A Study on Thermal Characteristics of Epoxy Composites Reinforced with Short Bagasse Fibres

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Abstract- The research reported in this thesis broadly consists of three parts: The first part provides the description of the materials used and the details of the experiments that are carried out during this research. It also presents the test results in regard to the micro-structural characteristics of the epoxy filled with bagasse fibers. The second part is about the development of a theoretical heat conduction model based on which a mathematical correlation has been proposed for estimation of effective thermal conductivity of polymer composites with uniformly distributed bagasse fibers. In this part, the correlation is validated through numerical analysis and experimentation. The last part has presented the experimental results related to the effective thermal conductivity of composites filled with bagasse fibers. The findings of this research suggest that by incorporation of bagsse fiber into epoxy resin, its effects, as expected are achieved in the form of modified thermal properties. Due to the presence of bagasse fiber, changes in their heat conduction behavior are seen. When bagasse fiberis added in epoxy matrix, the effective thermal conductivity of the composite is reduced as bagasse fiber is isolative in nature. With light weight, lowered thermal expansion coefficient and improved insulation capability, the bagasse fiber reinforced epoxy composites can be used for applications such as insulation boards, food containers, thermos flasks, refrigeration industry, building materials, interiors of air craft's and automobiles etc.
Keywords: epoxy, bagasse fiber, volume fraction, effective thermal conductivity.

I. INTRODUCTION

With growing shortage of fossil fuel and increasing global warming there is a greater demand to improve the energy efficiency of engineering component and structures. The advantage of energy efficient engineering structures and building is well known. To get this insulation one can apply thick layers of insulating materials. But this can make the constructions thick with added higher cost and loss of floor area. Best thermal insulating material that can be considered are vacuum insulating panels [1] and aerogel based materials. The insulating properties of the materials can be explained by a reduced gas phase conductivity based on vacuum and pore size under 100 nm. But these materials have te disadvantage of processibility and high cost.

THERMAL INSULATION

There is always heat transfer occurs when there is a temperature difference between two bodies. Insulation provides a medium to decrease the heat transfer. Thus thermal insulation can be said to decrease in heat transfer between bodies in contact or in range of radioactive influence.

Insulators are these materials which decrease heat transfer by doing any of the following function.

- Conservation of energy by decreasing heat loss or gain
- Manage surface temperature for staff protection and comfort
- Prevent vapor flow or water condensation on cold surface
- Enhance efficiency of heating or cooling process
- Prevent damage to equipment from fire or corrosive atmosphere

II. TYPES OF COMPOSITES

Composites are divided in three groups as per their matrix material.

- Metal Matrix Composites (MMC)
- Ceramic Matrix Composites (CMC)
- Polymer Matrix Composites (PMC)

a) Metal Matrix Composites

MMC have higher specific modulus, low thermal expansion, more specific strength, can retail their properties at higher temperature. Therefore MMC are suitable for many application like in rocket and space shuttle, housing, tubing etc.

b) Ceramic Matrix Composites

Ceramic matrix is tougher than any other matrix material. Most of the time it is seen that they have better strength and stiffness any other composite material.

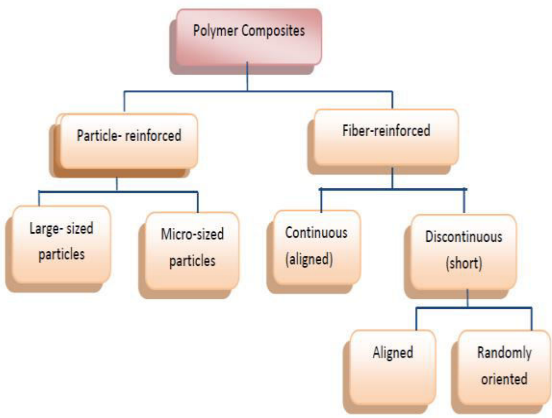

Figure 1: Types of Composites

c) Polymer Matrix Composites

These are mostly used matrix composite. Polymer's strength and stiffness are lower than ceramic and metal composite. But by reinforcing with polymer this disadvantage can be overcome. One more advantage is making of this matrix does not involve high pressure or temperature. With simple and cheap tool materials it can be made. Polymer matrix has higher elastic modulus without any brittleness like ceramic material.

