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Effect of Fiber Length on Thermal Properties of PALF Reinforced Bisphenol: A Composite

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Abstract:
Composites are becoming an essential part of today's materials because they offer advantages such as low weight, corrosion resistance, high fatigue strength, faster assembly etc. Composites are used as materials ranging from making, aircraft structures to golf clubs, electronic packaging to medical equipments.Composites are generating curiosity and interest in students all over the world,use of natural fibers as reinforcement in polymeric composites for technical application has been a research subject of scientist. Among several natural fibers, Pineapple leaf fibre (PALF) is one that has good potential as reinforcement in polymer composite. PALF was extracted from raw pineapple leaf; it was then chemically treated and dried in hot air oven to hinder the water content. In the present work the composite specimens are prepared by using Bisphenol-A (BPA) as a matrix and the short PALF fiber with length < 15mm and 30% volume fraction as reinforcement. The composites were prepared by hand lay-up technique. The objective of the present work is to investigate the thermal properties such has specific heat, thermal conductivity, thermal diffusivity of Short PALF reinforced Bisphenol-A composite. The composites reinforced with the fiber length of 2mm, 4mm, 6mm, 8mm, 10mm, 12mm & 14mm was subjected to thermal analysis to check the fecibility of utilizing PALF reinforced Bisphenol-A composite for thermal applications. From this experimental study, it was observed that the fiber length greatly influences the thermal behavior of PALF reinforced Bisphenol-A composites.

***Keywords**: PALF, BPA, Fiber length, Specific heat, Thermal conductivity, Thermal Diffusivity*

1. Introduction

Composite materials are materials made from two or more constituent materials with significantly different physical or chemical properties, that when combined, produce a material with characteristics different from the individual components. The individual components remain separate and distinct within the finished structure. The new material may be preferred for many reasons: common examples include materials which are stronger, lighter or less expensive when compared to traditional materials.

Natural fibers are plant based which are lignocelluloses in nature and composed of cellulose, hemicelluloses, lignin, pectin and waxy substances. Cellulose gives the strength, stiffness and structural stability for the fibre, and is the major framework components of the fibre. Pineapple Leaf Fibre (PALF) is one such fiber source known from a long time obtained from the leaves of pineapple. Pineapple leaves from the plantations are being wasted as they are cut after the fruits are harvested before being either composted or burnt. Additionally, burning of these beneficial agricultural wastes causes environmental pollution. Over the past decade, cellulosic fillers have been of greater interest, since they give improved mechanical properties to composite material compared to those containing non-fibrous fillers.

Bisphenol-A (BPA) resin is a thermoset resin with good thermal and environmental stability, high strength and wears resistance. This combination of properties permits the application of BPA in polymer-based heavy duty sliding bearings. For these purposes, BPA usually is compounded with reinforcements like glass or carbon fibers and ceramic .mineral oxides and inorganic fillers. The use of fibers in polymeric composites helps to improve tensile and compressive strengths, tribological characteristics, toughness (including abrasion), dimensional stability, thermal stability, and other properties.

2. Materials and Methodology

Pineapple Leaf Fibre (PALF) is one such fiber source known from a long time obtained from the leaves of pineapple plant (Ananascomosus) from the family of Bromeliaceous.
Bisphenol-A (BPA) is an organic compound which belongs to the group of diphenyl methane derivatives and Bisphenol. The chemical formula is $(CH_3)_2C\ (C_6H_4OH)_2$. BPA is used to make certain plastics and epoxy resins; it has been in commercial use since 1957.

2.1. Materials

PALF extracted from leaf of pineapple plant by biological method supplied from Chandra prakash.co, Jaipur, Rajasthan .Bisphenol-A resin was supplied from Balaji fabrications, Mysore, Karnataka.

2.2. Chemical treatment

Extracted fibers subjected to Alkali treatment or mercerization using sodium hydroxide (NAOH) is the most commonly used treatment for bleaching and cleaning the surface of natural fibers to produce high-quality fibers. Modifying natural fibers with alkali has greatly improved the mechanical properties of the resultant composites. Firstly 5% NAOH solution was prepared using sodium hydroxide pellets and distilled water. Pineapple leaf fibers were then dipped in the solution for 1hour. After 1 hour fibers were washed with 1% HCl solution to neutralize the fibers. Then it is washed with distilled water. It was then kept in hot air oven for 3hours at 65-70°c. Then fibers were chopped to different fiber length.

