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ANALYSIS ON THERMAL CONDUCTIVITY OF BANANA FIBRE AND GLASS FIBRE EPOXY COMPOSITES

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Abstract— **The present paper deals with the effect of volume fraction of fibers on the effective thermal conductivity (keff) for polymer composites. This work sees an opportunity of enhancement on insulation capability of a typical fiber reinforced polymer composite. A mathematical correlation for the effective thermal conductivity of polymer composites reinforced with fiber is developed using the law of minimal thermal resistance and equal law of the specific equivalent thermal conductivity. To validate this mathematical model, two sets of epoxy based composites, with fiber content ranging from 0 to 15.7 vol % have been prepared by simple hand lay-up technique. For one set of composite, natural fiber i.e. banana fibers are incorporated in epoxy matrix and for another set a well-known synthetic fiber i.e. glass fiber is taken as a filler material whereas matrix material remains the same. Thermal conductivities of these composite samples are measured as per ASTM standard E-1530 by using the Unitherm™ Model 2022 tester, which operates on the double guarded heat flow principle. Further, finite element method (FEM) is implemented to determine the keff of such composites numerically using a commercially available finite element package ANSYS. Experimentally measured values are then compared with the values obtained from the proposed mathematical model, the numerical values and also with models established earlier, such as Rule-of-Mixture (ROM), Maxwell's model, Nielson- Lewis model and Bruggeman model. From the experimental and numerical output, it can be seen that with an increase in fiber content, there is gradual decrease in effective thermal conductivity value for both sets of composites. This comparison tells that while none of the established models are correctly predicting the effective thermal conductivity of the composites, the results obtained from the proposed model fits well with the experimental data. This study shows that the effective thermal conductivity reduces quite significantly as the fiber loading in the composite increases. A reduction of about 8 % in the value of thermal conductivity is recorded with addition of 15.7 vol % of glass fiber in epoxy resin whereas 12 % decrease is noticed when filler is banana fiber. This study validates the proposed model and also proves that finite element analysis can be an excellent methodology for such investigations. With light weight and reduced heat conductivity, these insulative, fibers reinforced polymer composites finds their potential applications in insulation boards, food containers, thermo flask, building materials etc.**

Index Terms— **Thermal conductivity, Banana Fibre, Glass Fibre, FEM, ANSYS**

I. INTRODUCTION

A. Introduction to research work

The main function of insulation is to retard the heat flow and maintain temperature. It serves as thermal resistance and therefore prevents the damage of various devices and other articles which need to be maintained at constant temperature range. A thermal insulation performance of composite is influenced by three factors, i.e. solid conduction, gas conduction, and radiation heat transfer. Cellulose based insulation materials are dry plant materials like rice husk, and other agriculture wastes. Other available insulating materials are mineral wool, fiberglass, asbestos, wood, concrete, vegetable fiber, vermiculite and foamed plastics such as polystyrene, some of which depend on air pockets for much of their insulating effect. These substances retard the conduction and convection of heat transfer. The demand for low cost, structurally stable, effective and light-weight insulation materials is therefore increasing day by day. Synthetic and natural both the fibers have good insulation properties. So these fibers have a lot of research in this field.

In view of this, the present work has been undertaken to investigate the effect of adding insulative short fibers on the thermal conductivity of polymer resin. The main objective of the present work includes fabrication of a new class of low cost composites in which short banana fibers and short glass fibers are used as reinforcement to enhance the insulating capabilities of epoxy resin. A mathematical model is developed to evaluate keff using the law of minimal thermal resistance and equal law of the specific equivalent thermal conductivity. Based on this model, a correlation between the effective thermal conductivity of the composite and the fiber content is proposed. Short glass fiber and short banana fiber are the two fillers used in present investigation reinforced individually in epoxy resin to fabricate two sets of composites by hand lay-up technique. The proposed model is then validated through experimentation conducted in controlled laboratory conditions. The keff of all the fabricated composites with different compositions are numerically evaluated using finite element method and the results are validated through measured values. The comparison of keff values obtained from incorporation of two different fibers is also reported in present work.

II. LITERATURE REVIEW

A. Study on synthetic fiber based polymer composites

A great deal of work has been done by many researchers on synthetic fiber reinforced polymer composites. Marom et al. [1] concentrated on the elastic properties of synthetic fiber-reinforced polymer composite materials that pertain to biomedical applications and demonstrates the range of stiffness obtainable through selection of constituents and by choice of angle of reinforcement. Vijay et al. [2] delivered an in depth analysis and comprehensive knowledge to the beginners in the field of natural cellulose fibers/polymer composites. The main aim of this review article is to reveal the current development and emerging applications of natural cellulose fibers and their polymer materials. Yongli [3] studied the mechanical behaviours of unidirectional flax and glass fiber reinforced hybrid composites with the aim of investigation on the hybrid effects of the composites made by natural and synthetic fibers. Cho et al. [4] investigated the mechanical behaviour of carbon fiber/epoxy composites and obtained that the composites reinforced with nanoparticles improved mechanical properties such as enhanced compressive strength and enplane shear properties. Chauhan et al. [5] studied on the influence of fiber loading on mechanical properties, friction and wear behaviour of vinyl ester composites under dry and water lubricated conditions and reported that the density of composite specimens is affected marginally by increasing the fiber content. Huang et al. [6] studied on effect of water absorption on the mechanical properties of glass/polyester composites. It was established that the breaking strength and tensile stress of the composites decreased gradually with increased water immersion time because the weakening of bonding between fiber and matrix.