Composites are mainly of two types

- Fiber reinforced polymer (FRP)
- Particle reinforced polymer (PRP)

III. PROBLEM IDENTIFICATION

- There is very little investigation in improving insulating capacity of polymer material.
- Most authors used only one type of filler material, there is very little research on combined effect of two different fillers on thermal property.
- Very few papers are on behavior of co efficient of thermal conductivity when fiber is used as filler material.

IV. RESEARCH OBJECTIVES

- To develop a theoretical model predicts the effective thermal conductivity of polymer composite.
- To predict effective thermal conductivity using finite element method.
- Developing different samples of polymer composites with bagasse fiber.
- Validating the theoretical model with FEM result.
- Exploring the possibility of this polymer in household and industrial use.

V. METHODOLOGY

A. Matrix Material

Polymers have some very desirable properties like low thermal expansion coefficient, corrosion resistance, thermal conductivity, wear resistance etc. They are more popular because of their low cost, electrical insulating properties, easy to manufacture. Polymers are mainly divided into two main types, thermoplastics and thermo sets. Both of them have different properties as per their molecular structure.

Thermo set polymer are irreversible once they are heated and they have a structure of cross linked amorphous matrix. They show good thermal electrical and thermal insulating properties as they have bigger molecular structure. Due to their low viscosity they can wet well and have good thermal stability and creep resistance. Polyester, epoxy, vinyl ester are some commonly used thermo set plastics.

Thermoplastic are different from thermo set in a way that they can be remolded as the intermolecular forces increase after cooling and comes back to original properties. They normally produced in a step then are turned into different products in subsequent processing. So they can be recycled after reheating and can be given any shape afterwards. Nylon, acrylic, polypropylene, polyethylene, polyvinyl, polystyrene, Teflon is some of the popular thermoplastics. Epoxy is most popular among all the thermo set plastics as they good adhesion to many fibers, better electrical and mechanical properties and they show better properties at higher temperature. They also have desirable qualities like better chemical resistance, low shrink after curing. Epoxy (LY556) is used for matrix material in this investigation. Its common name is Biphenyl-A-Diglycidyl-Ether (commonly abbreviated to DGEBA or BADGE). And it is chemically belongs to epoxide family. In fig 4.1 its chemical structure is shown.

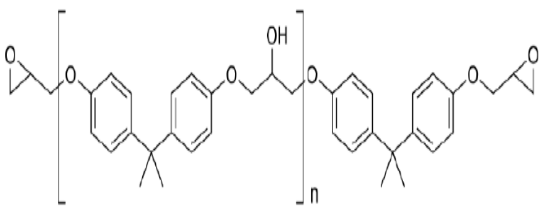

Figure 2: Unmodified Epoxy Resin

Table 1: Properties of Epoxy Resin

Characteristic Property	Inferences
Density	1.1 gm/cc
Compressive strength	90 MPa
Tensile strength	58 MPa
Micro-hardness	0.085 GPa
Thermal conductivity	0.363 W/m-K
Glass transition temperature	98°C
Coefficient of Thermal expansion	62.83 ppm /°C
Electrical conductivity	0.105×10^{-16} S/cm

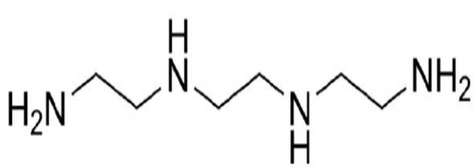

Figure 3: Triethylene Tetramine

Figure 4: Bagasse Fiber

B. Filler material – 1: (Bagasse fiber)

Bagasse fiber can be found from sugarcane after extracting its juice and it is normally treated as waste without any better use. They are cultivated in many parts of India. Its botanical name is Saccharin Of ficinarum. India is one of the major producers of sugar cane. It mainly grows in tropical regions. It needs a tropical climate and a good water supply.