2.3. Manufacturing of composite

A polypropylene (PP) mould having dimensions of 80 X 60 X 10 mm is used for composite fabrication. The mass fraction for the prepared mould is calculated using equation of volume fraction of the fiber and density of fiber. The mould was first cleaned with wax so that the laminate easily comes out of the die after hardening. Then around 15 to 20 ml of promoter and accelerator are added to Bisphenol and the color of the resin changes from pale yellow to dark yellow with the addition of these two agents. The laminates of different fibers lengths of short PALF are prepared using hand layup method. This method of manufacturing is a relatively simple method compared to other methods like vacuum bag molding, resin transfer molding, autoclave molding etc. Fig 1 shows the PALF reinforced laminated composites with fiber length of 2, 4, 6, 8, 10, 12 and 14mm respectively.

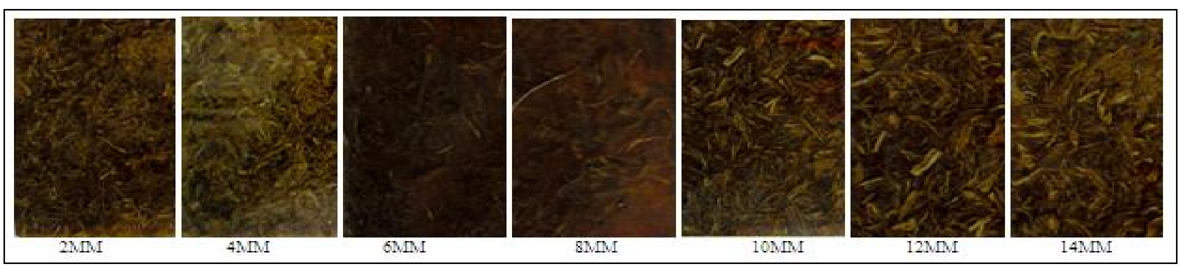

Figure 1: PALF reinforced composites of different fiber length

Figure 2: 80 X 60 X 10 mm^3 mould

The mass fraction for the prepared mould and for desired volume fraction of fiber is calculated using equations:
Volume fraction of fibers (V_F) = v_f / vc (2.1)
Density of the fiber (ρ) = m_f / v_f (2.2)
Were $v_{f\,=}$ Volume of the fiber, vc= Volume of the composite, $m_{f\,=}$ Mass fraction of the fiber.

2.4. Specific heat

The quantity of heat required to cause a temperature change of any substance is proportional to the mass (m) of the substance and the temperature change(ΔT), the proportionality constant 'Cp' is called Specific heat. When heat flows into a substance, the temperature of that substance will increase.
$q = Cp \times m \times \Delta T$ (2.3)
The specific heat can be considered to be the amount of heat required to raise the temperature of one gram of the substance by 1°C. Amounts of heat is measured in joules (historically: calories). The specific heat of water is 4.18 joules/g°C. Since 4.18 joules equals 1 calorie, we can also say that the specific heat of water is 1 calorie/g°C. Ordinarily heat flow into or out of a substance is determined by the effect that the flow has on a known amount of water. Because water plays such an important role in these measurements, the calorie, which was the unit of heat most commonly used until recently, was actually defined to be equal to the specific heat of water. The specific heat of a material can readily be measured in a calorimeter. A weighed amount of material is

heated to some known temperature and is then quickly poured into a calorimeter that contains a measured amount of water at a known temperature. Heat flows from the material to the water, and the two equilibrate at some temperature between the initial temperatures of the material and the water.

The amount of heat that flows from the material as it cools is equal to the amount of heat absorbed by the water and the calorimeter.

For the heat flow q,

q water + q caloriemeter = q composite (2.4)

If we now express heat flow in terms of Equation 2.3 for both the water and the metal M, we get

(Cp × m× ΔT)water + (Cp × m× ΔT) caloriemeter = (Cp × m× ΔT)composite (2.5)

In this experiment we measure the masses of water and metal and their initial and final temperatures. Given the specific heat of water, we can find the positive specific heat of the material by Equation 2.3.