B. Banana fiber reinforced thermoset composites

Composite of various thermoset matrices (Polyester, Phenol formaldehyde, Urea Formaldehyde and epoxy) reinforced with banana fibers were investigated by various researchers. Banana fiber reinforced with polyester matrix was extensively investigated by Laly et al [31]. The studied shows that the effect of the fiber length and content on mechanical properties of the composite. The investigation shows that the fiber length of 30-40 mm and 40 % volume content has better mechanical properties. Further, aging decreases the mechanical properties of the composite because of the affinity of the banana fibers towards moisture. The mechanical and water absorption behavior of banana fiber composite prepared by resin transfer moulding method shows that the maximum tensile, flexural and impact strength is achieved at 30 mm fiber length and 40vol%. It also showed that the maximum diffusion, sorption, and permeability coefficient are achieved at 50vol% [32]. The twisted form of banana yarn was placed on the warp direction and alternate bundles of banana and yarns are weaved in weft direction. It indicates that the tensile strength was the maximum for the two layered composite, whereas flexural strength is the maximum for the tri-layer and the impact strength increases with the number of layers. The storage modulus is maximum for the four layers woven composite, and further addition of layers shows the addition of peaks for the loss modulus of the hybrid woven composite. The effect of chemical treatment on the flexural, impact and water absorption properties of woven banana- polyester composite was analyzed by Jannah et al. [33]. The result indicates that up to 10vol % and 15vol% the flexural and impact strength of the treated composite increased. Further, the addition of fibers results in degrading the propertied due to poor adhesion. The chemical modification of banana fiber using silane as the coupling agent has showed that the dielectric constant values decreases due to the change in hydrophilic nature of the fiber surface. It also show that‟s that the dielectric constant measurement will serve as a tool for predicting the fiber-matrix adhesion [34]. The effect of the layering arrangement on the storage modulus, loss modulus and damping property of banana/sisal hybrid composite was studied by Mariers et al.

[35] as the function of temperature and frequency. It shows that the trilayer composite of banana fiber as skin and sisal as the core layer has maximum stiffness property.

The comparative study of Phenol Formaldehyde (PF) reinforced with banana and glass fibers showed that optimum mechanical properties are achieved at different fiber lengths. The interface adhesion was better between banana fiber and phenol formaldehyde when compared with glass fiber and phenol formaldehyde, which was determined from the single fiber pull-out test. It also revealed that the specific properties of the banana fiber- PF are superior to those of the glass fiber- PF composite [36].

C. Objective of the present investigation

The objectives of this work are outlined as follows:

1. To evaluate effective thermal conductivity of fiber reinforced polymer composites, a mathematical model is developed.
2. To validate this mathematical model, two sets of epoxy based composites have been fabricated.
3. For one set of composite, a well-known synthetic fiber i.e. glass fibers are incorporated in epoxy matrix and for another set low cost natural fiber i.e. banana fiber is taken as a filler material whereas matrix material remains the same.
4. Objective of the study is improving the thermal insulation properties of fiber reinforced polyester

composite with decreasing the effective thermal conductivity of composite system.

5. Measurement of effective thermal conductivity (Keff) of the fabricated fiber reinforced polymer composite (with different volume fraction) experimentally.
6. Estimation of effective thermal conductivity of these fiber reinforced polymer composite systems using Finite Element Method (FEM).Three dimensional cylinders in cube models are constructed to simulate the microstructure of the composite materials for various filler concentrations.
7. Validation of the proposed model by comparing the thermal conductivity values obtained from the proposed model with the values obtained from the FEM analysis and experimentation.
8. Finally, recommending the above fabricated composites for specific applications.

III. MATERIALS AND METHODS

The volume fraction and the fiber distribution are found to be more critical than polymer selection for enhancement thermal insulation. This chapter describes the materials and methods used for the processing of the composites under this investigation. It presents the details of the characterization and thermal conductivity tests which the composite samples are subjected. The numerical methodology related to the determination of thermal conductivity based on finite element method is also presented in this chapter.

A. Experimental details

1) Composite fabrication

Set 1 Epoxy composites reinforced with short glass fibers for the validation of FEM Modeling Low temperature curing epoxy resin (LY 556) and corresponding hardener (HY951) are mixed in a ratio of 10:1 by weight as recommended. Short glass fibers were reinforced in the resin to prepare the composites in different proportions according to the requirement. The uniformly mixed dough (epoxy filled with SGF) is then slowly decanted into the glass molds, coated beforehand with wax and a uniform thin film of silicone-releasing agent. The composites were cast in these molds so as to get disc type specimens (diameter 50 mm, thickness 3 mm). Composites of 6 different compositions with different volume fraction are made. The castings were left to cure at room temperature for about 24 hours after which the glass moulds are broken and samples are released. Table 3.4 provides the details of different composition of fabricated composites using glass fiber as filler for the validation of FEM modeling.

A schematic diagram of the fabrication process using hand-layup technique for fiber reinforced epoxy composites is given in figure 3.6. Figure 3.7 and Figure 3.8 shows some of these composite samples prepared through this hand-layup technique.

Set 2 Epoxy Composites reinforced with short banana fibers for the validation of FEM Modeling In a similar manner, epoxy composites of 6 more different compositions with different volume fraction were made for short banana fibers.

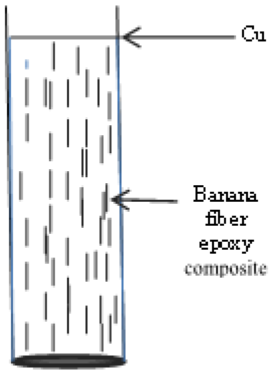

Fig. 3.6 Fiber reinforced epoxy composite fabrication by hand lay-up process

For each composition, the composites were cast in glass moulds so as to get both disc type specimens with similar dimensions. Table 3.4 also provides the details of different composition of fabricated composites using banana fiber as filler for the validation of FEM modeling.

