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Review paper Study of Improvement on the Effective Thermal Conductivity of Fiber Reinforced Epoxy Composites Material

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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 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.

1. INTRODUCTION

It is essential for comfort and in some cases, for the survival of humans and animals to retard the flow of heat by using some insulation medium. Insulation has many advantages in industry like it prohibits damage due to freezing of various articles or damage of articles by high temperatures, and lowers cost for heating and cooling. Heat flows from a hot body to a cold (i.e. less warm) body in one direction only so insulation helps to slow down this flow. In a refrigerator, for example, insulation retards the heat flow from the room air to the interior of the refrigerator. In a building, we can observe that insulation keeps out during summer heat and in during winter.

It can be observed that most of the studies in the field of thermal analysis of polymers are intended at enhancing the thermal conductivity of the polymer rather than trying to improve its insulation capabilities. In applications like pipe insulation, building insulation, thermo flasks and in food containers, thermal insulation is required. Also in space craft and automotive industries thermal insulation plays an important role.

It is remarkable to note that natural fibers such as sisal, jute, coconut coir, rice husk, banana etc., are richly available but are not optimally utilized. At present, the use of these fibers are in the production of mats, ropes, yarns and matting as well as in production of fancy articles like table mats, handbags, wall hanging and purses. Cotton, banana and pineapple are also used in making cloth in addition to being used in the paper industry. With growing environmental responsiveness and ecological concern, attention towards natural fiber reinforced composites have increased during the recent decades. The composites have many advantages, including low cost, light weight, nontoxic, biodegradable etc. Various natural fillers like pineapple, sisal and bamboo, coconut coir, jute etc. as the reinforcements in composites have been reported earlier. Apart from this, natural fibers possess very low thermal conductivity which is much lower than synthetic fiber and can be used as filler for various insulation applications.

1.1 TYPES OF COMPOSITE MATERIALS

On the basis of matrix material composite materials can be classified into three groups. They are:

1.1.1 Metal Matrix Composites (MMC)
1.1.2 Ceramic Matrix Composites (CMC)
1.1.3 Polymer Matrix Composites (PMC)

1.1.1 METAL MATRIX COMPOSITES:

Metal matrix composite made a breakthrough in the development of useful properties of metals and alloys in relation to the traditional approach of alloying and heat treatment. These composites, containing discontinuous or continuous reinforcement with particulates, whiskers or fibers are capable of providing properties not achievable in monolithic alloys. Ceramic particles or whiskers dispersed in a metal matrix either by powder metallurgy or molten metal processing can enhance the modulus, strength, wear resistance, elevated temperature properties or control of thermal conductivity or coefficient of thermal expansion.
The improved thermal conductivity and controlled coefficient of thermal expansion of SiC particle reinforced aluminum matrix composites are finding newer application as electronics packaging matrerials. Many potential aerospace applications have been identified for MMC. These are also having automotive applications.

1.1.2 CERAMIC MATRIX COMPOSITES:

Ceramics are characterized by lightness, hardness, corrosion and oxidation resistance and superior elevated temperature properties. Hence many ceramic matrix composites can be used as temperatures higher than those of the polymer and metal matrix composites. Important ceramic matrixes are oxides, carbides, nitrides, borides, glasses, glass-ceramics and silicates. The reinforcements used are SiC, $Si3N4$, $Al2O3$, BN, $ZrO2$, AIN and C in the form of fibers, whiskers or particulates. These composites are processed by sintering, hot pressing, hot isotactic pressing, infiltration, reaction bonding and combustion synthesis. Currently ceramic matrix composites are used as cutting tool inserts wear resistant composites, space shuttle tiles and aerospace components. Other potential application includes engine components, armor of military vehicles, and leading edge application in aerospace and high temperature corrosion resistant parts. Other potential application includes bio-ceramic and high temperature ceramic super conductor composite wires for power transmission cables, motors and super conducting magnetic energy storage system.

1.1.3 POLYMER MATRIX COMPOSITES:

In case of the reinforced plastics, the characteristics of the desired end product such as size, shape, function and quality determine the method by which the basic materials are combined, moulded, cured and machined. Prominent moulding process for reinforced plastics includes hand lay-up, spray up moulding, prepreg lay-up (vacuum bag and auto-clave moulding), press moulding (SMC, BMC etc.), resin injection moulding and filament winding. To make useful structure, the composite materials have to be joined and machined,The industrial applications of reinforced plastics have spread a wide spectrum of consumer goods, constructions, chemical plants, marine and road transportation and aerospace components. Mechanical engineering products include cylinders, rolls, shafts, coupling, spindles, robot arms, covering etc. the aerospace industry used a wide range of products including floor panels, skin panels, elevators, wings, flaps, covers, tanks, struts and rotor blades.