Table 2: Properties of Bagasse Fiber

Characteristic Property	Inferences
Density (g/cc)	0.07
Thermal conductivity (W/mK)	0.05

Bagasse fiber mainly consists of, cellulose, hemicelluloses, lignin, ash and waxes. It is an inhomogeneous material with 30-40% "pith" fiber which we get from the core of the plant mainly constituted of parenchyma.

Bagasse fiber was chosen as it has a lower thermal conductivity and low density. It is also friendly, renewable, cheap, good stability, no toxic and has high strength. Some pictorial view of bagasse fiber is shown below.

V. RESULTS AND ANALYSIS

A. Effective Thermal Conductivity

Effective thermal conductivity of the composite sample (Epoxy+ Bagasse fiber) experimentally and theoretically calculated.

Numerical Methods:

Concept of Finite Element Method and ANSYS

Finite element method (FEM) is one of the most versatile and powerful method that can beused to find the solution in thermal conduction problem of composite. Without making model for every situational problem we can use ANSYS as an alternate. The program which is used to find the effective thermal conductivity of the composite is written in APDL(Ansys Programming Design Language). The finite element method started by Turner et al is a very useful tool to solve practical engineering problems. There is some research work on thermal conductivity of composite polymers using experimental and numerical methods. To solve real life mechanical problems like structural analysis (linear or nonlinear) static or dynamic balancing heat transfer or fluid flow problems ansys can be highly useful.

The concept of FEM lies in the principle of Discretization of solution domain to different finite element by using weighted or variation residual method. Different problem with boundary value, initial and Eigen value problems can be discretize using finite element method into irregular domains.

Steps in finite element method

- First the structure is divided in subdivisions or elements using finite element method. Taking suitable number of finite element the structure of the problem should be modeled. Shape, size, arrangement and number of elements should be decided properly

- An interpolation model should be selected properly in the second step. Solution of complex structure cannot be predicted accurately, hence a suitable solution is to be assumed to predict the unknown solution.

- In the last step characteristic elemental matrix and input data should be derived using equilibrium condition.

Description the Problem

Composites have random distribution of fillers, have inclusions, still the effect of microstructure on various properties can be predicted analyzing the composite with symmetric structures. As per the micro structures of composites can be laminate composite or dispersed composite. Laminate composite have multi layered structures and in dispersed phase composite fillers are in dispersed phase. Ina dispersed phase composite structural features of composite and thermal conductivity of every particle is accounted for effective thermal conductivity. Shape and size of the matrix and shape size volume fraction and orientation of dispersion are considered under structural features. Here the shape of the composite is considered cubical.

3mm length bagasse fiber is used as filler in the composite material used for investigation. As the filler material of tetragonal shape the models used in FEM is taken as cubical shape for epoxy matrix and tetragonal shape for filler material.

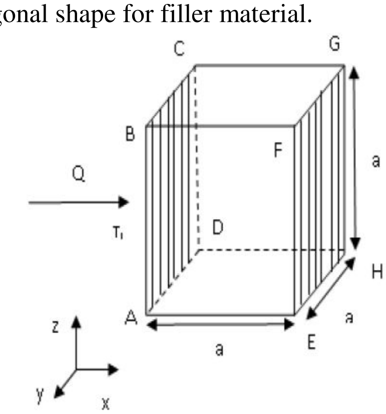

Figure 5: Heat Flow Direction and Boundary Conditions for the Composite

A pictorial representation of the composite body with symmetric arrangement and heat flow direction are shown in fig 5. Here ABCD surface temperature is 1000 C. Convective heat transfer coefficient on the face EFGH is 25 w/m2k. Ambient temperature is taken as 270 C. All the other surfaces parallel to heat flow as considered insulated.

Assumption made in this analysis is

- Component is homogenous and isotropic.
- Contact resistance between the matrix and filler material is negligible.
- There is no void inside the composite.
- There is no uniform distribution of filler

material.

Using Ansys the effective thermal conductivity of the composite is calculated. Some models with volume fraction 4.68%, 7.03% and 10.54% are shown in figure. Temperature profile also shown for the same composite with volume fractions stated earlier.