Table 3.4 List of fiber-reinforced polymer composites fabricated by hand-lay-up technique for the validation of FEM modelling

Sample	**Composition (Glass fiber as filler material)**	**Composition (Banana fiber as filler material)**
1.	Epoxy + 2.83 vol% Glass fiber	Epoxy + 2.83 vol% Banana fiber
2.	Epoxy + 5.65 vol% Glass fiber	Epoxy + 5.65 vol% Banana fiber
3.	Epoxy + 7.54 vol% Glass fiber	Epoxy + 7.54 vol% Banana fiber
4.	Epoxy + 10.05 vol% Glass fiber	Epoxy + 10.05 vol% Banana fiber
5.	Epoxy + 12.56 vol% Glass fiber	Epoxy + 12.56 vol% Banana fiber
6.	Epoxy + 15.7 vol% Glass fiber	Epoxy + 15.7 vol% Banana fiber

Set 3 Epoxy Composites reinforced with short glass fibers for the validation of Mathematical Model

Set 3 Epoxy Composites reinforced with short glass fibers for the validation of Mathematical Model

Using the same hand lay-up technique, short glass fibers were reinforced in the resin to prepare the composites of 6 different compositions with different volume fraction. The composites were cast on to glass moulds so as to get disc type specimens of dimensions with similar dimensions which are shown in figure 3.7. Table 3.5 provides the details of different composition of fabricated composites using glass fiber as filler for the validation of Mathematical modelling.

Set 4 Epoxy Composites reinforced with short banana fibers for the validation of Mathematical Model

In a similar manner, epoxy reinforced with short banana fibers composites of 6 more different compositions were made and for each of these compositions, the composites were cast in glass moulds so as to get both disc type specimens with same dimensions which are shown in figure

3.8. Table 3.5 also provides the details of different composition of fabricated composites using banana fiber as filler for the validation of Mathematical modelling.

Table 3.5 List of fiber-reinforced polymer composites fabricated by hand-lay-up technique for the validation of Mathematical model

Sample	**Composition (Glass fiber as filler material)**	**Composition (Banana fiber as filler material)**
1.	Epoxy + 2.83 vol% Glass fiber	Epoxy + 2.83 vol% Banana fiber
2.	Epoxy + 5.65 vol% Glass fiber	Epoxy + 5.65 vol% Banana fiber
3.	Epoxy + 7.54 vol% Glass fiber	Epoxy + 7.54 vol% Banana fiber
4.	Epoxy + 10.05 vol% Glass fiber	Epoxy + 10.05 vol% Banana fiber
5.	Epoxy + 12.56 vol% Glass fiber	Epoxy + 12.56 vol% Banana fiber
6.	Epoxy + 15.7 vol% Glass fiber	Epoxy + 15.7 vol% Banana fiber

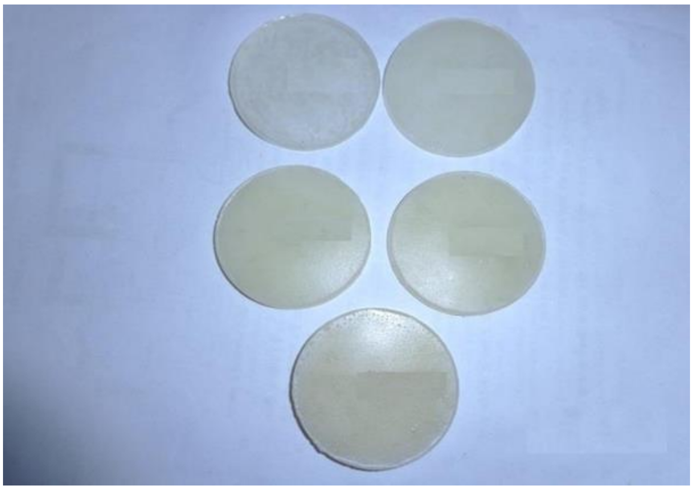

Fig. 3.7 Short glass fiber reinforced epoxy composites

Fig. 3.8 Short banana fiber reinforced epoxy composites

B. Thermal conductivity characterization

1) Experimental determination of thermal conductivity:

Unitherm Model 2022 Guarded Heat Flow Meter Thermal Conductivity Measurement System from Nortest.

The thermal conductivity of various materials is measured by the Unitherm Model 2022. These materials include polymers, composites, ceramics, glasses, rubbers, some metals and other materials of low to medium thermal conductivity. A minor sample test material is required to find out the thermal conductivity. Different containers are used to measure thermal conductivity of non-solids materials, such as glues or pastes or fluids. The tests are in accordance with ASTM E-1530 Standard. A hermetically sealed section is used to make atmosphere free form moisture with dry air purge for testing at temperatures below ambient. The thermal conductivity of polymers is measured through the melt using Superior suppression cells.

2) Operating principle of Unitherm-TM 2022:

Optional chiller circulator is provided for full utilization of the range of the instrument that can provide heat sink temperature to -10°C or for the cryogenic model, to -60°C. The Unitherm Model 2022 is provided with one of three operating range modules. Different thermal resistance area is covered by each module and each of the modules is field replaceable.

A uniform compressive load is given to sample test material between two surfaces which are controlled at a different temperature. Calibrated heat flow transducer is connected to the lower surface of sample test material.

The direction of the heat flow within the sample is from upper surface to the lower surface for the establishment of an axial temperature difference in the stack. When the thermal equilibrium is maintained, the heat flow transducer gives the output which is the temperature gradient through the sample and it is found with the help of reading of the transducer. The thermal conductivity of the sample test material is found using the measured values and the thickness of the sample. Temperature sensors are used to calculate the drop in temperature through the sample test material in the highly conductive metal surface layers on either side of the sample.

Fig. 3.8 Determination of Thermal Conductivity Using Unitherm™ Model 2022

3) Essential steps in FEM

The steps for the finite element method are as follows.

