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

Tussarkanti Pradhan

Department of Mechanical Engineering
National Institute of Technology Rourkela
Sundargarh, Odisha, India - 769 008

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

A Thesis submitted in partial fulfillment of
the requirements for the award of the degree of

Master of Technology in
Thermal Engineering

Submitted to

National Institute of Technology Rourkela

By

Tussarkanti Pradhan

(Roll No. 214ME3299)

under the supervision of

Dr.Alok Satapathy

Department of Mechanical Engineering
National Institute of Technology Rourkela
Sundargarh, Odisha, India - 769 008

Department of Mechanical Engineering
National Institute of Technology Rourkela
Rourkela-769 008,Odisha, India. www.nitrkl.ac.in

Dr. Alok Satapathy May 2016

Certificate

This is to certify that the work in the thesis entitled '*A Study on Thermal Characteristics of Epoxy Composites Reinforced with Short Bagasse Fibres* 'by *Tussarkanti pradhan*, bearing Roll Number *214ME3299*, is a record of an originalresearch work carried out by him under my supervision and guidance in partialfulfilment of the requirements for the award of the degree of *Master of Technology* in *Thermal engineering , Department of Mechanical Engineering*.Neither this thesis nor any part of it has been submitted for any degree or academicaward elsewhere.

Dr. Alok Satapathy
Professor
Mechanoical engineering department
NIT Rourkela

Acknowledgement

Firstly, I would like to convey my heartily thanks and gratitude to my beloved guide, Dr. Alok Satapathy (Dept. of Mechanical Engineering, NIT, Rourkela) for his continuous guidance and support, with the help of which I have successfully been able to complete my research work.

I would like to acknowledge my special thanks to the Head of the Department, Prof. S.S. Mahapatra and all the faculty members of the Department of Mechanical Engineering, for providing me the deep insight and discernments given through the various courses they taught and also for their valuable guidance during my work.

I am also thankful my classmate Mr. Tankadhar Bhoi whose timely help and cooperation allowed me to complete my research work in time and bring out this thesis. My special thanks to the staff of Mechanical Engineering Department.

In the end, I would like to profound my deepest gratitude to my family for their exceptional love and encouragement throughout this entire journey, without which I would have struggled to find the inspiration and motivation needed to complete this thesis.

Tussarkanti Pradhan

Roll No.-214ME3299

Thermal Engineering

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 insulative 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 crafts and automobiles etc.

Keywords: epoxy, bagasse fiber, volume fraction, effective thermal conductivity

Contents

Chapter 1

INTRODUCTION

1.0 Background and Motivation

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.

1-Conservation of energy by decreasing heat loss or gain

2- Manage surface temperature for staff protection and comfort

3-Prevent vapor flow or water condensation on cold surface

4- Enhance efficiency of heating or cooling process

5- Prevent damage to equipment from fire or corrosive atmosphere

1. 2 Composite Materials

When two or more materials are combined and one material is in reinforcing phase are in the form fibers and are embedded in the other material called matrix are called Composites. Main functions of composites is to transfer loads between reinforcing fibers and to protect them from mechanical damage. The function of fiber material in composite is to increase the mechanical properties such as strength and stiffness etc. A composite is therefore a synergistic combination of two or more constants which differ in physical form and chemical composition and are not soluble in each other. The motive is to take advantage of their respective properties.

Composites are mainly selected for engineering application because of their higher strength to weight ratio, high creep strength and high toughness. Strength of composite primarily depends on amount, arrangement and type of fiber.

1.2.1 Types of Composites

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

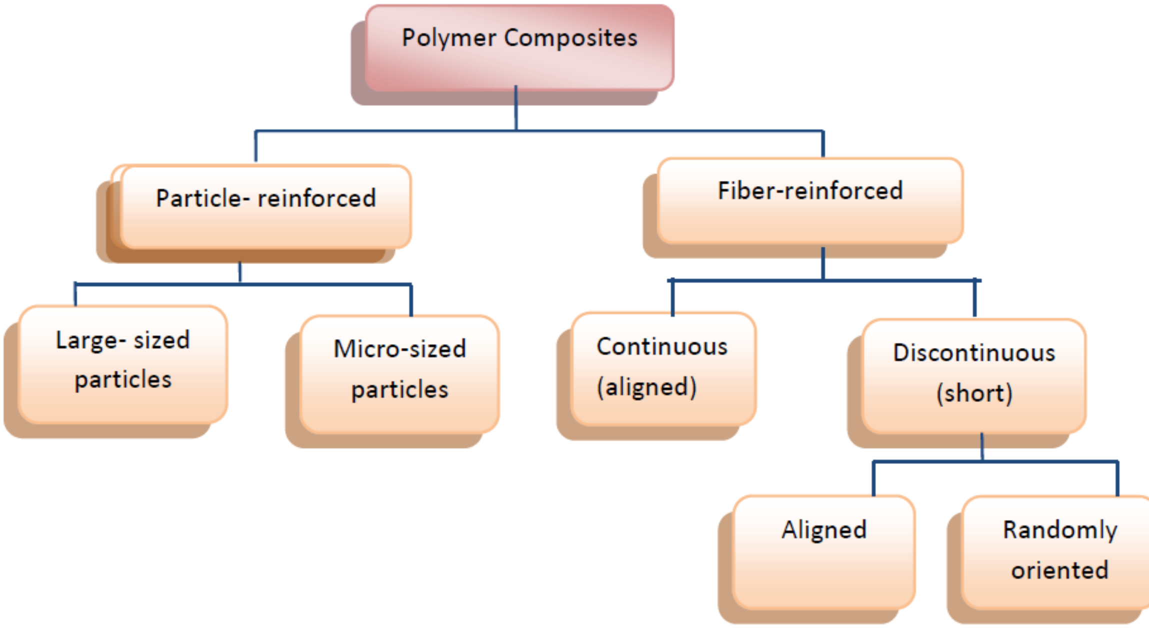
a) Metal Matrix Composites (MMC)
b) Ceramic Matrix Composites (CMC)
c) Polymer Matrix Composites (PMC)

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



d) <u>Polymer Matrix Composites:</u>

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 have higher elastic modulus without any brittleness like ceramic material.

Composites are mainly of two types

- Fiber reinforced polymer (FRP)

- Particle reinforced polymer (PRP)

<u>Fiber reinforced polymer</u>

In fiber reinforced polymer fibers increase the strength of compositematerial and matrix material support the fiber and redistribute the load among them. Load carried by fibers are longitudinally. Mostly used reinforcing materials are beryllium, beryllium carbide, beryllium oxide, aluminum oxide, molybdenum, glass fiber natural fiber etc. Likewise main matrix materials are phenol, vinyl ester epoxy etc.

Particle reinforced polymer

In particle reinforcing polymer mainly used particles are metal powders, ceramics, mineral particles, etc. Main function in particles in composite is to give greater modulus and lessen its ductility.As the particle material is cheap they can reduce the cost of the composite. Using ceramic and glass as particle we can impart high wear resistance, high stiffness low density and corrosion resistance.

1.4 Introduction to the Research Topic

This research is an experimental study on thermal characteristics of a new composites of natural fiber.Thermal conductivity is one the important property of polymer composite material. As it is influenced by many factors, a theoretical heat transfer model of heat transfer using law of minimal resistance made. A mathematical formula assuming one dimensional heat conduction to calculate effective thermal conductivity is derived. That mathematical formula is compared with numerical and experimental results with different percentage of filler material.

1.5 Thesis Outline

The rest of the thesis presented as follows:

Chapter 2: Literature review to give basic knowledge previous work on fiber reinforced polymer composites with giving importance to calculation of thermal conductivity.

Chapter 3: Includes a description of the raw materials used and the test procedures

Chapter 4: Includes results of thermal characteristic of composite under investigation

Chapter 5: Includes mathematical correlation for calculation of effective thermal conductivity of composite polymer. It also presents results of analytical, numerical and experimental values of effective thermal conductivity.

Chapter 6: Provides a summary of the findings of this research work.

Chapter 2

LITERATURE REVIEW

In literature review summary of the research has been presented. Objective of the literature review is to give the basic knowledge of present investigation. Reviews presented here are

Composite Materials for Thermal Insulation
- Particulate Filled Polymer Composites
  - Polymer Composites with Natural Fibers
  - Thermal Conductivity of Particulate Filled Polymers
  - Thermal Conductivity of Fiber Reinforced Polymers
  - Thermal Conductivity Models

2.1 Composite Materials for Thermal Insulation

Natural fibers from renewable raw material have low density and cell structure and they have better thermal and sound insulating characteristic. Large amount of energy can be saved by using proper insulating materials in engineering structures, buildings and equipment [2]. Gases have very less thermal conductivity. So enveloping any material with air packet can decrease the heat transfer significantly. Insulating material commonly like wool or glass fiber are cheap and available. Plastic like phenolic foam have greater insulating capacity with thermal stability.[3,4]. There is vital importance of insulation from technological and industrial view point. It is not only useful in saving energy but also plays a major role in industrial safety.

Bricks are normally used for developing structures which is main factor of farm land reduction. They are also not as much insulating as composite material. So they are undesirable both in terms of environmental pollution and energy wastage. Therefore there is focus to make environment friendly material which can be used for structures with insulating properties[9]Insulating materials like cellulose has thermal conductivity in the range of 40 -50w/mk. Experiments have shown that natural materials are as effective as common building material. Lingo cellulose fiber are investigated by some researchers and they have given satisfactory results. Coconut coir and durian peel can also be used to make cost effective insulating material as studied by Khedari et al [7, 8]. Keenaf core can be used to make insulating material with insulating capacity comparable to rock wool by steam injection processing as presented Xu et al.[9] Binder less cotton stalk from cotton is without using resin and additive can be also an environment friendly insulating material [10]. Agoudjid et al. [11] studied the insulating properties of date palm wood and found it to be equally effective as any other insulating material. Sheep wool fiber can also be considered as insulating material with insulating property compared to conventional insulating material [16]. The wastage of industry and food processing units as raw material can be used in building application [13-16]. Much of previous work mainly interested in strengthening by reinforcing to decrease the density, but with higher demand to energy saving material there is now a renewed focus in natural thermal insulating material [5]. As the natural fibers have better hygro thermal properties and cheap they can be used with petroleum derived products to make better composite material. Sunflower as binder mixed with protein and lingo fiber as reinforcing material .Evon et al[17] developed a thermally insulated composite. The lowest density of fiber board is 0.088 w/mk and experiments have shown that insulating character improved with low density of fiber board.