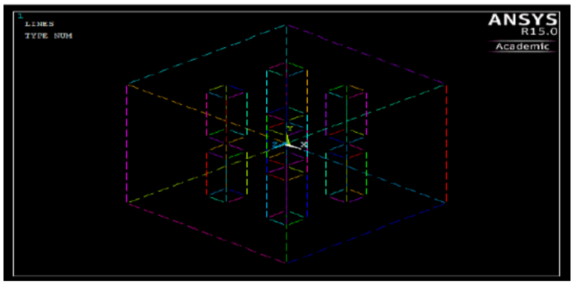

Figure 6: Volume Fraction 4.68%

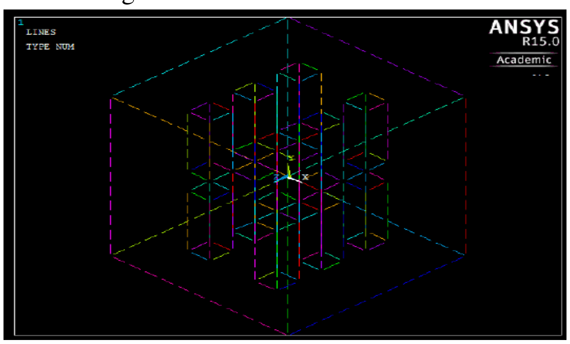

Figure 7: Volume Fraction 7.03%

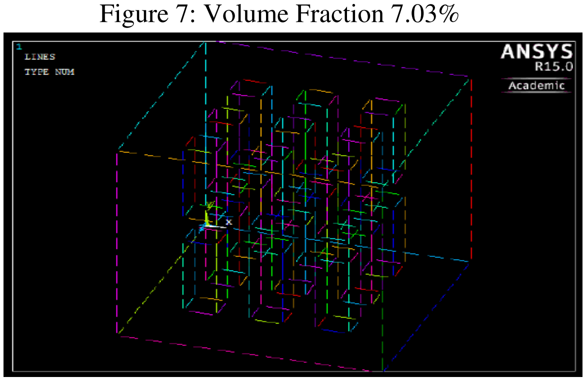

Figure 8: Volume Fraction 10.54%

Effective Thermal Conductivity: Comparison among results obtained from numerical and other existing theoretical correlations

We can calculate the value of effective thermal conductivity from temperature profile using one dimension heat conduction equation. For different volume fraction we will get different values thermal conductivity. Different thermal co relation like Maxwell correlation, rule of Mixture and lewis and neilsein model is used to get effective thermal conductivity for various volume fraction of filler material.

Table 3: All the Values of Effective Thermal Conductivity.

Volume fraction of filler	Weight % of filler	FEM Model	Rule of mixture	Maxwell correlation	Lewis and Neilsen Model
0 %	0	.363	.363	.363	.363
4.68 %	.311	.338	.348	.337	.343
7.03 %	.478	.331	.34	.3267	.333
10.54 %	.749	.319	.33	.3121	.318

From the above figure, the values we get from using Ansys is comparable to the other values we get from using various theoretical correlation. It is also seen that the values of thermal conductivity decreases monotonically with increases in volume fraction of filler material.

Development of a Theoretical Model for Estimation of Effective Thermal Conductivity of a Particulate-Polymer Composite System:

A schematic diagram of composite matrix with bagasse fiber as filler material shown in fig. A single fiber filler element taken out and shown in fig. Assumption made in the theoretical analysis is

- Matrix and filler both are homogenous and isotropic.
- There is no void inside the matrix.
- Heat conduction is 1 dimensional and temperature distribution is linear.
- Thermal contact resistance between filler material and matrix is negligible.

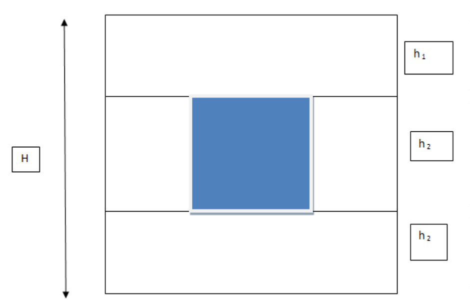

Figure 9: 3D View of Single Fiber under Study

Front view of the element under study is shown. Bagasse filler material has tetragonal shape; hence the filler material inside the cube is taken as tetragonal. The upper, lower and middle part of the composite has thermal conductivity K1, K2, K3 respectively. We can assume that the composite is made up of a number of cubical elements and in each element a single tetragonal filler material is there.