- Discretization
- Selection of the Displacement Models
- Deriving Element Stiffness Matrices
- Assembly of Overall Equations /Matrices
- Solutions for Unknown Displacements
- Computations for the Strains /Stresses

First, the governing differential equation of the problem is converted into an integral form. There are two techniques to achieve this:

(i) Variational Technique
(ii) Weighted Residual Technique.

C. A finite element package: ANSYS

For present work, finite element method is used for the study of thermal conductivity of the fiber reinforced polymer composite. A well-known finite element package ANSYS is used to calculate the effective thermal conductivity of fiber reinforced polymer composites. For the ANSYS modelling, short fibers, which are in cylindrical shape, are placed systematically in a cube lattice to simulate the microstructure of the composite lamina used. For different fiber loadings, the three dimensional physical model is prepared for the thermal analysis. Moreover, the effective thermal conductivity of these prepared epoxy composites reinforced with short fibers ranging from 0 to 15.7 vol % is numerically determined using ANSYS.

The steps used in ANSYS for calculating the thermal conductivity are as follows:

1. In the very first step we have to select the preference for the study. There are so many fields are available in ANSYS like thermal, fluid dynamics, structural design etc. As the present study is based on the thermal analysis so preference is given as thermal.
2. In the second step we have to select the preprocessor. In this step element type, description of work and type of node is selected. For present work have selected the thermal solid mass with 8 node brick 70 node is used.
3. In this step the material types and properties are described. For present work materials used are epoxy, glass fiber and banana fiber. The thermal conductivity for all these materials is described in this step.
4. The next step is modeling of the composite lamina. The shape of epoxy resin is taken as square in which the short cylindrical fibers are placed systematically. Three dimensional cylinders in cube lattice array are arranged for the present work. The no. of fibers in the cube depends upon the fiber loading. Finally all the created geometry is overlapped on each other for the meshing.
5. Now in this step meshing of the geometry is done. The type of meshing, size of the meshing etc. are described in this step. The accuracy of the results depends of the meshing. As good as meshing, the accuracy of the results increase.
6. In the next step, solution of the problem is done. For the solution purpose we have to first define the loads on all the faces of composite lamina. For present work, only one dimensional heat transfer is assumed within the composite system so we have to select the input for heat conducting face. Input is given in form of temperature. On the opposite face we have to select the heat transfer coefficient for convection and also the ambient temperature. All the other face is assumed as adiabatic.
7. This is the last step in which results of the analysis are found. The temperature profile for the composite system is found in this step. With the help of temperature profile we can calculate the effective thermal conductivity of composite system.

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8. This is the procedure for calculating thermal conductivity of the composites with the help of ANSYS.

IV. RESULTS AND DISCUSSION

A. Numerical analysis and theory of finite element method

The finite element analysis (FEA) or the finite element method (FEM) is a powerful tool used in numerical methods to arrive at approximate solutions to mathematical problems so that it can simulate the responses of physical systems to various forms of excitation. In the FEM analysis, the complex problems are reduced to simple one by converting the whole domain into a finite number of elements or pieces and for each element an approximate function is associated for the unknown field variables. Now the investigations are concentrated to these elements rather than the whole complex problem. Further, the analysis of thermal conductivity over the composite lamina is done with the help of a well-known FEM package ANSYS. For the ANSYS modelling, short fibers, which are in cylindrical shape, are placed systematically in a cube lattice to simulate the microstructure of the composite lamina used. For different fiber loadings, the three dimensional physical model is prepared for the thermal analysis. Moreover, the effective thermal conductivity of these prepared epoxy composites reinforced with short fibers ranging from 0 to 15.7 vol % is numerically determined using ANSYS.

1) Description of the problem

Fig. 4.1 shows the direction of heat flow within the composite lamina and the boundary conditions taken for the study of this heat transfer problem for the composite system reinforced by short fibers. The input of this heat transfer problem is in the form of temperature which is given at the nodules along the surface ABEF. The temperature on the surface ABEF is given as 100oC. There is a convective heat transfer from the composite lamina to the ambient air and the heat transfer coefficient for convection is supposed to be 2.5 W/m2-K at an ambient temperature of 27°C. All the other faces parallel to direction of the flow of heat are supposed adiabatic. The unknown temperatures at the inner nodes and on the other boundaries are obtained with the help of ANSYS.