Figure 3: Expiremental setup used to determine specific heat

2.5. Thermal Conductivity

Thermal conductivity is the property of a material to conduct heat. It can be defined as ‘the quantity of heat transmitted through a unit thickness in a direction normal to a surface of unit area, due to a unit temperature gradient under steady state conditions’. Thermal conductivity was measured using a steady state method and perpendicular to fiber direction.The air duct is the housing where the component and the heating coil assembly has been placed is as shown in Fig 4. It is a rectangular passage made of galvanized iron sheet. It has a dimension of 150×100×600mm.

Figure 4: Expiremental setup used to determine specific heat(Air duct, specimen, sandwiched specimen)

The specimen was sandwiched between two mild steel plates and thermocouples were placed at the bottom, intermediate contact surfaces and at the top surface. Specimen was placed on the heating element and then the heating elements and thermocouples were plugged into the test rig. voltage was set at 50V and allowed for 20 minutes to reach steady state and then temperature readings from $T_o$to T_L were taken. Thermal conductivity is calculated using formaula:

$$Q = \frac{T_o - T_L}{\frac{L_1}{k_1 A_1} + \frac{L_2}{k_2 A_2} + \frac{L_3}{k_3 A_3}} \qquad (2.6)$$

Q= Heat transfer at steady state, T_o= Base temperature, T_L= Surface temperature, L_1=L_3 Thickness of the known material, L_2= Thickness of the specimen, k_1=k_3= Thermal conductivity of known material, k_2= Thermal conductivity of specimen, A_1=A_3= Surface area of the known material, A_2= Surface area of the specimen

2.6. Thermal Diffusivity

Thermal diffusivity is a material-specific property for characterizing unsteady heat conduction. This value describes how quickly a material reacts to a change in temperature. It is the thermal conductivity divided by density and specific heat capacity at constant pressure. It measures the ability of a material to conduct thermal energy relative to its ability to store thermal energy. It has the SI unit of m²/s.An attempt was made to theoretically calculate thermal diffusivity of PALF reinforced Bisphenol composites using the equation -2.7.

$$\alpha = \frac{k}{\rho . C_p} \qquad (2.7)$$

α= Thermal diffusivity, k= thermal conductivity, ρ= density, C_p= specific heat

3. Results and Discussion

Specific heat of Bisphenol-A resin and composite with different fiber length is determined by Joule's calorimeter and tabulated in Table 1. For the short fiber specimens the highest value is obtained for 14mm specimen which is 6836.592 J/kg.K. The reason for increased specific heat of PALF reinforced composite is due to heat insulation ability of the fibers. Which indicates that as fiber length increases it effects on specific heat of PALF composites and it is plotted in graph as shown in Fig 5.

Thermal conductivity of the substance is its ability to allow heat to flow through it. The thermal conductivity of Bisphenol-A resin and composite with different fiber length is determined using steady state method. From the table 1 it was observed that the values of thermal conductivity for composite with fiber length of 2mm was more wen compared with other lengths of PALF reinforced polymer composites. But it was less then resin material by 2.35%. From the results it can be inferred that the thermal conductivity goes on decreasing as the fiber length increases.

From the foregoing results it is clear that the thermal conductivity of the matrix decreases to a greater extent when reinforced with pineapple leaf fibers. The major reason for this is the thermal conductivity value for the pineapple leaf fiber is lower than the Bisphenol-A matrix. Because these fibers content high weight ratio of cellulose, which have good thermal insulation properties. Therefore as the length fiber increases the thermal conductivity of the prepared composite decreased and it is plotted in the graph as shown in Fig 6.

The nature of pineapple leaf fibers as a hollow tubular structure [1], which leading to the transfer heat energy through it in two method (conduction and convection) then the elastic waves (phonon) transfer through the matrix material and solid part of the palm fiber by vibration motion of the atoms. Due to the covalent bond and upon the arrived of phonon to the hollow part of palm fiber phonon will suffer obstruction in there motion. Because the medium presence is different from the first medium, which will lead to decrease thermal conductivity values of the prepared composites.

For the fiber length of 2mm it was observed that the values of thermal diffusivity was more wen compared with other lengths of PALF reinforced polymer composites. But it was less then resin material by 6.1%. From the results it can be inferred that the thermal diffusivity goes on decreasing as the fiber length increases. Since specific heat for 2mm is very less and specific heat is inversely proportional to the thermal diffusivity, and hence 2mm thermal diffusivity increases.