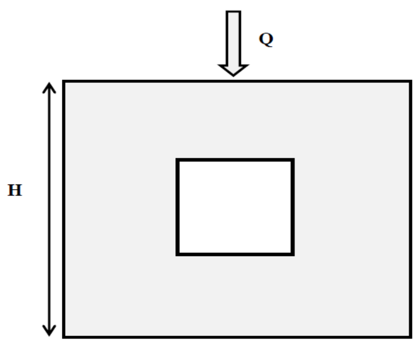

Figure 10: Model of Heat Transfer in Composite

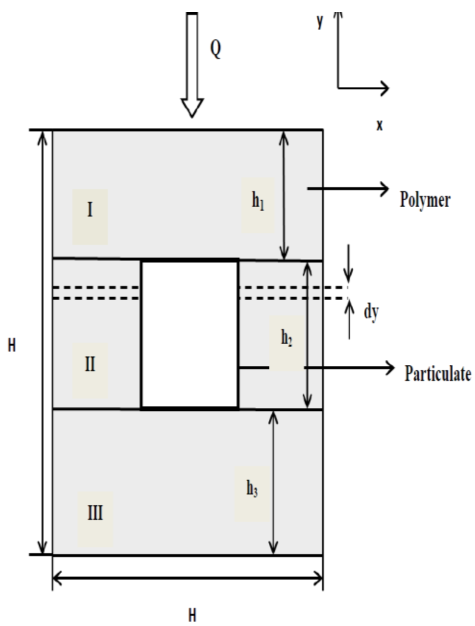

Figure 11: A Series Model of Heat Transfer in Particulate-Filled Composite

The model has two main phases, polymer phase and filler phase. Q amount of heat is given from the top. Transfer of heat between the top face and lower face occurs by heat conduction. Filler material has higher temperature gradient than the matrix element. Polymer composite used mainly in lower temperature, so radiation effect can be safely neglected.

PART 1

K1 = k2 = k3

PART 2

Thermal conductivity of matrix

$$\frac{\frac{H}{3}}{K_p\ (H^2-b^2)} = \frac{H}{3K_p\ (H^2-b^2)}$$

Thermal conductivity of matrix

$$\frac{\frac{H}{3}}{K_p(H^2-b^2)} = \frac{H}{3K_p(H^2-b^2)}$$

Thermal conductivity of filler material

$$\frac{\frac{H}{3}}{K_f b^2} = \frac{H}{3K_f b^2}$$

Effective thermal conductivity of part 2

$$\frac{1}{R_2} = \frac{3K_f b^2}{H} + \frac{3K_p(H^2-b^2)}{H}$$

$$R_2 = \frac{H}{3K_f b^2 + 3K_p(H^2-b^2)}$$

$$R_{eff} = R_1 + R_2 + R_3$$

Where $R1$, 2 and $R3$ of part 1, 2 and 3 respectively

$$R_{eff} = 2R_1 + R_2 \text{As } R_1 = R_3$$

$$= \frac{2H}{3\,k_p{*}H^2} + \frac{H}{3K_f b^2 + 3K_p(H^2-b^2)}$$

$$\frac{H}{K_{eff}{*}H^2} = \frac{2H}{3\,k_p{*}H^2} + \frac{H}{3K_f b^2 + 3K_p(H^2-b^2)}$$

$$\frac{1}{K_{eff}} = \frac{2}{3\,k_p} + \frac{1}{3K_p\left(1-\frac{b^2}{H^2}\right) + 3K_f\left(\frac{b}{H}\right)^2}$$

Again volume fraction φ is given by

φ $= Volume of filler Material / Volume of composite$

$$\varphi = \frac{1}{3}\left(\frac{b^2}{H^2}\right)$$

Putting the value of φin the above equation

$$\frac{1}{K_{eff}} = \frac{2}{3\,k_p} + \frac{1}{3K_p(1-3\varphi)+3K_f 3\varphi}$$

$$K_{eff} = \frac{1}{\frac{2}{3\,k_p} + \frac{1}{3K_p\,(1-3\varphi)+3K_f\,3\varphi}}$$

In reality heat transfer occurs in a complex process, so the effective thermal conductivity value we get by the above formula may not be sufficient if it is not compared with experimental values and other theoretical model values. The exact values of effective thermal conductivity found by using UnithermTM 2022 model in controlled condition. For various values of volume fraction of filler material the calculated values of effective thermal conductivity are shown in table 2.