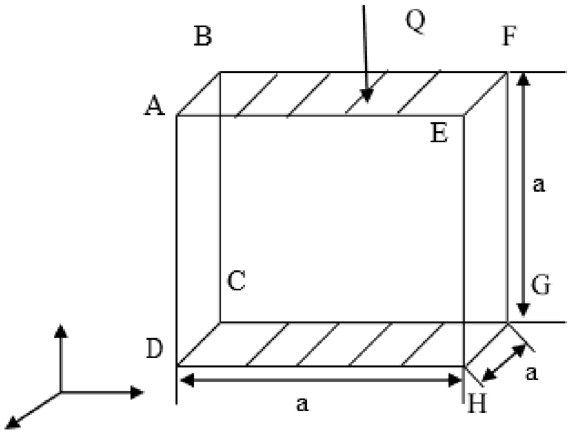

Fig. 4.1 Boundary condition

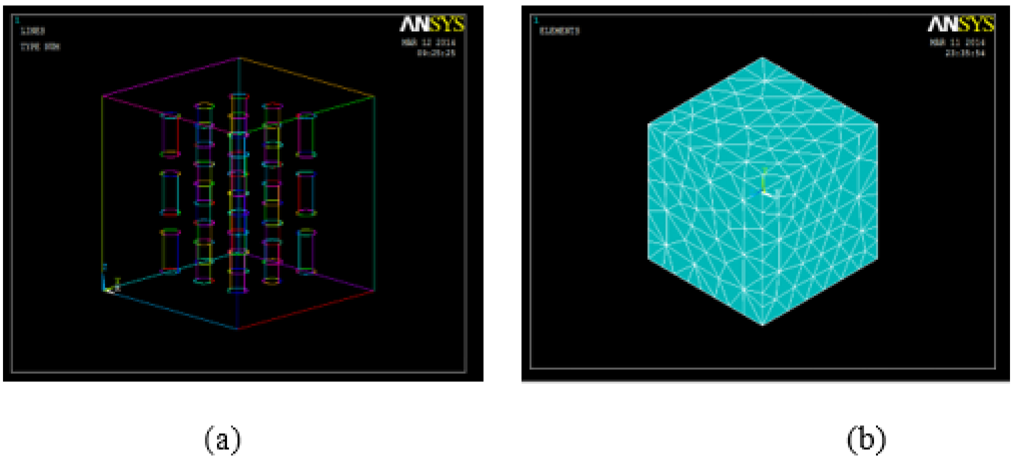

Fig. 4.2 Three dimensional view of short fiber in cube model (a) fiber arrangement within matrix body, (b) Meshing of such model

B. Effective thermal conductivity of the composites

Fig. 4.2 shows the three dimensional view of short fiber in cube model. A typical arrangement of short fiber within the matrix body is shown in Fig. 4.2(a) where fibers are uniformly distributed within the resin and heat is transferred from top to bottom along the axial direction of the fiber. Fig. 4.2(b) shows the meshed view of such fiber in cube model where size of the meshing element purely depends upon the dimension of short fiber.

By applying the various boundary conditions, the temperature profiles can be obtained which are presented in Fig. 4.3 and Fig. 4.4.

Fig 4.3(a-f) shows the temperature profiles for glass fiber reinforced epoxy composites with fiber volume fraction of 2.83, 5.65, 7.54, 10.05, 12.56 and15.7 vol% respectively.

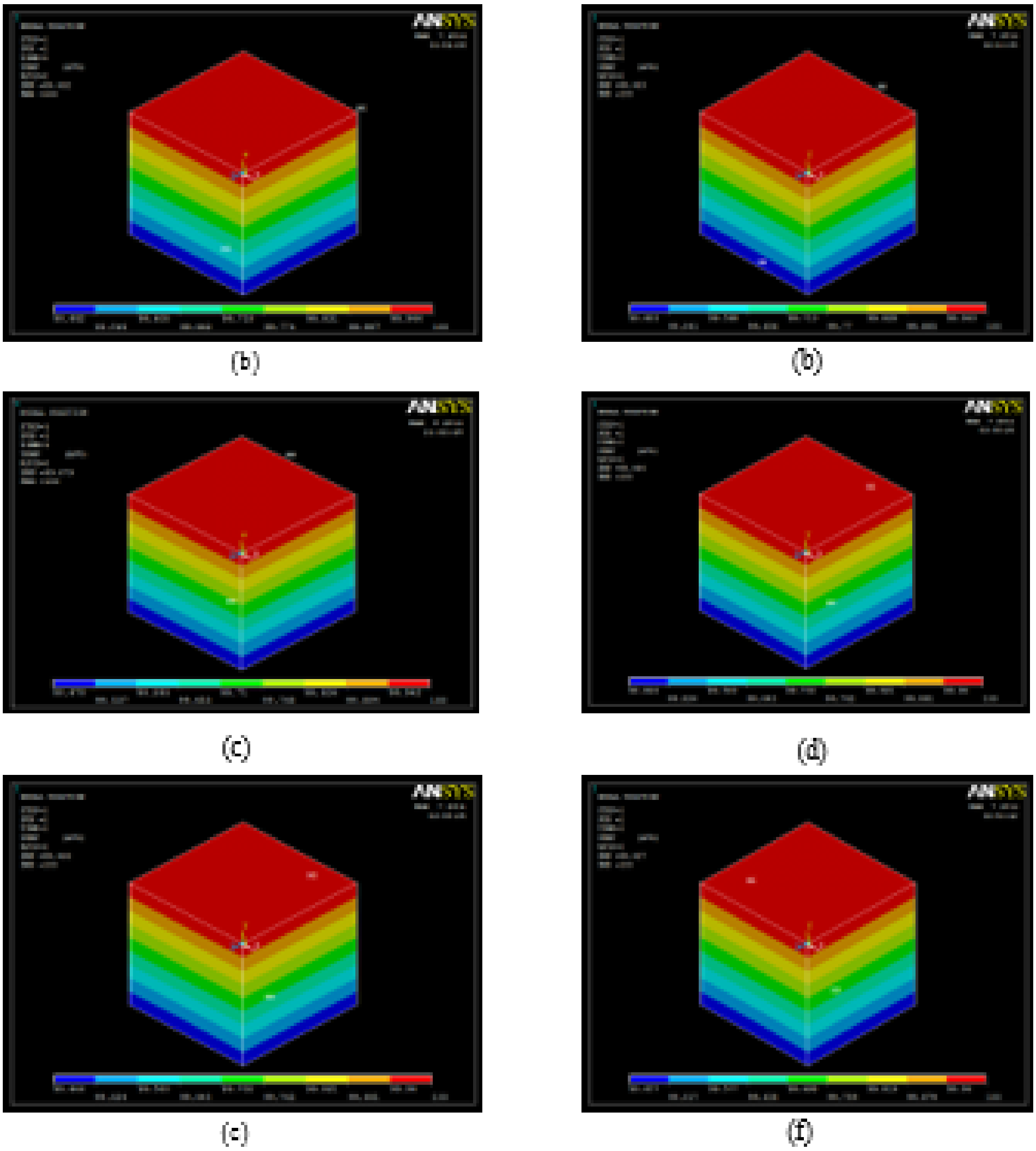

Fig. 4.3 Temperature profile of composites with glass fiber loading of (a) 2.83 vol% (b) 5.65 vol% (c) 7.54 vol% (d) 10.05 vol% (e) 12.56 vol% (f) 15.7 vol%

The corresponding temperature profiles for banana fiber reinforced epoxy composites are shown in Fig. 4.4(a-f).