1.2 TYPES OF POLYMER COMPOSITES

Broadly, polymer composites can be classified into three groups on the basis of reinforcing material. They are:

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

1.2.1 FIBER REINFORCED POLYMER

It is also known as fibre-reinforced plastic. In this type of polymer composite fibres are reinforced with a polymer matrix. The common used fibres are glass, carbon, or aramid, while other fibres such as paper or wood or asbestos can also be used. The Fibre reinforced polymer composites can potentially application in the aerospace, automotive, marine, and construction industries.

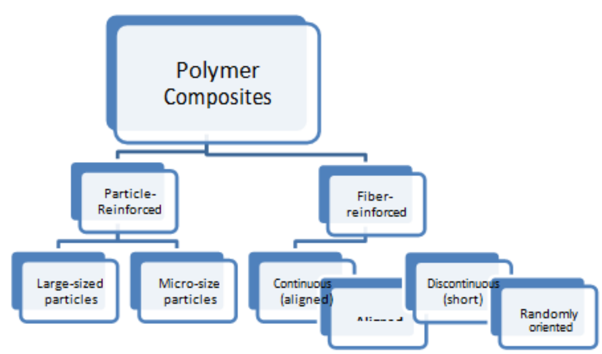

Fig. 1.1 Classification of composites based on reinforcement type

1.2.2 PARTICLE REINFORCED POLYMER

Particulate composites have an additive constituent which is essentially one or two dimensionally and macroscopic /microscopic. In some composites however, the additive constituent is macroscopically non-dimensionally, i.e., conceptually a point, as opposed to a line or an area.Only on the microscopic scales does it become dimensional, i.e., a particle, and thus the concept of composite must come down to the microscopic level if it is to encompass all the composite of interest of engineers. Particulate composites differ from the fiber flake types in that distribution of the additive constituent is usually random rather than controlled. Particulate composite are therefore usually isotropic. This family of composites includes dispersion-hardened alloy and cermet.

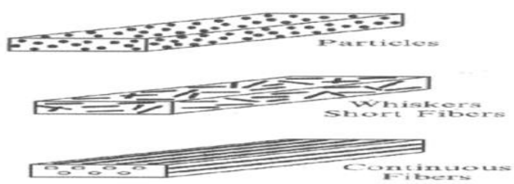

Fig. 1.2 Different types of composites

1.5 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.

2. LITERATURE SURVEY

This chapter includes a survey of the past research already available involving the issues of interest. It presents the research works on the fiber reinforced polymer composites and the influence of various factors on the performance of composites studied by various investigators. The literature review is done based in the following points:

2.1 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.

2.2 STRUCTURE AND PROPERTY OF GLASS FIBER

Glass fiber is one of the most widely used filler which are being incorporated in polymers. Glass fiber is a lightweight, extremely strong and robust material. Stephen and Thomas [7] studied that the bulk strength and weight properties of glass fiber are favorable properties when compared to metals, and also it is easily moldable. Jiang and Zhang [8] studied that the glass is considered a vitreous super cooled liquid that is in a thermodynamically metastable state between the molten liquid state and the crystalline state. Different glass structures are influenced by the thermal history of the cooling process. Some typical properties of two important classes of glass fibers are shown in Table 2.1.

Material	Density (g/cm3)	Tensile strength (MPa)	Young's Modulus (GPa)	CTE (10-6K)
S-Glass	2.55	3400	73	5.0
E-Glass	2.49	4400	86	5.6

2.3 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].