Short fiber addition to matrix acts as flaws, and since the PALF-reinforced Bisphenol-A polymer composite is brittle, it forms air-lane cracks were formed in the sample under heat and pressure, and these cracks create air voids thus reducing the heat capacity and corresponding thermal conductivity, thermal diffusivity. Graph of themal diffusivity is plotted as shown in Fig 7.

As fiber length increases it forms insulating chains so thermal diffusivity decreases and also Thermal diffusivity of a material decreases with fiber angle, since the short fiber is arranged randomly not strictly oriented, the conductivity, diffusivity decreases.

Sl. no	Specimen	Specific heat (J/kg.K)	Thermal conductivity(W/m°C)	Thermal diffusivity(m^2/s)
1	Resin	4200.124	1.402	$2.962*10^{-7}$
2	2mm	4444.173	1.369	$2.7813*10^{-7}$
3	4mm	4835.21	1.31	$2.2798*10^{-7}$
4	6mm	5271.28	1.18	$2.0157*10^{-7}$
5	8mm	5448.532	1.057	$1.6688*10^{-7}$
6	10mm	6506.55	0.9348	$1.0467*10^{-7}$
7	12mm	6681.427	0.9164	$1.0176*10^{-7}$
8	14mm	6836.592	0.8836	$0.9537*10^{-7}$

Table 1: Expiremental results of thermal properties

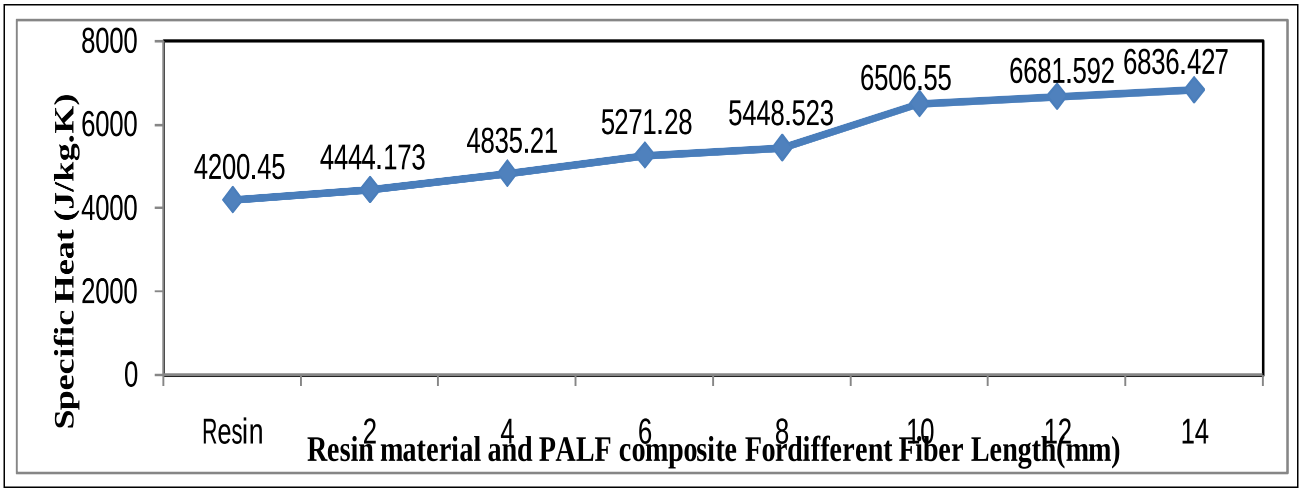

Figure 5: Specific heat of resin material and PALF composite of different fiber length