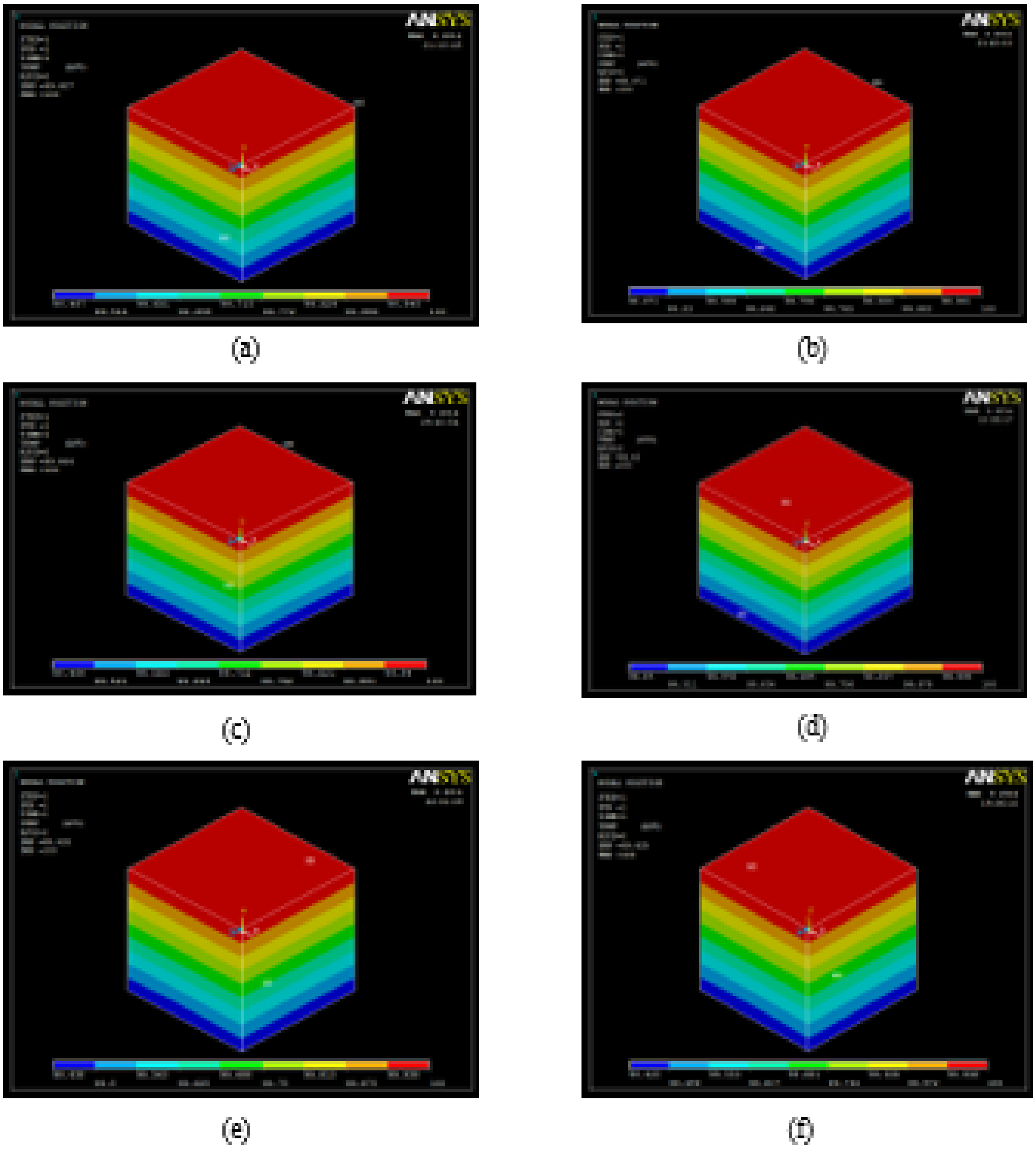

Fig. 4.4 Temperature profile of composites with banana fiber loading of (a) 2.83 vol% (b) 5.65 vol% (c) 7.54 vol% (d) 10.05 vol% (e) 12.56 vol% (f) 15.7 vol%

With the help of various temperature profiles, keff values for different sets of epoxy-fiber composites are calculated.

The keff values for different methods along with the experimental values for glass fiber reinforced epoxy composites are shown in table 4.1. The similar values for banana fiber reinforced epoxy composites are shown in table 4.2.

Table 4.1 The keff values for composites obtained from different methods for glass fiber reinforced epoxy composites

Sample	Fiber loading (vol%)	Effective thermal conductivity of the composite (W/mK)					
		ROM	Maxewell model	Lewis-Nilsen model	Proposed model	Experi. values	FEM
1	2.83	0.353	0.356	0.357	0.357	0.360	0.357
2	5.65	0.343	0.350	0.345	0.352	0.356	0.350
3	7.54	0.337	0.346	0.339	0.349	0.352	0.347
4	10.05	0.328	0.340	0.329	0.343	0.346	0.342
5	12.56	0.322	0.336	0.323	0.339	0.341	0.338
6	15.7	0.313	0.329	0.313	0.334	0.337	0.333

Table 4.2 The keff values for composites obtained from different methods for banana fiber reinforced epoxy composites

Sample	Fiber loading (vol%)	Effective thermal conductivity of the composite (W/mK)					
		ROM	Maxewell model	Lewis-Nilsen model	Proposed model	Experi. values	FEM
1	2.83	0.334	0.353	0.354	0.355	0.359	0.353
2	5.65	0.309	0.343	0.345	0.347	0.352	0.342
3	7.54	0.295	0.336	0.339	0.342	0.348	0.338
4	10.05	0.275	0.326	0.329	0.334	0.342	0.329
5	12.56	0.263	0.319	0.323	0.328	0.336	0.322
6	15.7	0.246	0.308	0.313	0.319	0.329	0.315

The comparison of effective thermal conductivity of glass fiber reinforced epoxy composites obtained from various established model like Rule of Mixture, Maxwell‟s model and Bruggeman‟s model together with proposed model, FEM analysis and experimental values are shown in Fig. 4.5.