Using sunflower and chitosan Mati- Baouche et al[18] developed a bio composite. Coconut coir with bagasse used by Panykaew and Fotios [19] to produce light weight composite material. These material have conductivity 0.046 to 0.068 w/mk which is comparable mineral wool cellulose fiber. There are some new insulating material developed from bio based products [20, 21]. These insulating material are environment friendly but with lower strength and sensitivity to water and humidity.

Binici et al. [22] using epoxy with sun flower and cotton textile waste developed a thermal insulating material. Experimental results shows that these composites have lower thermal conductivity. Other agro products like soy based adhesive, hybrid organic- inorganic binders are used by other authors[23-25] to develop insulating materials. Xiaoyan Zhou et al [26] shows that straws can be used as filler material in building. Goodhew and Griffith [27] investigated on insulating values of straws and found that it has thermal conductivity of only 0.067 w/mk.

2.2 On particulate filled polymer composites

When particles are dispersed in a matrix to better the physical and mechanical properties of ceramic, metal and polymer matrix the matrices are called particle reinforced composites. Various organic and inorganic fillers are added to improve the properties like mechanical strength, thermal conductivity [28, 29]. The properties of particulate filled material is a strong function of distribution, size and shape of the particles in the matrix [30]. Electrically insulating but to dissipate heat glass particles, silica are used as fillers in epoxy to use in automotive and electronic industry. The young modulus can be increased by adding particles [31, 32]. The size and weight of particle for matrix reinforcement are to be selected carefully to impart desired properties to the composite.

Glass fiber fillers and metal ceramic particles can be used to enhance the wear resistance to a high value [33]. Where durability at high temp [34] needed polymer and polymer matrix composites with metal particle reinforced are used. Lots of research has been going on for ceramic filled polymer composites.

Silica particle can better the thermal and electric properties when added to polymer matrix [35, 36]. Now a day’s particle size is reduced to see the effect on composite properties. Research by Yamamoto et al. [37] shows that shape and structures of particle of silica have very influential effect on composite properties. Study by Nakamura et al. [38-39] shows that effect of shape and size of silica particles that there is an increase in tensile and flexural strength as the particle specific surface area increased. Research by Moloney et al. [40-42] and adachi et al.[43] shows that epoxy material mechanical property is a function of volume fraction of properties. Study by Yuan et al [44] and Ny et al.[72] shows the result of particles of micron size magnitude and Nano particle on various composite material properties.

Filler which are alkali treated shown higher tensile strength as study by M K Islam et al [45] Improvement in tensile property can be due to increased surface adhesion characteristic by alkali treatment. Filler size is reduced by alkali treatment which increased aspect ratio that increase filler matrix interface adhesion and enhanced mechanical properties. Wheat flour composites has shown better mechanical properties as it has small particle size that the composite of wood saw dust. TakianFakkal et al. [46], Mati and Singh [47] shown the effect wood floor size mixed with HDPE in extrusion molding.

Fu et al. [48] shown that small particle result in better mechanical properties as it has a higher surface area which result a more efficient transfer of stress. The mechanical and morphological characters are studied by Yang et al.[49] who made a composite sample with rice husk filler and polypropylene as matrix.

Mineral particle scan also be added to increase mechanical properties of composites. As mineral particles has higher stiffness, it resulted in composite stiffness [50]. Perfectly bonded particle to polymer can results the crazing of matrix around the particles and impact resistance is reduced [52-55]. Liu and Sun [56-57] and Jiang et al studied particle reinforced composites by considering interphase among the particle and matrix and shown the effect of particle size on deformation.

Inorganic rigid particles of micro or Nano particles can be added to polymer matrices to improve their stiffness or Young's modulus[58-59]. Stress successfully transferred to particle from composite if the particle are also well bounded[60]. Adding a little BaSo4 in polypropylene may not show any change in composite yield strength, but when BasSo4 added greater amount yield strength of the compound decreases. It can be shown that interfacial modification is a major factor that determines yield strength.

2.3 Polymer Composites with Natural Fibers

In recent days plant fibers are used by scientists to make fiber reinforced polymer. Sisal, bagasse, jute pineapple, banana are the natural fibers which are normally considered for making composite materials.

Mechanical properties PLA reinforced with rayon fibers studied by Bax and Musings [61]. When fiber proportion is 30% it shown maximum tensile and impact strength. The mechanical and physical properties of composites with natural fibers were studied by WakambooAndAnsul[62]. Cashew nut shell reinforced with treated fibers' mechanical properties along with surface topography noted. Aim was to find out how much maximum amount of natural fiber can be added to the composite. It is concluded that untreated hemp fiber with lignin shows cross linking sites and the untreated fiber structure is more accommodating with CNSL. Natural fiber like banana, bagasse, and jute coir are available in country like India without any proper use.

Banana can be used as reinforcement material with many thermoplastics like high density Polyethylene(HDPE), polystyrene(ps), low density polyethene(LDPE). Normally extrusion method is used to make the composite. As sisal fiber greater elongation before it breaks its composite shows better impact strength. Sushanta et al.[63] studied the performance of banana and glass fiber with polypropylene composite. It concluded that adding fiber in polypropylene matrix enhance mechanical strength up to 30%. Polypropylene matrix biodegradability using pineapple, banana and bamboo researched by sanjay et al. [64]. This shows that polypropylene composite is only 5- 15% degradable. Better thermal and tensile properties can be get when they are added with rice straw cotton and banana plant as fibers when compared with plane low density Polyethylene. The chemical composite of the fibers also a major effect of the physical and mechanical properties of composites.

The reaserch of Ashida et al.[65] shows the effect of fiber constant and fiber loading on various mechanical properties. Treating banana fiber with alkali,Psma, benzoylation improve interface adhesion and it results n better mechanical properties.

Thermoset material like polyester,urea, epoxy with banana fiber as reinforcing element studied by many researchers. Study by Laly et al.[66] shows the fibers length and amount on composite mechanical properties. It concluded that when the volume percentage is 40% and fiber length 30-40 mm, it has better mechanical properties. Banana fiber has affinity towards moisture, so the composite age with time. Jonnah et al.[67] studied on flexural impact and water absorption properties of chemically treated banana polyster composite.. It shows that we get 10-15% gain in flexural and impact strength of treated composite. Marrier et al. [68] analyzed effect of layer arrangement on damping property loss in modulus of banana and sisal hybrid composite with frequency and temperature.

At different fiber length when phenol formaldehyde reinforced with glass fiber and banana shows the optimization of properties at different fiber length. The study also shows that specific properties of banana fiber with phenol have better properties than glass fiber with phenol composite.

2.4 Thermal Conductivity of Particulate Filled Polymer Composites

Polyethylene thermal conductivity increases from .35 to .50w/mk when we change the orientation to 50. All the studies made by researchers thermal properties of polymers not to their composites.

We can not change molecular orientation when fabricating a composite but to increase or decrease thermal conductivity of polymer by adding conductive or insulating material to it. Many work has been done on thermal conductivity of polymer composite with particulate fillers.

Due to their high thermal conductivity metal can be used as fillers in polymer composite. The effect of adding various metal powder like copper, iron zinc with high density polyethylene matrix studied by Sofian et al[69]. When thermoplastic and thermoset filled with copper and nickel there is improvement in thermal conductivity of composite as shown by Mamunya et al.[70]. When copper used with 24%by volume to low density Lyut LS et al.[71] shown that there is a increase of 150% in the value of thermal conductivity. Silver can also be considered as filler material as it has very high thermal conductivity. As metal particle are heavier than matrices there use as filler restricted as it increases weight of the composite material.

Carbon based fillers such as Graphite, Carbon fiber and carbon black have good thermal conductivity and low density and are good choice for filler material. Graphite is both good thermally conductive and cheap, so it can be considered for filler material. Graphite has high thermal conductivity of around 800w/mk. Han and Fina[72] have studied the thermal conductivity of polymer composite with carbon Nano tube as fillers.

Carbon and metallic based filler material are conductive both thermally and electrically. But there are application where we need only thermal conductivity but not any electrical conductivity. As ceramic filler material have good thermal conductivity, but electrically insulating tey can be used for such application. Ceramic fillers like Si_3N_4[73], CeO_2 [74] can be used to better the effective thermal conductivity of various polymers. It is shown from the results that the ceramic filled composites have better thermal conductive properties without any appreciablechange in electrical conductivity.

Factor like size, shape, inter connectivity and distribution also influence effective thermal conductivity. As reviewed by Boudene et al. [75]that composites with higher filler size of Al are more conductive than particles with smaller size. Some authors also focused on better thermal conductivity with reduced size particles. Weidenfeller B et al. [76] reviewed rule of filler material's interconnectivity with enhancing effective thermal conductivity. Shape factor can also have influential effect on the thermal conductivity of the composite. Jiajun et al[77] shown the interfacial thermal barrier with shape and size of added filler.

Maximum of the research work to find the effective thermal conductivity is by experimental basis and therefore very few papers to find theral conductivity numerically[78,79]. Veyret et al .[80] proposed a mathematical model for thermal conductivity of granular fiber reinforced composites. Kumlutas D and TavmanIH [81] proposed a model for polymer with particle type filler which are comparable to particle type filler which are comparable with experimental values.

2.5 Thermal Conductivity of Fiber Reinforced Polymer Composites

There has been many work carried out by many authors on thermal characteristics of fiber reinforced composites. Polymetalphosphate which are reinforced by glass fiber reinforced by glass fiber reviewed by Dong-pyo Kim[82]. Role of 3-D fiber strengthening on effective thermal conductivity of composite material researched by Schuter et al[83]. To fully understand the role of composite material and to improve the present analytical model finite element models can be used. Role of morphology tube size defect on thermal conductivity were studied by Zhidong et al[84].Effect of particle and polymer, particle and particle interface further studied by many researchers. Thermal transport mechanism and character when conducting fibers filled along the thickness of a three dimensional polymer composite studied by Hang et al.

2.6 Thermal Conductivity Models

In past many model and correlation have proposed by researchers to calculate effective thermal conductivity of two phase mixture and composite. Maxwell Garnet model was the first model to predict thermal conductivity of two component composite. Ina two component composite a simple model can be arranged either in parallel or series as per heat flow which gives the lower and upper limit of thermal conductivity.

