5 the effective thermal conductivities values obtained from the experimental study for the particulate filled epoxy composites with varied proportions of teak wood dust are compared with Rule of Mixture thermal conductivity model, Maxwell thermal conductivity model Russel model and Baschirow & Selenew model. From the above figure, it is found that the Rule of mixture model underestimates the value of thermal conductivity with respect to the experimental one (22mm Dia.) up to 18% of volume fraction, after that it over estimates. On the other hand, Maxwell model, Russel model and Baschirow & Selenew model overestimate the values of thermal conductivity with respect to experimental one(22mm Dia.). On comparison, it has been found that the errors associated with all the above four models with respect to experimental ones (22mm Dia.) lie in the range of 7.32 to 23.39%, 11.46 to 30.90%, 14.22 to 33.33% and 2.30 to 26.25% respectively.

7. CONCLUSION

From the above investigation on thermal conductivity of wood dust filled epoxy composites the following conclusions may be drawn:

1. Wood dust is an environment friendly waste product which can be gainfully utilized for preparation of composites.
2. A successful fabrication of a wood dust filled epoxy composite with different types of wood is possible by hand lay- up technique.

3. A reduction in thermal conductivity was observed with increasing filler content in the mixture due to presence of air voids during preparation of composites and also presence of interfacial material having low thermal conductivity (TWD) which increases the interfacial resistance between the epoxy resin and filler.

4. Incorporation of wood dust results in reduction of thermal conductivity of particulate (TWD) filled epoxy composites and thereby improves its thermal insulation capability.

REFERENCES

[1] Russel HW. " Principle of Heat flow in Porous Insulation." J Am Ceran Soc Vol.18(1), 1935.

[2] Maxwell JC. "A Treaties on Electricity and Magnetism," 3rd ed. New York,: Dover; 1954.

[3] Baschirow AB. And Manukian A M. " Thermal Conductivity of Polymer at various Temperatures and Pressures." Mech Polim.Vol 3, 1974.

[4] Steinhagen H. P. "Thermal Conductivity Properties of Wood, Green or Dry , from -40^0C to +100^0C: a literature review." In: Gen. Tech. Re FPL-09, U.S. Department of Agriculture Forest Service, Forest products Laboratory, Madison WI., 1977.

[5] Suleiman B. M., Larfeldt J., Leckner B. and Gustavsson M., "Thermal Conductivity and Diffusivity of Wood," Wood Sci. Technol. Vol. 33 (6), 1999, pp. 465-473.

[6] Fu, S. Y. and Mai, Y.W., " Thermal conductivity of Misaligned Short Fibre Reinforced Polymer Composites," J. Appl. Polymer Sci., Vol.(88), 2003, pp. 1497-1505.

[7] Abdul Razak A. A., Salah N J. and Kazem W, A., "Electrical and Thermal Properties of Epoxy Resin Filled with Carbon Black," Eng. & Tech. J. Vol. 27, No. 11, 2009.

[8] Alam M., Rahman S., Haldar P. K., Raquib A, and Hasan M., "Lee's and Charlton's Methods for Investigation of Thermal Conductivity of Insulating Materials, IOSR Journal of Mechanical and Civil Engineering, Vol. 3, Issue 1,2012, pp. 53-60.

[9] Prisco Umberto, "Thermal Conductivity of Flat-pressed Wood Plastic Composites at Different Temperatures and Filler Content," Science and Engineering of Composite Materials, Vol. 0, Issue 0, 2013, pp. 1-8.

[10] Mohapatra Ramesh Chandra, Mishra Antaryami and Choudhury Bibhuti Bhushan, "Investigations on Thermal Conductivity of Palm Fibre Reinforced Polyester Composites," IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) Volume 11, Issue 1 Ver. I (Feb. 2014), PP 01-05.