2.4 STUDY ON THERMAL CONDUCTIVITY OF FIBER REINFORCED POLYMER COMPOSITES

A great deal of research work has been reported by various authors on the study of fiber reinforced composites. Dong-Pyo Kim et al [37] studied the glass fiber reinforced polymetalphosphate matrix composites prepared by a simple process displayed excellent thermal insulating and mechanical properties. Schuster et al [38] investigated the effect of three- dimensional fiber reinforcement on the out-of-plane thermal conductivity of composite materials. Using finite element models to better understand the behavior of the composite material, improvements to an existing analytical model were performed to predict the effective thermal conductivity as a function of the composite material properties and in-contact thermal material properties. Zhidong et al [39] studied the dependence of thermal conductivity of nanotubes on the atomic structure, the tube size, the morphology, the defect. The roles of particle/polymer and particle/particle interfaces on the thermal conductivity of polymer/CNT nano composites are discussed in detail. Yüksel et el [40] studied the temperature dependence of effective thermal conductivity (ETC) for samples of binary, ternary, and quadruple glass wools reinforced with aluminum foil was examined. The experiments were realized by the guarded hot plate in temperature differences of 5, 10 and 15 °C and the temperatures of 25 and 40 °C. The results revealed that in the case of reinforcing the aluminium foil, ETC increased with increasing the temperature or changing of temperature difference (5, and 15 °C). Hang et al [41] investigated thermal transport mechanisms and characterized when highly conductive fibers are embedded across the thickness of a three-dimensional polymer composite. An experimental setup was designed, fabricated and validated to measure through-thickness thermal conductivity.

2.5 STUDY ON EFFECTIVE THERMAL CONDUCTIVITY ANALYTICAL MODELS

Numerous theoretical and empirical models have been proposed in the past to estimate and predict the effective thermal conductivities of fiber reinforced polymer composites. Comprehensive review articles have discussed the pertinent applicability of many of these analytical models. The simplest alternative for a two-component composite system would be with the arrangement of materials in either parallel or series with respect to heat flow which gives the upper or lower bounds of effective thermal conductivity. For parallel conduction model [42, 43]

$$k_c = (1-\phi_1-\phi_2)k_m + \phi_1 k_{f_1} + \phi_2 k_{f_2} \tag{2.1}$$

where, kf1, kf2, km, kc are thermal conductivities of 1st filler, 2nd filler, composite matrix, conductivity of the composite as a whole and ϕ1 and ϕ2 are volume fractions of 1st and 2nd filler respectively.For series conduction model [42, 43]

$$\frac{1}{k_c} = \frac{1-\phi_1-\phi_2}{k_m} + \frac{1}{k_{f_1}} + \frac{1}{k_{f_2}} \qquad (2.2)$$

The correlations represented by Equations (3.1) and (3.2) are derived on the basis of the rules-of- mixture.

The geometric mean model [42, 43], also known as Ratcliffe Empirical Model gives the effective thermal conductivity as:

$$k_c = k_m^{(1-\phi_1-\phi_2)} k_{f_1}^{\phi_1} k_{f_2}^{\phi_2} \qquad (2.3)$$

Bruggeman [44] derived an equation employing different assumptions for permeability and field strength for dilute suspension of spheres for a homogeneous medium and the implicit equation is given as:

$$1-\phi = \left[\frac{k_c - k_f}{k_m - k_f}\right]\left(\frac{k_m}{k_c}\right)^{1/3} \qquad (2.4)$$

Maxwell [45] has obtained an exact expression for thermal conductivity, using potential theory for an infinitely dilute composite of spherical particulates dispersed randomly and devoid of mutual interaction in a homogeneous medium, which is given by

$$k_c = k_m\left[\frac{k_f + 2k_m + 2\phi(k_f - k_m)}{k_f + 2k_m - 2\phi(k_f - k_m)}\right] \qquad (2.5)$$

Where, kc, km and kf are thermal conductivities of composite, continuous- phase (matrix), and dispersed-phase (filler) respectively, and ϕ is the volume fraction of the dispersed-phase. Lord Reyleigh [45] extended Maxwell‟s solution by considering the thermal interaction between particles. For a cubic array the following expression was derived for the thermal conductivity:

$$k_e = k_m\left[\frac{2k_m + k_f - 2\phi - 0.525\left(\frac{3k_m - 3k_f}{4k_m + 3k_f}\right)\phi_f^{10/3}}{\frac{2k_m + k_f}{k_m - k_f} + \phi - 0.525\left(\frac{3k_m - 3k_f}{4k_m + 4k_f}\right)\phi_f^{10/3}}\right] \qquad (2.6)$$

Here, ke is the effective thermal conductivity of the composite. This reduces to Maxwell‟s equation whenever „ϕ‟ is sufficiently small and the last term may be neglected.Lewis and Nielsen [42] derived a semi-theoretical model by modification of the Halpin-Tsai equation for a two phase system which assumes an isotropic particulate reinforcement and also takes into consideration the shape of particle as well as its orientation.

$$k_c = k_m\left[\frac{1+AB\phi}{1-B\phi\psi}\right] \qquad (2.7)$$

$$B = \left[\frac{(k_f/k_m)-1}{(k_f/k_m)+A}\right] and, \psi = 1+\left[\frac{1-\phi_m}{\phi_m^2}\right]$$

Where, kf is thermal conductivity of filler material and „ϕ‟ is the volume fraction of filler material.