For parallel arrangement

$$k_c = (1-\phi)k_m + \phi k_f \qquad (2.1)$$

Where K_c = thermal conductivity of composite

K_m =Thermal conductivity of matrix

K_f =Thermal conductivity of filler

ϕ =volume fraction of filler

$$\frac{1}{k_c} = \frac{(1-\phi)}{k_m} + \frac{\phi}{k_f} \qquad (2.2)$$

This is the model for series arrangement

Rule of mixture can be used to derive the above correlation. Effect of special distribution and the conductivity of each molecule on the effective thermal conductivity derived by Tsao[85].Taking parabolic duistribution of filler materialCheng and Vachon[86] proposed a solution that do not need any other additional information. Using parallel and series conduction mechanism Agari and Uno derived a new model for polymers. The correlation derived by Agari and Uno is

$$\log k_c = \phi C_2 \log k_f + (1-\phi) \log(C_1 k_m) \qquad (2.3)$$

Where C_1, C_2 are constants

C_1 = Effect of particles on structures of polymer

C_2 = Potentiality of conductive chain formation of the particles

By assuming permeability and field strength of spheres for dilute suspension a homogenous medium and implicit as proposed by Bruggeman[86] is

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

Kanari model[87] is another model of Bruggeman's equation which used inorganic filler particles. It proposed a correlation between volume fraction and thermal conductivityof composite as a function of shape of filler.

$$1-V_f=\frac{k_c-k_f}{k_m-k_f}\left(\frac{k_m}{k_c}\right)^{\frac{1}{(1+x)}} \qquad (2.5)$$

V_f = Volume fraction of composite

K_f = Thermal conductivity of filler

K_c =Thermal conductivity of composite

K_m =thermal conductivity of matrix

X= Constant depend upon sphericity of filler

For randomly distributed spherical filler which are non-interacting in continuous medium. Maxwell[88] proposed another equaition. But it do not have much agreement where filler has high volume fraction in the composite.

$$k_c=k_m\left[\frac{k_f+2k_m+2\phi\left(k_f-k_m\right)}{k_f+2k_m-2\phi\left(k_f-k_m\right)}\right] \qquad (2.6)$$

K_c =thermal conductivity of composite

K_m =Thermal conductivity of matrix

K_f =thermal conductivity of dispersed filer

Another model proposed by Lewis and Neilsen[89] which is modification of Halpin- Tsai for 2 phase system assuming isotropic orientation of filler particles. In this model particles' shape also taken into consideration.

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

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

K_f=Thermal conductivity of filler material

ϕ = volume fraction of filler material

Table 2.1- value of A for different filler dispersed phase

Type of dispersed phase	Direction of heat flow	A
Cubes	Any	2
Spheres	Any	1.5
Aggregates of spheres	Any	$(2.5/\phi_m)$ -1
Randomly oriented rods Aspect ratio=2	Any	1.58
Randomly oriented rods Aspect ratio=4	Any	2.08
Randomly oriented rods Aspect ratio=6	Any	2.8
Randomly oriented rods Aspect ratio=10	Any	4.93
Randomly oriented rods Aspect ratio=15	Any	8.38
Uniaxially oriented fibers	Parallel to fibers	2L/D
Uniaxially oriented fibers	Perpendicular to fibers	0.5

Table 2.2- Value of ϕ_m *for various system*

Shape of particle	Type of packing	ϕ_m
Spheres	Hexagonal close	0.7405
Spheres	Face centred cubic	0.7405
Spheres	Body centred cubic	0.60
Spheres	Simple cubic	0.524
Spheres	Random close	0.637
Rods and fibres	Uniaxial hexagonal close	0.907
Rods and fibres	Uniaxial simple cubic	0.785
Rods and fibres	Uniaxial random	0.82
Rods and fibres	Three dimensional random	0.52

When material subjected to alternate higher and lower temperature it leads to thermal failure of matrix material. Co effcicient of thermal expansion considerably reduced when Boron Nitride is added as filler material as reported by Iyer et al[90]. The effect of volume fraction of filler material on co efficient of thermal expansion was studied by Dey et al [91]. As per the report of Yasmin et al when volume fraction of graphite in composite is 2.5 % co efficient of thermal expansion decreases but adding further filler material co effcicient of thermal expansion increases.

Co-efficient of thermal expansion and glass transition temperature has amajor influence on thermal properties of composites. Benito[[93] studied coefficient of thermal expansion of composite material with TiO_2 used as filler and also the filler shape and size. Thomas[94] reported the influence of $Sm_2Si_2O_7$ as filler material in different matrix material like(polyethylene and polystyrene) as the coefficient of thermal expansion.

Adding Al_2O_3 to WO_3+ZrO_2 system has increase Young's modulus of elasticity with considerable change in coefficient of thermal expansion as observed by Li Sun et al[95]. Devendra et al[96]studied the effect of volume fraction of filler material on coefficientof thermal expansion. Silicon can be used as filler to decrease the coeffiecient of thermal expansion of soldering material to get high reliability [97]. Goyal et al [98] studied the polymer composites for electronic application and observed that it has desirable combination of linear thermal expansion co efficient with dielectric properties.. When epoxy components added with AiN and Al_2O_3 as filler there has been a change in thermal expansion co efficient and glass transition temperature as studied by Agrawal [99]. Mishra and Sahu [100] also the same results when epoxy is added with TiO_2 and glass microsphere.

2.8 Knowledge Gap in Earlier Investigations

There is a demand for systematic research in composite material filled with fibers..

- 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

In view of the above, this work investigated thermal characteristic like effective thermal conductivity of epoxy composite filled with bagasse fiber.

2.9 Objectives of the Present Work

Objectives of the work are

- To develop a theoretical model predict 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

The next chapter explains the methods used for preparation and characterization of composite under study.

Chapter 3

MATERIALS AND METHODS

In this chapter the material and the methods tat are used to process and characterizing composites are described. It gives the detail of the thermal characterization of epoxy composites used in this investigation.

3.1 MATERIALS

3.1.1 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[101]. Polymers are mainly divided into two main types, thermoplastics and thermosets [102]. Both of them have different properties as per their molecular structure

Thermoset 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[103]. Polyester, epoxy, vinyl ester are some commonly used thermoset plastics.

Thermoplastic are different from thermoset 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 are some of the popular thermoplastics.

Epoxy is most popular among all the thermoset 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 Bisphenol-A-Diglycidyl-Ether (commonly abbreviated to DGEBA or BADGE). And it is chemically belongs to epoxide family. In fig 3.1 its chemical structure is shown.

Table 3.1- 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

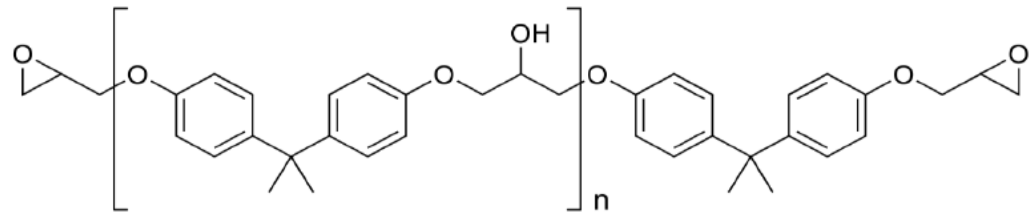


Fig. 3.1 Unmodified epoxy resin ('**n**' denotes number of polymerized unit)

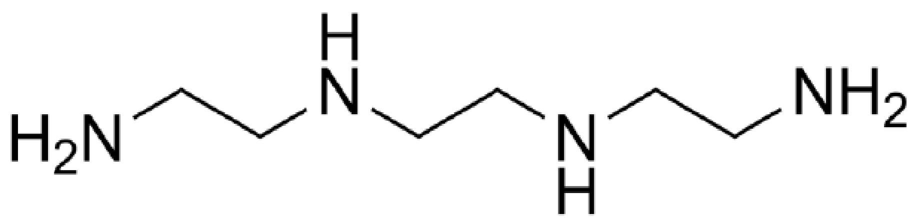


Fig. 3.2 Tri-ethylene-tetramine (hardener used for epoxy matrix)

Fig. 3.3 Epoxy resin and corresponding hardener

Fig 3.4 Bagasse Fiber

3.1.2 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 SaccharumOfficinarum. India is one of the major producer of sugar cane. It mainly grows in tropical regions. It need a tropical climate and a good water supply

Table 3.2 – 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 inhomogenous 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 are shown below.

3.2 EXPERIMENTAL DETAILS

3.2.1 Composite Fabrication

Epoxy composite filled with bagasse fiber

One of the oldest and simplest method is hand lay up in composite making process. It is less labour needed process with lower volume products. Squeezing manually we can remove all the air entrapped in the composite. Epoxies and polysters which can be at room temperature commonly used for matrix material. A catalyst can be used to initiate curing in the resin without heating externally. To get a part surface with high quality a pigmented gel coat is applied to mold surface.

- All the composite samples with various composition made with hand lay up technique. Bagasse fiber thoroughly washed with clean water, then it is soaked with NaOH water solution for four hours. After that bagasse fiber separated out from the solution and dried for four days under bright sun light. When it is totally dried single fiber separated out from the bagasse fiber and cut into approximate length of 3 mm.
- Epoxy (LY556) and hardener (HY951) re mixed in a ratio of 10:1 by weight
- Bagasse fiber with particle size 3 mm is mixed with epoxy resin in various proportion.
- Uniformly mixed epoxy filled with bagasse fiber is slowly poured into glass molecule.
- Composite with varying composition of bagasse fiber are made.(Table 3.4). Casting then left for curing at ambient temperature for 24 hours. After the mold was broken and samples collected.

Table 3.4 Set-1 Epoxy composites filled with Bagasse Fiber

COMPOSITION
Epoxy + 0 vol % of Bagasse fiber
Epoxy + 4.68 vol % of Bagasse fiber
Epoxy + 7.03 vol % of Bagasse fiber
Epoxy + 10.54vol % of Bagasse fiber

3.3 COMPOSITE CHARACTERIZATION

3.3.1 Physical Characterization

Density and void fraction

Density of composite material and their component can be calculated by any of the three methods below

- Archimedes method
- The sink float method
- Density gradient method

In Archimedes principle using water as medium actual density of composite can be calculated. In ASTM D792 this principle is used. As per this principle when any object is immersed in the liquid the apparent loss in its weight is same as the up thrust and equal to weight of liquid displaced. Density of the component can be calculated using equation 3.1

$$\rho_a = \frac{\rho_w W_a}{W_a - W_w} \tag{3.1}$$

Here ρ_a= actual density of composite

Pw =density of water

W_a = weight of the composite

W_w= Weight of composite in water

As per equation (3.2) proposed by Agarwal and Broutman[104] theoretical density in terms of weight fraction can be calculated.

$$\rho_t = \frac{1}{\left(W_p / \rho_p\right) + \left(W_m / \rho_m\right)} \tag{3.2}$$

Here W and ρ represents filler and matrix material.