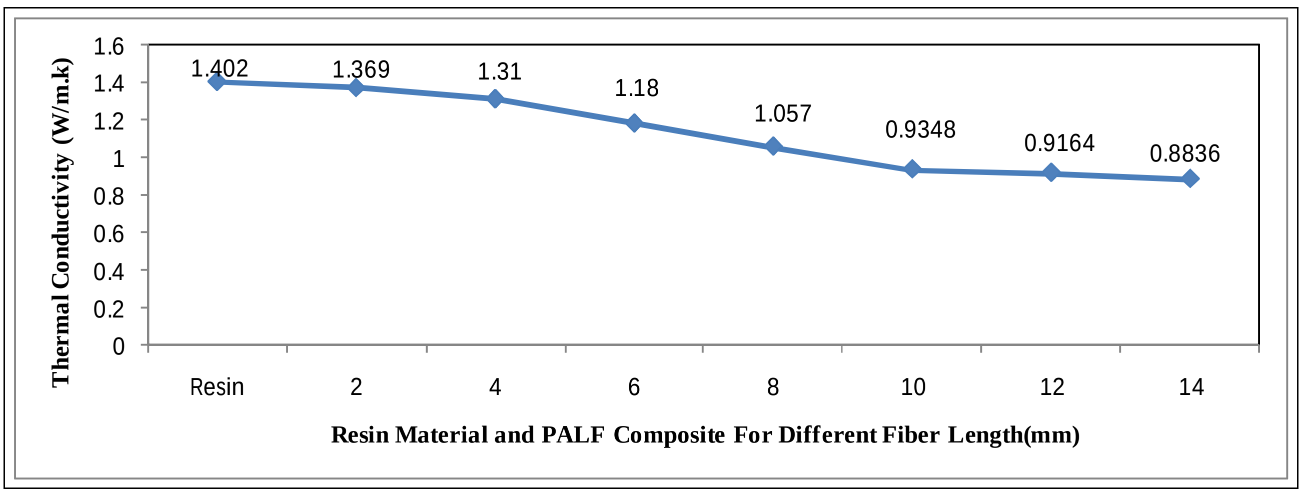

Figure 6: Thermal conductivity of resin material and PALF composite of different fiber length

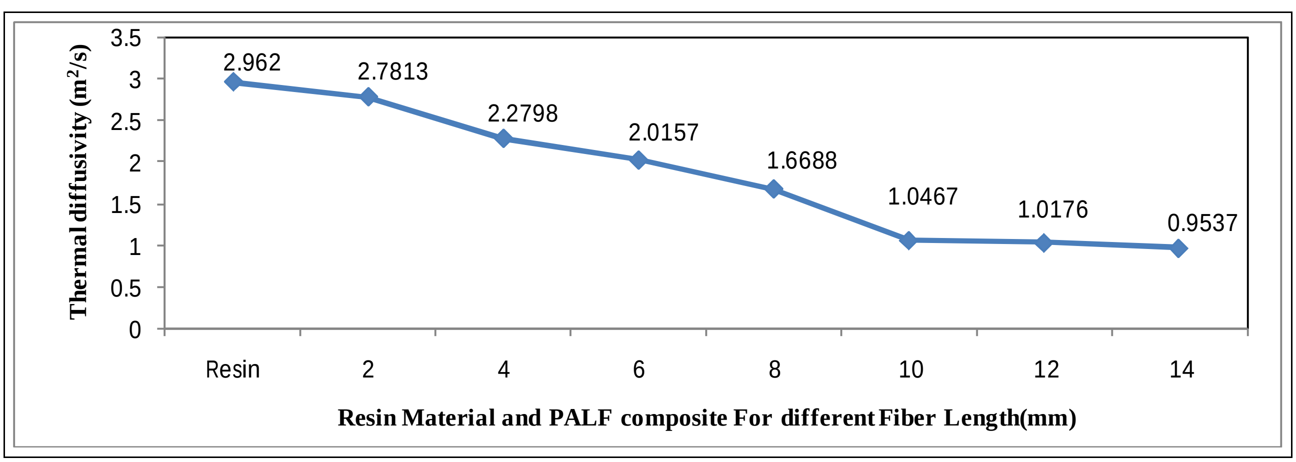

Figure 7: Thermal diffusivity of resin material and PALF composite of different fiber length

4. Conclusion

In the study of thermal poperties, specific heat increases as length increases is due to heat insulation ability of the fibers. Conductivity decreased after reinforcement of fibers. The decrease was due to thermal conductivity value of the pineapple leaf fiber is lower than the Bisphenol-A matrix, because these fibers contains high percentage of cellulose. The cellulosic fibers have good thermal insulation properties, therefore as the length fiber increases the thermal conductivity of the prepared composite decreased. As the nature of pineapple leaf fibers as a hollow tubular structure.Therfore leading to the transfer of heat energy through it in two method conduction and convection. The elastic waves (phonon) transfer through the matrix material and solid part of the PALF fiber by vibration motion of the atoms, Due to the covalent bond and upon the arrived of phonon to the hollow part of PALF fiber phonon will suffer obstruction in there motion, Hence the medium present is different from the first medium, which will lead to decrease in thermal conductivity values of the prepared composites.The decrease in thermal diffusivity indicates the material ability to resist the increase in temperature.

5. References

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