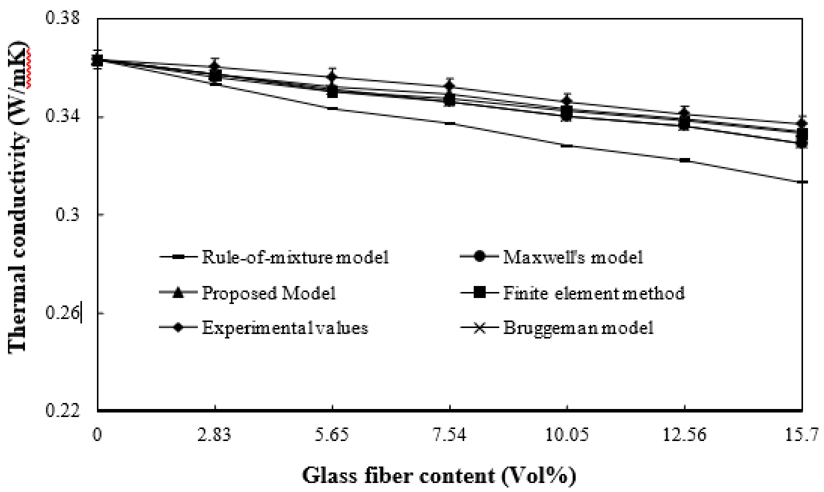

Fig. 4.5 Effective thermal conductivity of short glass fiber/epoxy composites: Rule-of mixure, Maxwell‟s model, Bruggeman model, Proposed model, FEM and Experimental values

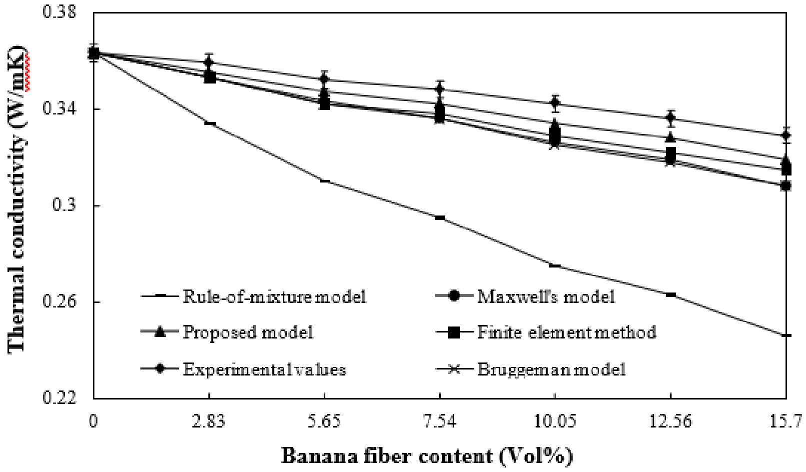

Fig. 4.6 Effective thermal conductivity of short banana fiber/epoxy composites: Rule-of mixure, Maxwell‟s model, Bruggeman model, Proposed model, FEM and Experimental values

The similar comparison for banana fiber reinforced epoxy composites are shown in Fig. 4.6.

From both the figures, it is observed that as the fiber loading in the epoxy resin increases, the values of keff decreases which is obvious because both the fibers possesses low value of intrinsic thermal conductivity as compared to epoxy resin. The trend is followed by all the analytical models, numerical model and measured values.

Further it is noticed that the values obtained from Maxwell‟s model, Bruggeman‟s model, proposed model and FEM analysis fit well with the experimental data whereas rule of mixture model is far from satisfaction.

The percentage error associated with each of the method used in present investigation for glass fiber-epoxy composites are presented in table 4.3.

The similar percentage error associated with each of the method used in present investigation for banana fiber-epoxy composites are presented in table 4.4.

Table 4.3 Percentage errors associated with respect to experimental value for glass fiber/epoxy composites

Sample	Fiber loading (vol%)	Percentage errors with respect to experimental value				
		Rule of mixture	Maxewell model	Bruggeman model	Proposed model	FEM
1	2.83	1.983	1.123	0.841	0.843	0.840
2	5.65	3.790	1.714	1.424	1.424	1.714
3	7.54	4.451	1.734	1.149	1.734	1.440
4	10.05	5.487	1.764	1.169	1.765	1.169
5	12.56	5.901	1.488	1.186	1.488	0.887
6	15.7	7.667	2.431	1.813	2.431	1.201

From the tables it is observed that the errors associated with respect to the experimental values for glass fiber reinforced epoxy composite for proposed model, FEM values, Maxwell‟s model and Bruggeman‟s model lie in range of 0.8-2% and for rule-of mixture model it gets widen up to 2-8%.

Table 4.4 Percentage errors associated with respect to experimental value for banana fiber/epoxy composites

Sample	Fiber loading (vol%)	Percentage errors with respect to experimental value				
		Rule of mixture	Maxwell"s model	Bruggeman model	Proposed model	FEM
1	2.83	7.485	1.608	1.699	1.127	1.169
2	5.65	13.548	2.624	2.924	1.441	2.924
3	7.54	17.966	3.571	3.571	1.754	2.958
4	10.05	24.363	4.908	5.231	2.395	3.951
5	12.56	27.756	5.329	5.660	2.439	4.347
6	15.7	33.739	6.818	6.818	3.135	4.444

Again for banana fiber reinforced epoxy composites the errors associated with respect to measured values for proposed model and FEM values lie in the range of 1-4%, for Maxwell"s model and Bruggeman"s model lie in range of 1.6-7% and for rule-of mixture it is in range of 7- 34%. It is observed that the values obtained from the proposed model and FEM simulation are showing least percentage variation with measured values when both sets of composites are considered for the complete range of fiber loading, whereas Maxwell"s and Brugmann"s model show more variation with respect to measured value for banana fiber epoxy composites as compared to glass fiber-epoxy composites. It is seen that rule-of-mixture model underestimates the measured values completely for both sets of composites. It can be observed that for predicting the effective thermal conductivity of composites for a wide range of fiber concentration, proposed model and FEM model are giving the most suitable results.