The suffix p and m represent filler and matrix material.

3.3.3 Thermal Characterization

Thermal Conductivity: Experimental Determination

Equipment used- Unitherm^{TM} Model 2022 Thermal conductivity tester

Test Standard- ASTM E1530

Operating principle

Thermal conductivity is the heat transfer between adjacent molecules and electrons. Mathematically it defines the heat flow per temperature difference per unit area. For one dimensional heat conduction the equation can be written as

$$Q = kA\left(\frac{T_1 - T_2}{x}\right) \tag{3.3}$$

Where Q= heat flux in watt

A = cross sectional area in m^3

K =thermal conductivity in (W/mk)

x= thickness of sample

Thermal resistance can be written as

$R = (T_1 – T_2)/ Q$

Where R = thermal resistance of the sample

Again we can write

$k= x/RA$

Acertain amount of heat flux Q given and a temperature difference between upper face and lower face of the sample is maintained which is measured by Unitherm^{TM} 2022. From getting the values of above parameter thermal conductivity of the sample can be found out.

Chapter Summary

This chapter has explained

- Detail of materials (matrix and filler) used in this experiment
- Description of composite fabrication
- Details of thermal characterization test

In the next chapter test results are explained.

Chapter 5

Results and Discussion

THERMAL CHARACTERISTICS OF THE COMPOSITES

In this chapter we can get the test results of thermal conductivity (k_{eff}) of the composite (epoxy-bagasse) used in this experiment. As one dimensional theoretical model has been formulated and according to this a mathematical formula for effective thermal conductivity has been developed. The actual value of effective thermal conductivity as obtained from tests compared with results from numerical analysis.

5.1. EFFECTIVE THERMAL CONDUCTIVITY

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

5.1.1. 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 [105] is a very useful tool to solve practical engineering problems.

There are 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.

3mmlength 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.

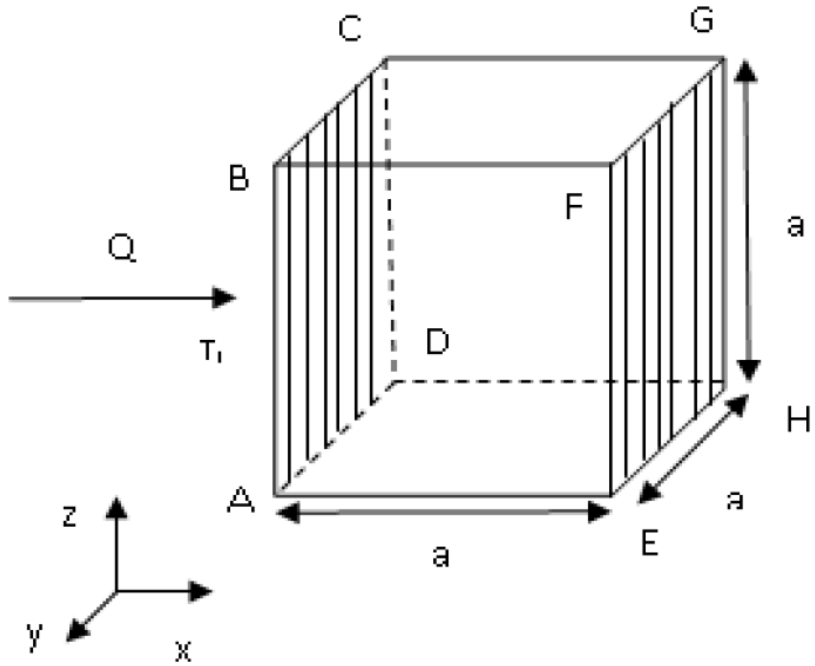


Fig 5.1 Heat flow direction and boundary conditions for the composite

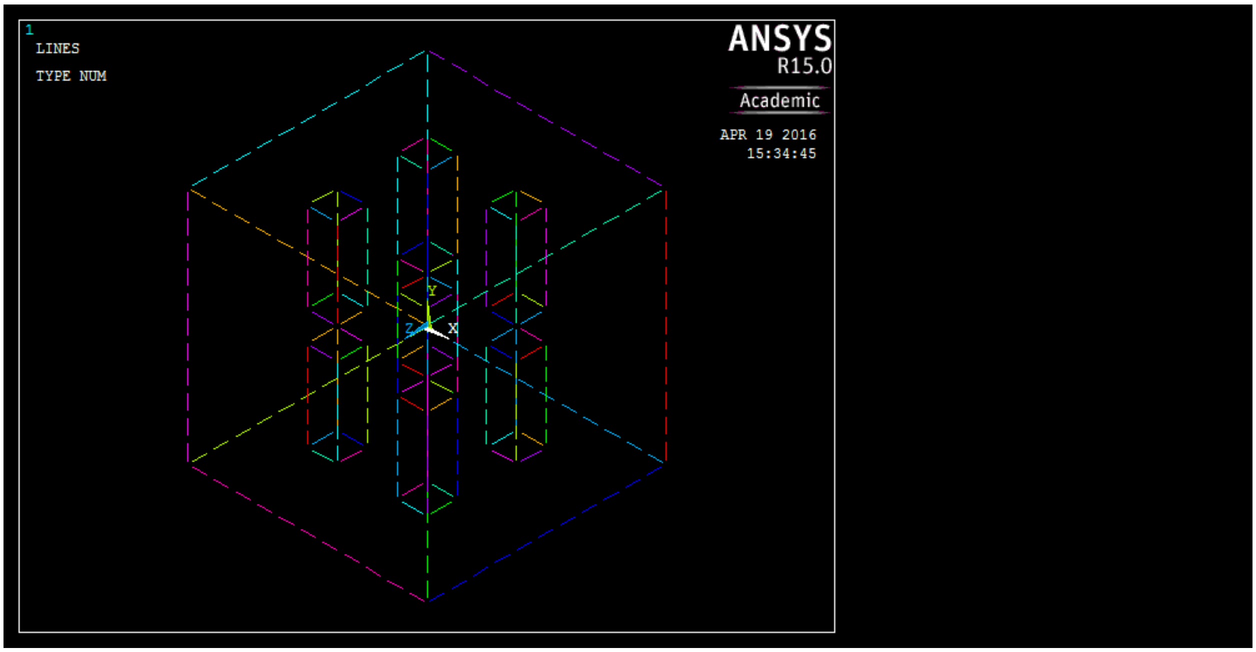
A pictorial representation of the composite body with symmetric arrangement and heat flow direction are shown in fig 5.1 . Here ABCD surface temperature is 100^0 C. Convective heat transfer coeffcicient on the face EFGH is 25 w/m^2k. Ambient temperature is taken as 27^0 C. All the other surfaces parallel to heat flow as considered insulated.