2.5 THE KNOWLEDGE GAP

In the past, a number of studies have been published on the thermal conductivity of particulate composites but a very few investigation has been carried out on the thermal conductivity of fiber reinforced polymer composites so that there is a huge knowledge gap that demands a well- planned and systematic research in this area of fiber reinforced polymer composites. A comprehensive evaluation of the available literature tells that:

- Most of the studies are intended at improving the heat conduction capacity of the polymer rather than trying to improve its insulation capability.
- Even though a large number of particulates and fibers have been used as fillers in the past, there is no report available on natural fibers like banana fiber being used for composite making for the insulation purpose.
- Investigation on heat conduction mechanism of fiber reinforced polymer composites is rare.
- The understanding of the relationship between the effective thermal conductivity of a composite material and the micro-structural properties (volume fractions, distribution of fibers, size of fibers, properties of individual components, etc.) is far from satisfactory.

Further, though it becomes clear that improvisation on thermal conductivity of polymers may be achieved either by molecular orientation or by the addition of conductive fillers, it is yet to be seen how the incorporation of natural fibers with poor heat conductivity affects the overall conductivity of any polymer composite..

3. OBJECTIVE OF THE PROJECT

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.

4 . METHODOLOGY & EXPERIMENTAL PROCEDURE

4.1 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.

4.2 Materials

4.2.1 Matrix material

Matrix materials are of different types like metals, ceramics and polymers. Polymer matrices are most commonly used because of cost efficiency, ease of fabricating complex parts with less tooling cost and they also have excellent room temperature properties when compared to metals and ceramic matrices. Polymer matrices can be either thermoplastic or thermoset. Thermoset matrices are formed due to an irreversible chemical transformation of the resin into an amorphous cross-linked polymer matrix. Due to huge molecular structures, thermoset resins provide good electrical and thermal insulation. They have low viscosity, which allow proper fiber wet out, excellent thermal stability and better creep resistance.The most commonly used thermoset resins are epoxy, polyester, vinyl ester and phenolics. Among them, the epoxy resins are being widely used for many advanced composites due to their excellent adhesion to a wide variety of fibers, superior mechanical and electrical properties and good performance at elevated temperatures. In addition to that they have low shrinkage upon curing and good chemical resistance. Due to several advantages over other thermoset polymers, epoxy (LY 556) is chosen as the matrix material for the present research work. It chemically belongs to the „epoxide" family. Its common name is Bisphenol-A-Diglycidyl-Ether (commonly abbreviated to DGEBA or BADGE) and its molecular chain structure is shown in Figure 3.1. It provides a solvent free room temperature curing system when it is combined with the hardener tri-ethylene-tetramine (TETA) which is an aliphatic primary amine with commercial designation HY 951 (Figure 3.2). The LY 556 epoxy resin (Figure 3.3) and the corresponding hardener HY- 951 are procured from Ciba Geigy India Ltd. Table 3.1 provides some of the important properties of epoxy.

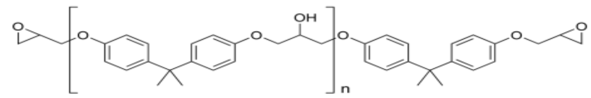

Fig. 3.1 Unmodified epoxy resin chain („n" denotes number of polymerized unit)

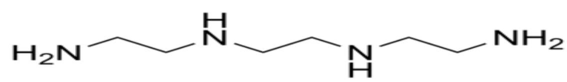

Fig. 3.2 Tri-ethylene-tetramine (hardener used for epoxy matrix)

Characteristic Property	Inferences
Density	1.1 gm/cc
Compressive strength	90 MPa
Tensile strength	58 MPa
Thermal conductivity	0.363 W/m-K
Glass transition temperature	104°C
Coefficient of Thermal expansion	62.83 ppm /°C
Electrical conductivity	0.105×10^{-16} S/cm