V. Chapter summery

This chapter has presented the results of the numerical analysis and mathematical model and experiments conducted to evaluate the thermal insulation of the polymer composites under study. The measured values of the effective thermal conductivity are obtained for different volume fractions of fibers. Incorporation of fiber results in reduction of thermal conductivity of epoxy resin and thereby improves its thermal insulation capability. A reduction of 8 % in keff is obtained for the composites with addition of 15.7 vol % of glass fiber whereas for banana fiber it goes down to 12 % for similar fiber loading. The next chapter presents the conclusions based on the research presented in this thesis along with recommendations for future work.

VI. CONCLUSİON AND SCOPE OF THE FUTURE WROK

A. Conclusion

Based on the numerical, analytical and experimental investigation on the thermal conductivity of fibers (glass fiber and banana fiber) reinforced composites, it can be concluded that:

1. Different sets of epoxy/ glass fiber and epoxy/banana fiber composites can be successfully fabricated by simple hand lay-up technique for varied volume concentration.

2. The values obtained from the proposed mathematical model are in close approximation with the measured values for all the fabricated composites over the entire range of fiber content.

3. The results obtained from the proposed mathematical model are also in closer approximation with the values obtained by FEM simulation using ANSYS.

4. It is seen that the Finite element method (FEM) can be gainfully employed for determination of effective thermal conductivity of fiber reinforced polymer composites with different volume concentration of fiber.

5. The study shows that the keff reduces quite significantly as the fiber loading in the composite increases. A reduction of about 8 % in the value of the keff is recorded with addition of 15.7 vol % of glass fiber in epoxy resin whereas 12 % decrease is noticed when filler is banana fiber.

6. Also is can be concluded that banana fiber reinforced epoxy composites shows much lower keff values than that of glass fiber reinforced epoxy composites. Banana fibers have also properties like non-corrosive, biodegradable, low cost, recyclable etc. So it can be said that a natural fiber i.e. banana fiber can replace a well-known synthetic fiber i.e. glass fiber for insulation purpose used as reinforcement in composite materials.

7. With light weight and reduced heat conductivity, these fibers reinforced polymer composites finds their potential applications in insulation boards, food containers, thermo flasks, building material etc.

B. Scope for future work

This work leaves a wide scope for future investigators to explore many other aspects of thermal behaviour of fiber reinforced polymer composites. Some recommendations for future research include:

- Study on effect of filler orientation and size on thermal properties of the composites.
- Investigation of new fillers and polymers for development of materials having low thermal conductivity and low electrical conductivity.
- Possible use of other polymeric resins and natural fibers in the development of new hybrid composites.
- Study on the response of these composites to other wear modes such as abrasion and slurry erosion.
- Study on the effect of filler shape and size on thermal properties of the composites.

REFERENCES

[1] Gad Marom, Albert Reuveni and Daniel Cohn, "Stiffness Variability and Stress-Dependent Elastic Response of Synthetic Fiber-Reinforced Composites for Biomedical Applications", Biomaterials, Vol. 14, No. 2, 1993.

[2] Vijay Kumar Thakur and Manju Kumari Thakur, "Processing and Characterization of Natural Cellulose Fibers/Thermoset Polymer Composites", Carbohydrate Polymers, Vol.109, pp. 102–117, 2014.

[3] Yongli Zhang, Yan Li, Hao Ma and Tao Yu, "Tensile and Interfacial Properties of Unidirectional Flax/Glass Fiber Reinforced Hybrid Composites", Composites Science and Technology, Vol. 88, pp. 172–177, 2013.

[4] Cho, J., Chen, J. Y. & Daniel, I. M. "Mechanical Enhancement of Carbon Fiber/Epoxy Composites by Graphite Nanoplatelet Reinforcement", Scripta materialia, Vol. 56 (8), pp. 685- 688, 2007.

[5] Chauhan, S. R., Gaur, B. & Dass, K. "Effect of Fiber Loading on Mechanical Properties, Friction and Wear Behaviour of Vinylester Composites Under Dry and Water Lubricated Conditions", International Journal of Material Science,Vol. 1(1), pp. 1-8, 2011.

[6] Huang, G. & Sun, H. "Effect of Water Absorption on the Mechanical Properties of Glass/Polyester Composites", Materials & design, Vol.28, pp.1647-1650. 2007.

[7] Stephen Tsai and Thomas Hann, "Introduction to Composite Materials", Technomic Publications, Lancaster, 1980.

[8] Zhong-Hong Jiang and Qin-Yuan Zhang, "The Structure of Glass: A Phase Equilibrium Diagram Approach", Progress in Materials Science, Vol. 61, pp. 144–215, 2014.

[9] Alexander Markov, Bodo Fiedler and Karl Schulte, "Electrical Conductivity of Carbon Black/Fibers Filled Glass-Fiber-Reinforced Thermoplastic Composites", Composites: Part A, Vol. 37, pp. 1390–1395, 2006.

[10] D. Olmos and J. Gonzalez-Benito, "Visualization of the Morphology at the Interphase of Glass Fiber Reinforced Epoxy-Thermoplastic Polymer Composites", European Polymer Journal, Vol. 43, pp. 1487–1500, 2007.