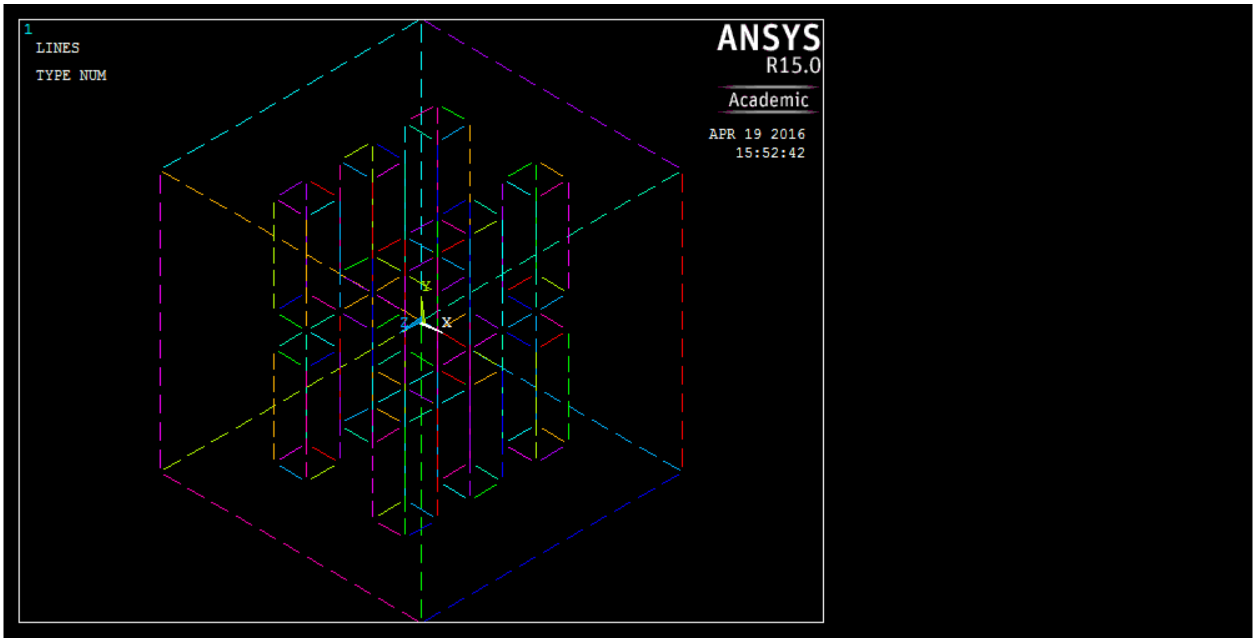
Assumption made in this analysis are

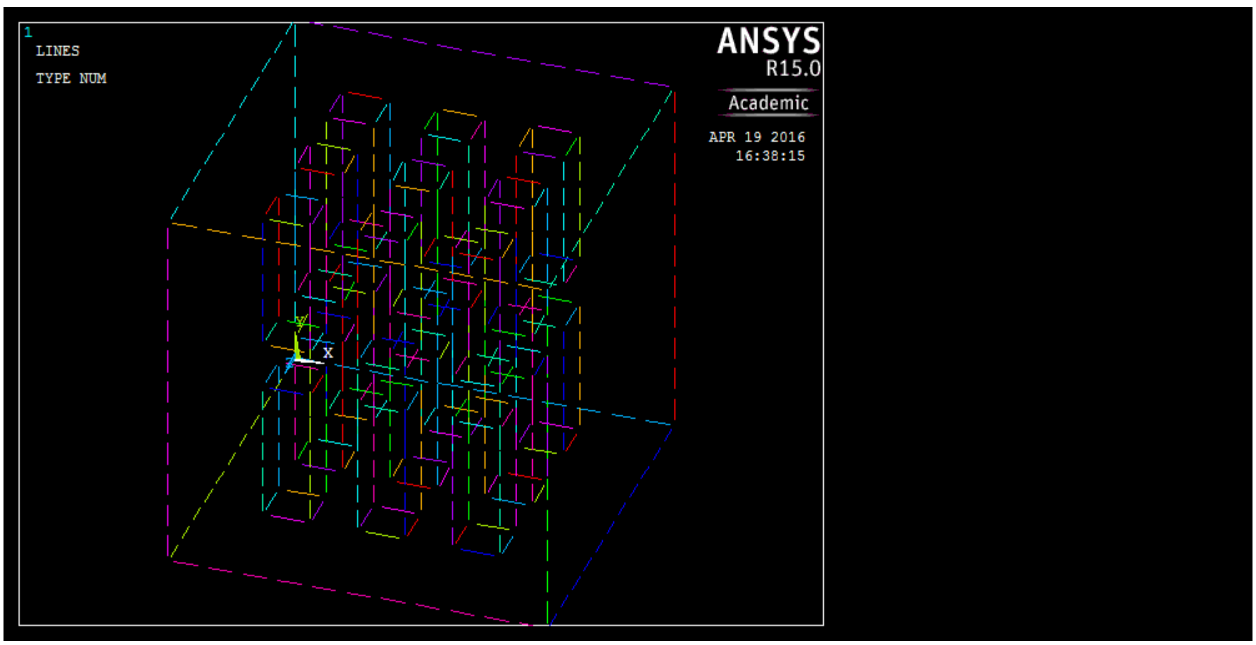
- Component is homogenous and isotropic
- Contact resistance between the matrix and filler material is negligible
- There is no void inside the composite
- There is no uniform distribution of filler material

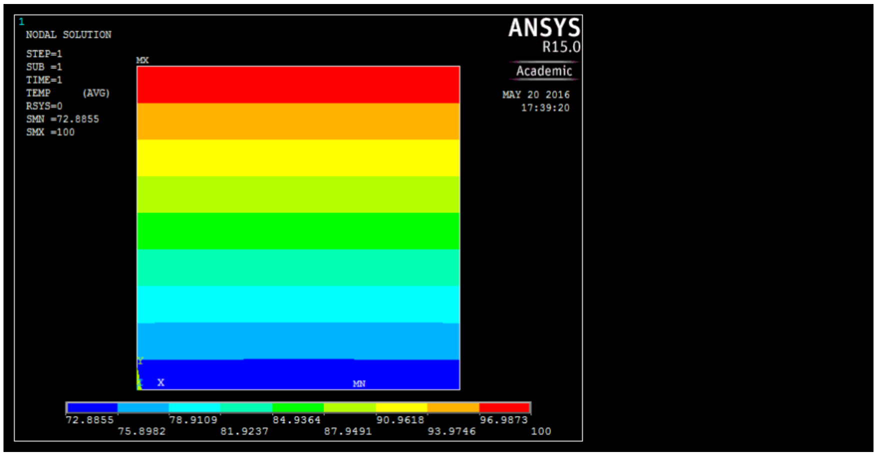
Using Ansys the effective thermal conductivity of the composite is calculated. Some models with volume fraction 4.68%, 7.03% and 10.54% are shown in figure.Temperature profile also shown for the same composite with volume fractions stated earlier.

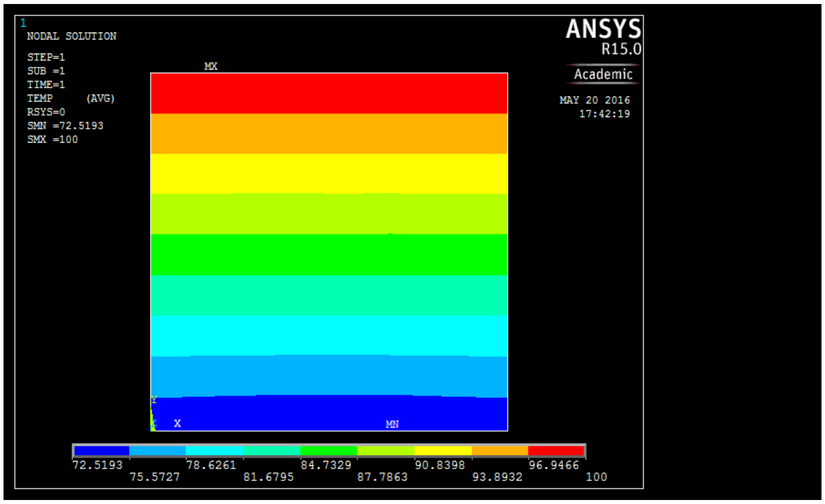
\

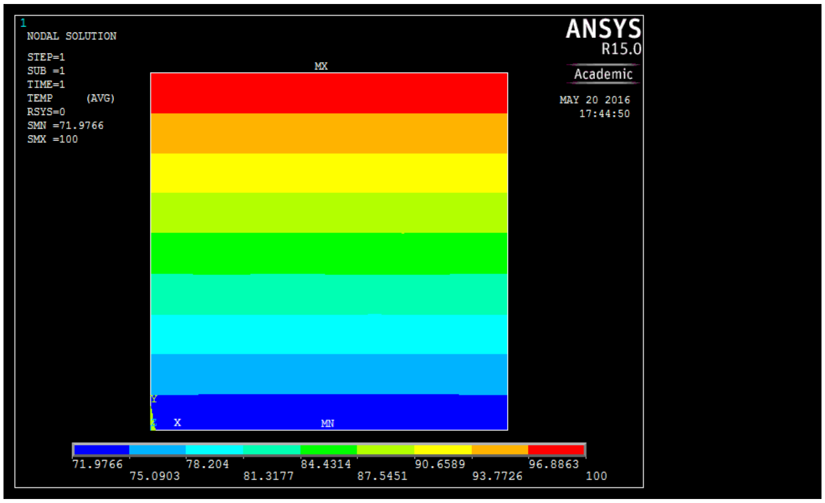



1
LINES
TYPE NUM
ANSYS
R15.0
Academic
APR 19 2016
15:52:42
Y
Z
X


1
LINES
TYPE NUM
ANSYS
R15.0
Academic
APR 19 2016
16:38:15
Y
X


1
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
TEMP (AVG)
RSYS=0
SMN =72.8855
SMX =100
MX
MN
ANSYS
R15.0
Academic
MAY 20 2016
17:39:20
72.8855
75.8982
78.9109
81.9237
84.9364
87.9491
90.9618
93.9746
96.9873
100


1
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
TEMP (AVG)
RSYS=0
SMN =72.5193
SMX =100
MX
MN
ANSYS
R15.0
Academic
MAY 20 2016
17:42:19
72.5193
75.5727
78.6261
81.6795
84.7329
87.7863
90.8398
93.8932
96.9466
100


1
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
TEMP (AVG)
RSYS=0
SMN =71.9766
SMX =100
MX
MN
ANSYS
R15.0
Academic
MAY 20 2016
17:44:50
71.9766
75.0903
78.204
81.3177
84.4314
87.5451
90.6589
93.7726
96.8863
100

5.2. 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 are used to get effective thermal conductivity for various volume fraction of filler material. In table 5.1 all the values of effective thermal conductivity are shown.

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.

5.3. 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 5.6. A single fiber filler element taken out and shown in fig 5.7. Assumption made in the theoretical analysis are

- Matrix and filler both are homogenous and isotropic
- There are 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

<u>Nomenclature</u>

- H – side of cube
- a - side of filler
- K_p - thermal conductivity of polymer material
- K_f- thermal conductivity of filler material
- Q – heat quantity
- Q_p- heat quantity through polymer matrix
- Q_f – heat quantity through filler material
- h_1 – (H-a)/2
- S – Total area of cross-section
- S_p–total area of polymer
- S_f - correctional area of filler
- V_p– Volume of polymer matrix
- V_f– Volume of filler
- V_c– Volume of composites
- D_p– Density of polymer matrix phase

- D_f– Density of filler phase
- D_{pc}- Density of Composition
- R_1, R_2, R_3 – Heat resistance of part-1, part-2 and part-3
- R - Total resistance
- Q - Volume fraction

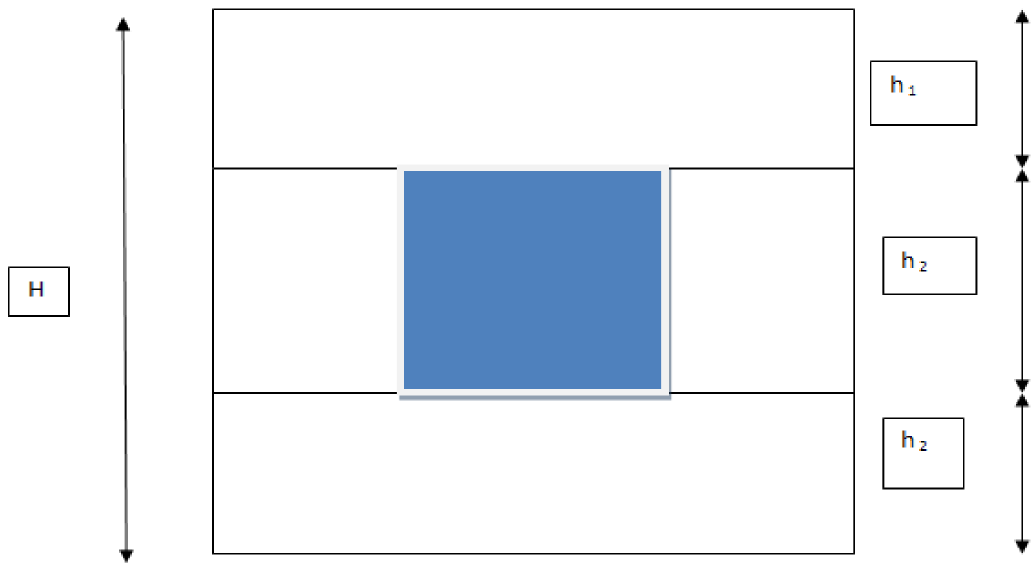


Fig 5.6 3D view ofsingle fiber under study

In fig 5.7 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 have thermal conductivity K_1 ,K_2,K_3 respectively. We can assume that the composite is made up of a numberofcubical elements and in each element a single tetragonal filler material is there.