Table 3.1 Some important properties of epoxy

Fig. 3.3 Epoxy resin and hardener

4.2.2 FILLER MATERIAL - 1 :(GLASS FIBER)

For fabrication of polymer composite a well-known synthetic fiber i.e. short glass fiber is used as filler material. It is the one of the most widely used reinforcements. Glass fiber is formed when thin strands of silica based or other formulation glass are extruded into many fibers with small diameters suitable for textile processing. The first commercial production of glass fiber was in 1936. Glass fiber is considered as a filler material because of its low density (1.5 gm/cm3); also it happens to be extremely strong and robust material. Most importantly it is insulating in nature (0.18 W/m-K). Uses for regular glass fiber include mats and fabric for thermal insulation, electrical insulation, sound insulation, high strength fabric, heat and corrosion resistant fabric. Glass fiber is extensively used for making FRP tanks and vessels. Glass fibers used in present investigation are procured from Saint Govion, India. Table 3.2 provides some of the important properties of glass fiber. Figure 3.4 shows short glass fiber used as filler in the present investigation.

Characteristic Property	Inferences
Density	1.5 gm/cc
Compressive strength	1080 MPa
Tensile strength	3445 MPa
Thermal conductivity	0.18 W/m-K

Table 3.2 Some important properties of glass fiber

Fig. 3.4 Short glass fiber used as filler in the present work

4.2.3 FILLER MATERIAL - 2 :(BANANA FIBER)

For fabrication of second set of polymer composite natural fiber i.e. banana fiber is used as filler material. Scientific name of banana is musa acuminata. They have a high tensile strength and resist rot. Historically they have been used to make rope. Main organic constituents of banana fiber are: cellulose, hemicellulose, pectin, lignin and some extractives. Banana fiber is considered to be remarkable filler because of its very low density (0.2 gm/cm3), low cost, nontoxic, biodegradable and environmental friendly nature. It possesses very low thermal conductivity (0.09 W/m-K) which is prime requirement for present investigation. Banana fibers

are used for making cloths, paper, ropes etc. Banana fibers used in present investigation are procured from M/s ROPE (Rural Opportunity Production Enterprises) International, India. Table 3.2 provides some of the important properties of banana fiber. Figure 3.5 shows short banana fiber used as filler in the present work.

Characteristic Property	Inferences
Density	0.2 gm/cc
Compressive strength	22.25 MPa
Tensile strength	49.85 MPa
Thermal conductivity	0.09 W/m-K

Table 3.3 Some important properties of banana fiber

Fig. 3.5 Short banana fiber used as filler in the present work

4.3 Experimental details

4.3.1 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.

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

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

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.

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

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

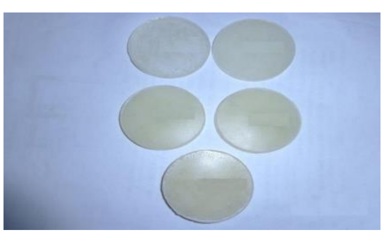

Fig. 3.7 Short glass fiber reinforced epoxy composites

Fig. 3.8 Short banana fiber reinforced epoxy composites

4.4 THERMAL CONDUCTIVITY CHARACTERIZATION

4..4.1 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.

4.4.2 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

We know that thermal conductivity of the material gives the amount of energy conducted through a body of unit area and unit thickness in unit time when the difference in temperature between the faces causing heat flow is unit temperature difference. The Fourier‟s equation for one-dimensional heat conduction is given as equation 3.1.

$$Q = KA\frac{T_1 - T_2}{x} \qquad (3.1)$$

Where,

Q = the heat transfer in W

K = the thermal conductivity of the material in W/m-K

A = the cross sectional area through which heat is transferred in m^2

T_1-T_2 = the temperature difference in K and

X = the thickness of the sample in m.

The thermal resistance of a test sample material can be given as

$$R = \frac{T_1 - T_2}{Q / A} \qquad (3.2)$$

Where,

R = the resistance of the sample in m^2-K/W.

From Equations 4.1 and 4.2 we can derive that.

$$K = \frac{x}{R} \qquad (3.3)$$

Where,

Q = the heat transfer in W

K = the thermal conductivity of the material in W/m-K

A = the cross sectional area through which heat is transferred in m2 T1-T2 = the temperature difference in K and

X = the thickness of the sample in m.