Table 4: The Calculated Values of Effective Thermal Conductivity

Volume fraction of filler	Weight fraction of filler	Effective thermal conductivity (W/m-K)						
		FEM Model	Rule of mixture	Maxwell	Lewis and Nelson	Proposed Model	Measured Value	Proposed co-relation
0	0.363	0.363	0.363	0.363	0.363	0.363	0.363	0.363
4.68	0.311	0.338	0.348	0.337	0.343	0.347	0.341	0.344
7.03	0.478	0.331	0.34	0.3267	0.333	0.337	0.328	0.333
10.54	0.749	0.319	0.33	0.3121	0.318	0.332	0.309	0.316

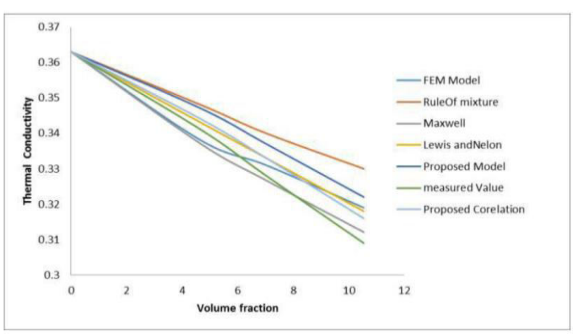

Figure 12: Thermal Conductivity vs Volume Fraction

Though the mathematical model proposed shows values which are in good agreement with the other values, large difference are still noted with these values and the actual values we got from experiment.

Experimental values of effective thermal conductivity are much lower than all the other theoretical values with indifference to filler concentration. This can be reasoned with presence of pores and voids inside composite body. But most possible reason can be thermal resistance at the interface filler matrix surface. As polymer have hydrophobic surface so filler which have polar surface like bagasse fiber gives very bad interfacial bonding with the polymer which gives high resistance at the interface. So thermal contact resistance of the fiber and matrix interface has a major role in disrupting heat conduction of composite.

Here, we did not consider the effect of contact resistance due to the interface and the values of effective thermal conductivity is overestimated for different composite with various filler concentration it is observed that predicted and measured thermal conductivity values differ with proportional to ratio of total filler matrix interface area Aint to volume of composite. So a new term ψ* (Aint/V) introduced to the equation to achieve better accuracy of the model. Ψ is proportionality constant and it depends on thermal contact resistance matrix and filler material. Using this correlation K_{eff} of the composite calculated for various filler fraction. Ψ values arbitrarily chosen as 11*10-6. New thermal values we get from this correlation are compared with other model and experimental values.

VI. CONCLUSIONS

This analytical and experimental investigation on epoxy composite with bagasse fiber has given the following conclusion

- Using hand layup method epoxy bagasse fabricated composite can be made
- Using one dimensional heat conduction a mathematical model to calculate effective thermal conductivity of fiber filled polymer composite is developed. The values we get from this model are in very much agreement with the experimental values and can be used to calculate K_{eff} for polymer composite.

- It is seen that thermal insulating property of bagasse fiber filled polymer composite shows much improvement than epoxy resin.

The bagasse fiber filled epoxy polymer composite can be used for food container, insulating board, refrigeration industry, flasks, interior of air craft's etc as it very light weight and good insulating material.

VII. SCOPE OF FUTURE WORK

This research work gives future investigator to explore in many fields. Some suggestions are

- Possible use of organic filler other than bagasse fiber and epoxy polymer in developing new composite material.
- Using ceramic particle to fabricate new composite with better functional properties.
- Cost analysis to check their economic feasibility in industrial approach.

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