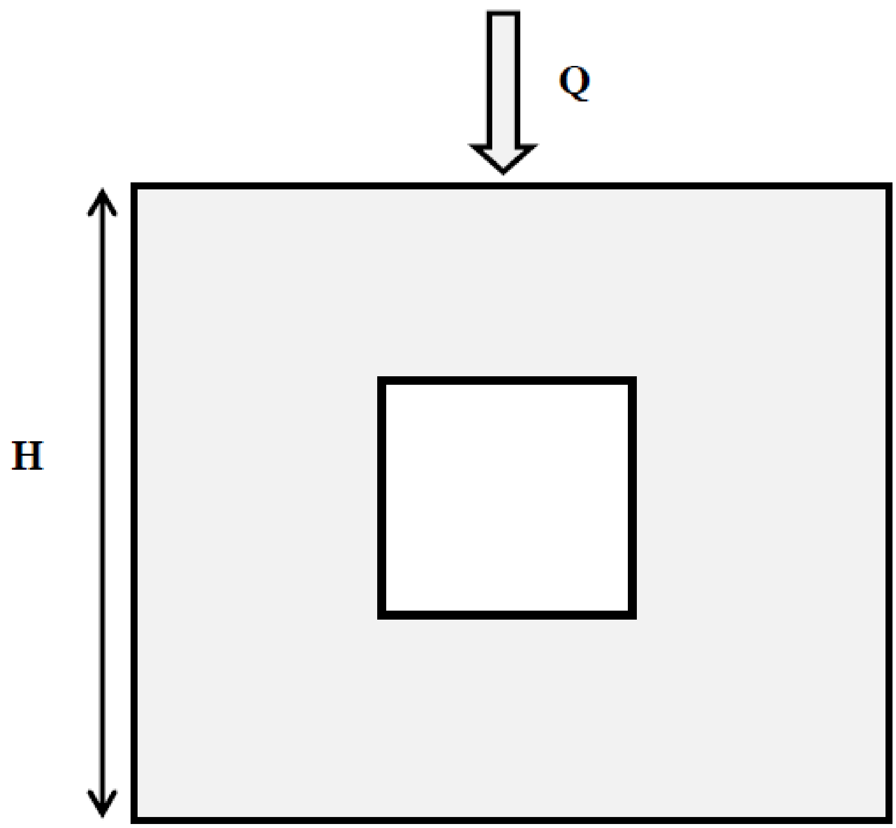


Fig- 5.7 Model of heat transfer in composite

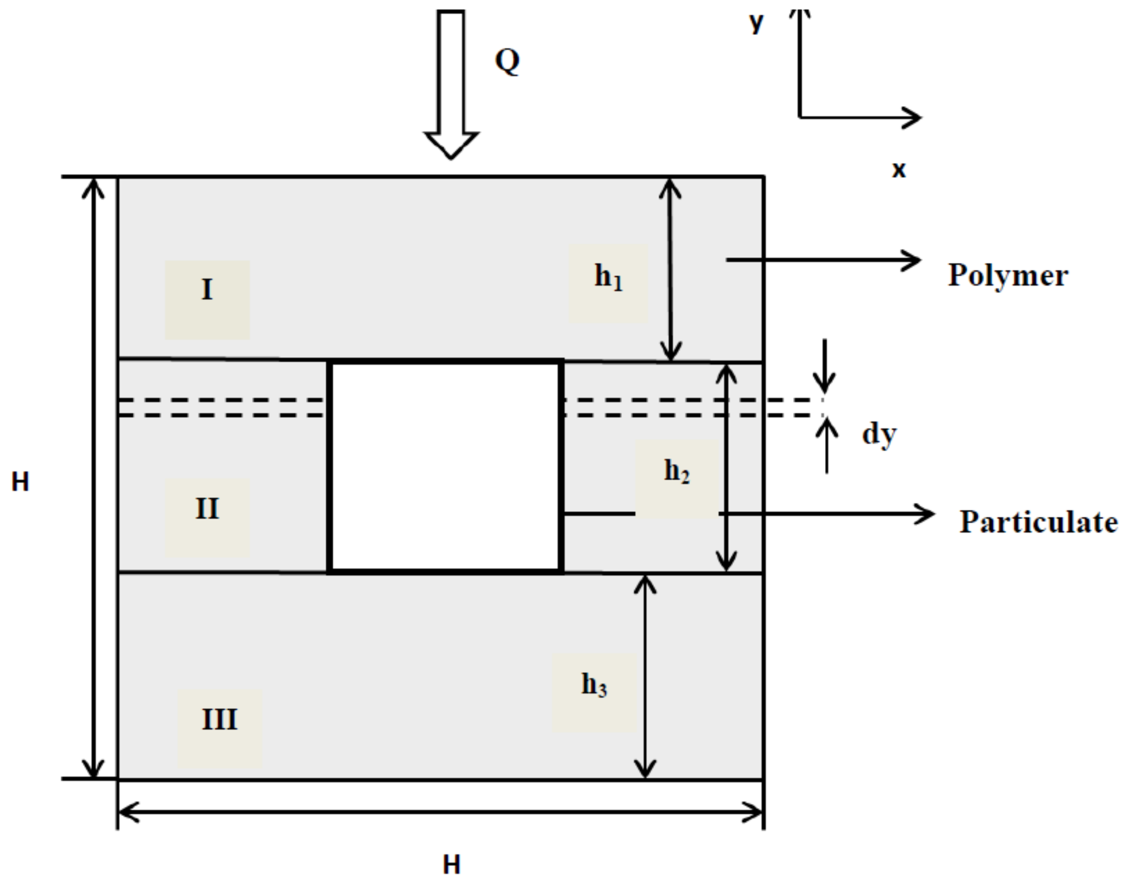


Fig.5.9 A series model of heat transfer in particulate-filled composite

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

$K_1 = k_2 = k_3$

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 R_1 ,R_2 and R_3 of part 1, 2 and 3 respectively

$R_{eff}=2R_1+R_2$ 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

$$\varphi=\frac{Volume of filler Material}{Volume of composite}$$

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

Putting the value of φ in the above equation

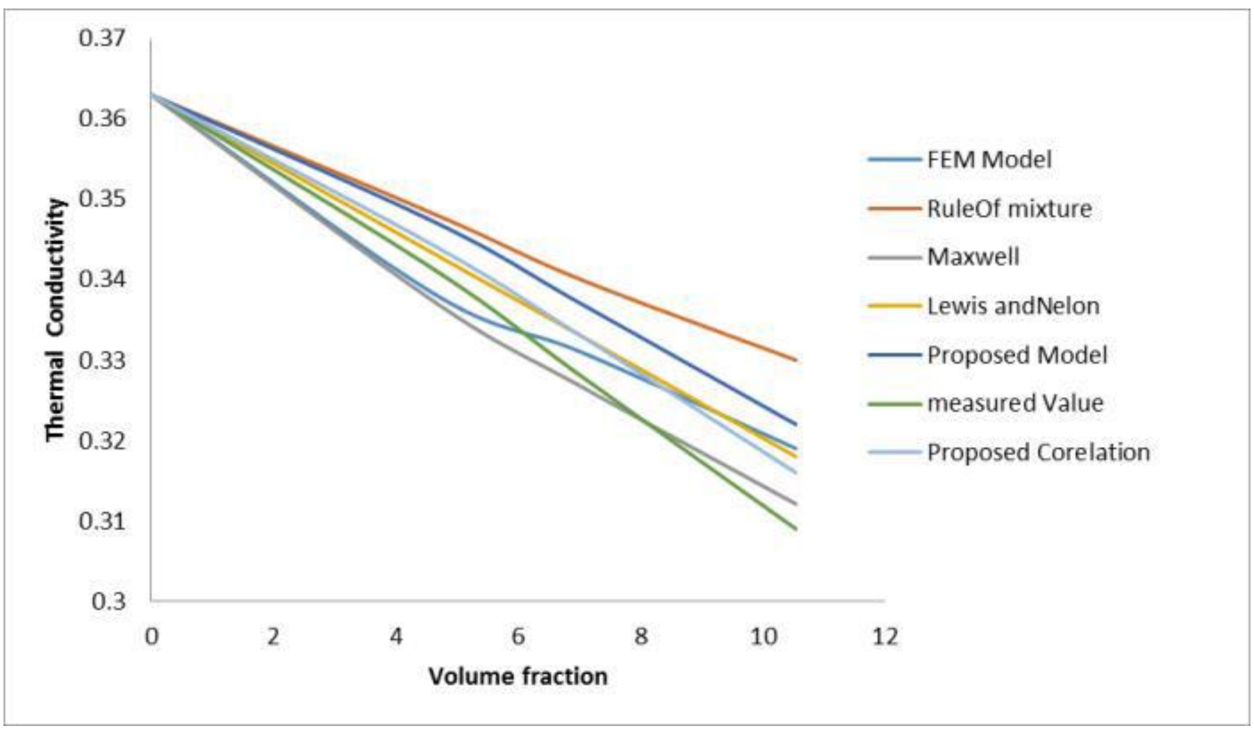
$$\frac{1}{K_{eff}}=\frac{2}{3\,k_p}+\frac{1}{3K_p(1-3\varphi)+3K_f 3\varphi}$$

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

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 Unitherm^{TM} 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 5.2 .

Table 5.2

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



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 A_{int} to volume of composite. So a new term ψ^{*} (A_{int}/V) introduced to the equation to achieve better accuracy of the model. Ψ is a proportionality constant and it depends on thermal contact resistance matrix and filler material. Using this correlation K_{eff} of the compoite 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.

Chapter summary

This chapter has provided –

- Results using numerical analysis and experimental values of effective thermal conductivity of the composite with different filler concentration

- Comparison of the model with experimental results

- Effect of bagasse fiber on insulating capacity of epoxy

In the next chapter a summary of research finding and conclusion noted. Some potential use of the composite suggested. Some ideas and direction for future research in this field also suggested.

Chapter 6

SUMMARY AND CONCLUSIONS

This research can be divided into 3 parts.