In Unitherm model2022, heat flux are measured with the help of heat flow transducer the temperature gradient through the sample test material between the upper plate and lower plate are obtained. Thus the thermal resistance of sample can be calculated between in the upper and lower surfaces. The thermal conductivity of the samples can be calculated using the input value of thickness and taking the known cross sectional area

4.5 NUMERICAL ANALYSIS: CONCEPT OF FINITE ELEMENT METHOD (FEM) AND ANSYS

The finite element method (FEM), or finite element analysis (FEA), is very powerful and simple tool for the analysis of complex physical and engineering problems. In the FEM analysis, the domain of the complex problems or objects is converted into a finite no. of elements or pieces for making it simple analysis. The investigation is concentrated on these elements rather than the whole problem. The complex object has an infinite number of degrees-of-freedom (DOF), while the discretized model has a finite number of DOF. Because of this reason, this method is called as finite element method or finite element analysis. Firstly FEM is used to investigate the stress distribution in complicated aircraft structure. Then it is applied to other field of continuum mechanics, like that Acoustics, heat transfer, fluid mechanics, electromagnetic, biomechanics, aeromechanics. We can say that the FEM analysis can be gainfully used in our daily life problems and also in complex problems of engineering fields. . Powerful computational technique for the solution of differential equations too complicated to be solved satisfactorily by classical analytical methods. The FEM analysis was firstly used in 1956 by Turner. It is most a powerful and simple computational tool for imprecise solutions to a variability of "real-world" engineering problems. FEM analysis can be used for designing the physical phenomenon in various engineering disciplines.

In the FEM analysis, the domain or area of the continuum are converted into a finite number of sub areas i.e. elements which depend on the basis of FEM analysis. Biased residual methods are used for the construction of the orderly approximate solution. In the FEM analysis, the complex problem is reduced to simple analysis by dividing the domains or areas into finite no. of elements and these elements are associated an approximate function to express the unknown field variable. These functions (also called interpolation functions) are defined in terms of the values of the field variables at specific points, referred to as nodes. Nodes are usually located along the element boundaries and they connect adjacent elements.

4.5.1 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.

In the variational technique, the calculus of variation is used to obtain the integral form corresponding to the given differential equation. The solution of the problem is obtained by minimizing the integral.

In the second step, Discretization of the solution domain into appropriate computational of the mesh means problem is divided into a number of parts, called as elements. (1-D) problems, the elements are nothing but line segments having only length and no shape. For problems of higher dimensions, the elements have both the shape and size. For two-dimensional (2D) or axi-symmetric problems, the elements used are triangles, rectangles and quadrilateral having straight or curved boundaries. When the domain boundary is curved, curved sided elements are good choice. For three- dimensional (3-D) problems, the shapes used are tetrahedron and parallelepiped having straight or curved surfaces. Division of the domain into elements is called a mesh. In this step, over a typical element, a suitable approximation is chosen for the primary variable of the problem using interpolation functions (also called as shape functions) and the unknown values of the primary variable at some pre-selected points of the element, called as the nodes. Usually polynomials are chosen as the shape functions. For 1-D elements, there are at least 2 nodes placed at the endpoints. Additional nodes are placed in the interior of the element. For 2-D and 3-D elements, the nodes are placed at the vertices (minimum 3 nodes for triangles, minimum 4 nodes for rectangles, quadrilaterals and tetrahedral and minimum 8 nodes for parallelepiped shaped elements). In the fourth step, the approximation for the primary variable is substituted into the integral form. If the integral form is of variational type, it is minimized to get the algebraic equations for the unknown nodal values of the primary variable. If the integral form is of the weighted residual type, it is set to zero to obtain the algebraic equations. In this step, the post-processing of the solution is done. That is, first the secondary variables of the problem are calculated from the solution. Then, the nodal values of the primary and secondary variables are used to construct their graphical variation over the domain either in the form of graphs (for 1-D problems) or 2-D/3-D contours as the case may be.

4.6 BENEFITS OF THE FEM OVER FORMER NUMERICAL METHODS ARE AS FOLLOWS:

- In FEM no geometric limitation, it can be applied the body or region with any shape of product.
- Boundary loading and conditions are not restricted (boundary condition and load may be applied to any portion of the body.
- Domain problems consisting of more than one material (composite) can be easily analyzed.
- The method can be used for any irregular-shaped domain and all types of boundary conditions.
- Accuracy of the solution can be improved either by proper refinement of the mesh or by choosing approximation of higher degree polynomials. The algebraic equations can be easily generated and solved on a computer. In fact, a general purpose code can be developed for the analysis of a large class of problems.
- FE structures closely resemble the actual body or region to be analyzed.
- The results and the analysis are easily improved by mesh refinement.
- In the finite element method it is easy to produce detailed visualizations of a complex problem.

4.7 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.

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

5. EXPECTED OUTCOME

5.1 EXPECTED OUTCOME

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

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