1- In the first part what are the material used and procedure of the experiments have explained.
2- In the second part a theoretical model for heat conduction is proposed. This model is based on a mathematical correlation to predict the thermal conductivity of fiber filled polymer composite. The results are compared with numerical analysis and experimental value.
3- The last part contained experimental values of effective thermal conductivity of composite polymer with bagasse fiber.

6.1 Summary of research finding

Characteristic of a new material is tested by its behavior in various mechanical, physical or thermal condition. In this work a data set has been created for polymer composite with various volume fraction of filler material. A semi empirical equation has been proposed which include the influence of contact resistance of polymer and filler material on effective thermal conductivity. It is found that incorporating bagasse fiber inside the polymer material reduce the thermal conductivity of the composite. It can be predicted as bagasse fiber is insulating in nature.

6.2 Conclusion

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

- Using hand lay up 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 crafts etc as it very light weight and good insulating material.

6.3 Scope for future research

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

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

References

[1] Jelle BP , Gustavsen A. and Baetens R. (2010) “The Path to the High Performance Thermal Building Insulation Materials and Solutions of Tomorrow”, *Journal of Building Physics*, 34, 99-123.

[2] Al-Homoud MS. (2005) “Performance characteristics and practical applications of common building thermal insulation materials”, *Build. Environ*. 40 353–366.

[3]Leventis N et al. (2011) “Polyimide aerogels by ring opening metathesis polymerization (ROMP)”, *Chem. Mater*. 23 2250–2261.

[4]Lei S et al.(2010) “Preparation and properties of the phenolic foams with controllable nanometer pore structure”, *J. Appl. Polym. Sci*. 117 3545–3550.

[5]Korjenic A, Petranek V, Zach J and Hroudova J. (2011) “Development and performance evaluation of natural thermal-insulation materials composed of renewable resources”, *Energy Build*. 43 (9) 2518–2523.

[6]Jelle BP. (2011) “Traditional, state-of-the-art and future thermal building insulation materials and solutions – properties, requirements and possibilities”, *EnergyBuild*. 43 (10) 2549–2563.

[7] Khedari J, Nankongnab N, Hirunlabh J and Teekasap S. (2004) “New low-cost insulation particleboards from mixture of durian peel and coconut coir”, *Building and Environment* 39 (1) 59–65.

[8] Khedari J, Nankongnab N, Hirunlabh J and Teekasap S. (2003) “New insulating particleboards from durian and coconut coir”, *Building and Environment* 38 (3) 435–441.
Xu JY, Sugawara R, Widyorini R, Han GP and Kawai S. (2004) “Manufacture and properties of low-density binderless particleboard from kenaf core”, *Journal of Wood Science*
50 2–67.

[10]Zhou X, Zheng F, Li H and Lu C. (2010) “An environment-friendly thermal insulation material from cotton stalk fibers”, *Energy and Buildings* 42 1070–1074.

[11]Agoudjil B, Benchabane A, Boudenne A, Ibos L and Fois M. (2011) “Renewable materials to reduce building heat loss: characterization of date palm wood”, *Energy and Buildings* 43 491–497.

[12]Zach Z, Korjenic A, Petránek V, Hroudova J and Bednar T. (2012) “Performance evaluation and research of alternative thermal insulations based on sheep wool”, *Energy Build*. 49 246–253.

[13]Madurwar MV, Ralegaonkar RV, Mandavgane SA. (2013) “Application of agro-waste for sustainable construction materials: a review”, *Constr Build Mater*; 38: 872–8.

[14]Biagotti J, Puglia D and Kenny JM. (2004) "A review on natural fibre-based composites – part I: Structure, properties and processing of vegetable fibres", *J Nat Fibers*; 1(2):37–68.

[15]Mohanty AK, Misra M and Drzal LT. (2002) "Sustainable bio-composites from renewable resources: opportunities and challenges in the green materials world", *J Polym Environ*; 10(1/2):19–26.

[16]Shea A, Lawrence M and Walker P. (2012) "Hygrothermal performance of an experimental hemp-lime building", *Constr Build Mater*; 36:270–5.

[17] Evon P, Vandenbossche V, Pontalier PY and Rigal L. (2014) "New thermal insulation fiberboards from cake generated during bio-refinery of sunflower whole plantin a twin-screw extruder", *Ind. Crops Prod*. 52 354–362.

[18]P Mati-Baouche N, Baynast HD, Lebert A, Sun S, Lopez-Mingo CJS, Leclaire P and Michaud P. (2014) "Mechanical, thermal and acoustical characterizations of an insu-lating bio-based composite made from sunflower stalks particles and chitosan", *Ind. Crops Prod.* 58 244–250.

[19]Panyakaew S and Fotios S. (2011) "New thermal insulation boards made from coconut husk and bagasse", *Energy Build,* 43 (7) 1732–1739.

[20]Quintana G, Velasquez J, Betancourt S and Ganan P. (2009) "Binderless fibre board from steam exploded banana bunch", *Ind. Crops Prod,* 29 (1) 60–66.
Lertsutthiwong P, Khunthon S, Siralertmukul K, Noomum K and Chandrachang S. (2008) "New insulating particleboards prepared from mixture of solid wastes from tis-sue paper manufacturing and corn peel", *Bioresour. Technol,* 99 (11) 4841–4845.

[22]Binici H, Eken H, Dolaz M, Aksogan O and Kara M. (2014) "An environmentally friendly thermal insulation material from sunflower stalk, textile waste and stubble fibres", *Constr. Build. Mater,* 51 24–33.

[23]Wang DH and Sun XS. (2002) "Low density particleboard from wheat straw and corn pith", *Ind. Crops Prod,* 15 (1) 43–50.

[24]Yang HS, Kim DJ and Kim HJ. (2003) "Rice straw–wood particle composite for soundabsorbing wooden construction materials", *Bioresour. Technol*. 86 (2) 117–121.

[25]Sassoni E, Manzi S, Motori A, Montecchi M and Canti M. (2014) "Novel sustainable hemp-based composites for application in the building industry: physical, thermal and mechanical characterization", *Energy Build.* 77 219–226.

[26]Zhou X, Wei K, Lv C, Chen M, Dai Z, Shen D. (2015) *Energy and Buildings,* 87 116–122

[27]Goodhew S and Griffiths R. (2005) “Sustainable earth walls to meet the building regulation”, *Energy Build,* 37 (5) 451–459.

[28]Wong CP and Bollampally RS. 1999 “Thermal Conductivity, Elastic Modulus, and Coefficient of Thermal Expansion of Polymer Composites Filled with Ceramic Particles for Electronic Packaging”, *Journal of Applied Polymer Science*, 74(14) 3396-3403.

[29] Lu X and Xu G. (1997) “Thermally Conductive Polymer Com- posites for Electronic Packaging”, *Journal of Applied Polymer Science,* 65(13) 2733-2738.

[30]Boonyapookana A, Nagata K and Mutoh Y. (2011) “Fatigue crack growth behavior of silica particulate reinforced epoxy resin composite”, *Compos Sci Technol*, 71 1124–31.

[31] Rosso P, Ye L, Friedrich K and Sprenger S. (2006) “A toughened epoxy resin by silica nanoparticle reinforcement”, *J Appl Polym Sci*,100 1849–55.

[32]Isik I, Yilmazer U and Bayram G. (2003) “Impact modified epoxy/montmorillonite nanocomposites: synthesis and characterization”, *Polymer,* 44 6371–7.

[33] Sawyer GW, Kevin FD, Pravee B and Linda S. (2003) “A study on the friction and wear behavior of PTFE filled with alumina nanoparticles”, *Wear*, 254 573–580.

[34] Nikkeshi S, Kudo M and Masuko T. (1998) “Dynamic viscoelastic properties and thermal properties of powder-epoxy resin composites”, *Journal of Applied Polymer Science,* 69 2593-2598.

[35]Nielsen LE and Landel RF. (1994) “Mechanical properties of polymers and composites”, *2nd ed. New York: Marcel Deckker,* 377– 459.

[36]Peters ST (1998) “Handbook of composites”, *2nd ed. London: Chapman and Hall*, 242–243.

[37]Yamamoto I, Higashihara T and Kobayashi T (2003), “Effect of silica-particle characteristics on impact/usual fatigue properties and evaluation of mechanical characteristics of silica-particle epoxy resins”, *The Japan Society of Mechanical Engineers Int Journal,* 46(2) 145–153.

[38]Nakamura Y, Yamaguchi M, Kitayama A, Okubo M and Matsumoto T (1991), “Effect of particle size on fracture toughness of epoxy resin filled with angular-shaped silica”, *Polymer*, 32(12) 2221–2229.

[39] Nakamura Y, Yamaguchi M, Okubo M and Matsumoto T. (1992), “Effects of particle size on mechanical and impact properties of epoxy resin filled with spherical silica”, *Journal of Applied Polymer Science*, 45 1281–1289.

[40] Moloney AC, Kausch HH and Stieger HR. (1983) “The fracture of particulate filled epoxide resins”, *Journal of Material Science*, 18 208-16.

[41] Moloney AC, Kausch HH, Kaiser T and Beer HR. (1987) “Review parameters determining the strength and toughness of particulate filled epoxide resins”, *Journal of Material Science*, 22 381–393.

[42]Moloney AC, Cantwell WJ and Kausch HH. (1987) “Parameters determining the strength and toughness of particulate-filled epoxy resins”, *Polymer Composites*, 8(5), 314–323.

[43] Adachi T, Araki W, Nakahara T, Yamaji A and Gamou M. (2002) “Fracture toughness of silica particulate-filled epoxy composite”, *Journal of Applied Polymer Science*, 86, 2261–2265.

[44]Yuan JJ., Zhou SX, Gu GG and Wu LM. (2005) “Effect of the particle size of nano-silica on the performance of epoxy/silica composite coatings”, *Journal of Material Science*, 40 3927–3932.

[45] Islam MK, Hussain MF and Islam MA. (2014) “Effect of chemical treatment on the mechanical and physical properties of wood saw dust particle reinforced polymer matrix composites” , *Procedia Engineering*, 90 39-45.

[46] Fakhrul T, Mahbub R and Islam MA. (May 2013) “Properties of wood saw dust and wheat flour reinforced polypropylene composites”, *Journal of Modern Science and Technology*, 1(1) 135-148

[47]Maiti SN and Singh K. (1986), “Influence of wood flour on the mechanical properties of polyethylene”, *Journal of Applied Polymer Science*, 32(3) 4285-89.

[48]Fu SY, Feng XQ, Lauke B and Mai YW. (2008) “Effects of particle size, particle/matrix interface adhesion and particle loading on mechanical properties of particulate–polymer composites”, *Composites Part B,* 39 933–96.

[49] Yang HS, Kim HJ, Son J, Park HJ, Lee BJ and Hwang TS. (2004) “Rice – husk flour filled polypropylene composites; mechanical and morphological study”, *Composite structures,* 63 305 – 312.

[50] Wilbrink MWL, Argon AS, Cohen RE and Weinberg M. (2001) “Toughenability of Nylon-6 with CaCO3 Filler Particles”, *Polymer,* 42 10155-10180

[51] Lin Y, Chen H, Chan CM and Wu J. (2010) “The toughening mechanism of polypropylene/calcium carbonate nanocomposites”, *Polymer,* 51 3277-3284

[52] Wang K, Wu J, Ye L and Zeng H. (2003) “Mechanical properties and toughening mechanisms of polypropylene/barium sulfate composites”, *Composites: Part A* 34 1199-1205.

[53] Zhang QX, Yu ZZ, Xie XL and Mai YW. (2004) “Crystallization and impact energy of polypropylene/CaCO3 nanocomposites with nonionic modifier”, *Polymer* 45 5985-5994.

[54] Lin JC. (2008) “Investigation of impact behavior of various silica-reinforced polymeric matrix nanocomposites”, *Composite Structures,* 84 125-131

[55] Lin Y, Chen H, Chan CM and Wu J. (2011) “Effects of coating amount and particle concentration on the impact toughness of polypropylene/CaCO3 nanocomposites”, *European Polymer Journal,* 47 294-304.

[56] Liu HT and Sun LZ. (2005) “Multi-scale modeling of elastoplastic deformation and strengthening mechanism in aluminum-based amorphous nanocomposites”, *Acta Mater,* 53 2693–2701.

[57] Liu HT and Sun LZ. (2008) “A micromechanics-based elastoplastic model for amorphous composites with nanoparticle interactions”, *ASME J Appl Mech,* 75 031009-1–10.

[58] Zhu ZK, Yang Y, Yin J and Qi ZN. (1999) “Preparation and properties of organo-soluble polyimide/silica hybrid materials by sol–gel process”, *J Appl Polym Sci,* 73 2977–84

[59] Dekkers MEJ, Heikens D. (1983) “The effect of interfacial adhesion on the tensile behavior of polystyrene–glass-bead composites”, *J Appl Polym Sci,* 28 3809–15.

[60] Hsueh CH. (1987) “Effects of aspect ratios of ellipsoidal inclusions on elastic stress transfer of ceramic composites”, *J Am Ceram Soc,* 72 344–7.

[61] Bax B and Mussing J. (2008) “Impact and Tensile Properties of PLA/Cordenka and PLA/Flax Composities”, *Composites Science and Technology*, 68 1601-1607,

[62] Waikambo M, LY and Ansell MP. (2003) “Hemp Fiber Reinforced Chasew Nut Shell Liqiud Composites”, *Composite Science and Technology*, 63 1297-1305

[63] Samal SK, Mohanty S and Nayak SK. (2009) “Banana/Glass Fiber-Reinforced Polypropylene Hybrid Composites: Fabrication and Performance Evaluation”, *Polym Plast Technol Eng*, 48(4) 397-414.

[64] Chattopadhyay S, Singh S, Pramanik N, Niyogi UK, Khandal RK, Uppaluri R and Ghoshal AK. (2011) “Biodegradability Studies On Natural Fibers Reinforced Polypropylene Composites”, *J. Appl Polym Sci*, 121 2226-2232

[65] Haneefa A, Bindu P, Aravimd I and Thomas S. (2008) “Studies On Tensile And Flexural Properties Of Short Banana/ Glass Hybrid Fiber Reinforced Polystyrene Composites”, *J. Compos Mater*, 42 1471-1489.

[66] Pothan L, Thomas S and Neelakantan NR. (1997) “Short Banana Fiber Reinforced Polyester Composites: Mechanical, Failure and Aging Characteristics”, *J. Reinf Plast Compos*, 16 744-765

[67] Jannah M, Maiatti M, Baker A and Khalil A. (2009) “Effect of Chemical Surface Modification on the Properties of Woven Banana-Reinforced Unsaturated Polyester Composites”, *J. Reinf Plast Compos*, 28 1519-1532.

[68] Indicula M, Malhotra, Joseph K and Thomas S, (2005) “Effect of Layering Pattern on Dynamic Mechanical Property of Randomly Oriented Short Banana/Sisal Hybrid Fiber-Reinforced Polyester Composites”, *J. Appl Polym Sci*, 97 2168-2174.

[69] Sofian NM, Rusu M, Neagu R and Neagu E. (2001) “Metal Powder-filled Polyethylene Composites. V. Thermal Properties”, *Journal of Thermoplastic Composite Materials*, 14 (1) 20–33

[70] Mamunya YP, Davydenko VV, Pissis P and Lebedev EV. (2002) “Electrical and Thermal Conductivity of Polymers Filled with Metal Powders”, *European Polymer Journal*, 38 1887–1897

[71] Luyt LS, Molefi JA and Krump H. (2006) “Thermal, mechanical and electrical properties of copper powder filled low-density and linear low-density polyethylene composites”, *Polymer Degradation and Stability*, 91 1629-1636.

[72] Han Z and Fina A. (2011), "Thermal conductivity of carbon nanotubes and their polymer nanocomposites: A review*", Progress in Polymer Science,* 36 914-944.

[73] Zhou W, Yu D, Min C, Fu Y and Guo X. (2009) "Thermal, dielectric, and mechanical properties of SiC particles filled linear low-density polyethylene composites", *Journal of Applied Polymer Science*,112 1695-1703.

[74] Subodh G, Manjusha MV, Philip J, Sebastian MT. (2008), "Thermal properties of polytetrafluoroethylene/ Sr2Ce2Ti5O16 polymer/ceramic composites", *Journal of Applied Polymer Science*, 108 1716-1721

[75] Boudenne A, Ibos L, Fois M, Gehin E and Majeste JC. (2004), "Thermophysical properties of polypropylene/Aluminium Composites", *Journal of Polymer Composite: Part B: Polymer Physics*, 42 722-732

[76] Weidenfeller B, Hofer M and Schilling FR (2004) "Thermal Conductivity, Thermal Diffusivity, and Specific Heat Capacity of Particle Filled Polypropylene", *Journal of Composites Part A: Applied Science and Manufacturing*, 35 423–429.

[77] Jiajun W and Su YX. (2004), "Effects of interfacial thermal barrier resistance and particle shape and size on the thermal conductivity of AlN/PI composites", *Composites Science and Technology*, 64 1623–1628.

[78] Sanada K, Tada Y and Shindo Y. (2009) "Thermal conductivity of polymer composites with close-packed structure of nano and micro fillers", *Composites: Part A*, 40, pp724-730.

[79] Agrawal A and Satapathy A. (2012), "A numerical study on heat conductivity characterization of aluminium filled polypropylene composites", *Advanced Material Research*, 585 14-18

[80] Veyret D, Cioulachtjian S, Tadrist L and Pantoloni J. (1993), "Effective thermal conductivity of a composite material: A numerical approach", *ASME Journal of Heat Transfer*, 115 866-871

[81] Kumlutas D and Tavman IH. (2006) "A numerical and experimental study on thermal conductivity of particle filled polymer composites", *Journal of Thermoplastic Materials*, 19 441-455.

[82] Dong-Pyo Kim, M. Rusu, R. Neagu, and E. Neagu, (2003). “Fabrication and Properties of Thermal Insulating Glass Fiber Reinforced Composites from Low Temperature Curable Polyphosphate Inorganic Polymers”, Sage Publications, *Journal of Thermoplastic Composite Materials*, 14 20-23.

[83] Schuster HS, Kumlutas D, and Tavman IH, (2008) “Thermal Conductivities of Three-dimensionally Woven Fabric Composites”, *Denizli*, 96–304.

[84] Zhidong T and Nielsen L. (2011) “Thermal Conductivity of Carbon Nanotubes and Their Polymer Nanocomposites: A Review”, 141449-1471.

[85] Tsao TNG. (1961) “Thermal Conductivity of Two Phase Materials”, *Journal of Industrial and Engineering Chemistry*, 53(5) 395-397.

[86] Cheng S, Vachon R. (1970) “A technique for predicting the thermal conductivity of suspensions: emulsions and porous materials”, *International Journal of Heat & Mass Transfer*, 13 537–542

[87] Kanari K .Dai, (1977) Kai Nippon Dennetu Sinpojiumu Ronbuns, 14 208-10.

[88] Maxwell JC (1954). “A treatise on electricity and magnetism”, *3rd edition, Dover, New York*: 263-269

[89] Lewis T, Nielsen L. (1973) “Thermal conductivity of particulate-filled polymers”, *Journal of Applied Polymer Science*, 29 3819–3825.

[90] Iyer S, Detwiler A, Patel S and Schiraldi D. (2006) “Control of coefficient of thermal expansion in elastomers using boron nitride”, *Journal of Applied Polymer Science*, 102 5153-5161.

[91] Dey TK and Tripathi M. (2010) “Thermal properties of silicon powder filled high-density polyethylene composite”, *Thermochimica Acta*, 502 35-42.

[92] Yasmin A and Daniel IM. (2004), "Mechanical and thermal properties of graphite platelet/epoxy composites", *Polymer* 45 8211-8219

[93] Bejito JG, Castillo E and Caldito JF. (2013) "Coefficient of thermal expansion of TiO2 filled EVA based nanocomposites. A new insight about the influence of filler particle size in composites", *European. Polymer Journal.*, 49 1747-1752

[94] Thomas S, Deepu V, Uma S, Mohanan P, Philip J and Sebastian MT. (2009), "Preparation, characterization and properties of Sm2Si2O7 loaded polymer composites for microelectronic application", *Material Science and Engineering B*, 163 67-75.

[95] Sun C (2010) "Controlling the rheology of polymers/silica nanocomposites", *PhD thesis, Eindhoven University of Technology, Netherlands*.

[96] Devendra K, Rangaswamy T.(2012) "Evaluation of thermal properties of E glass/epoxy composites filled by different filler materials", *International journal of computational engineering research*. 2(5) 1708-1714.

[97] Konsowski SG and Helland AR.(1997) "Electronics Packaging of High Speed Circuitry", *New York: McGraw-Hill*, ch. 3.

[98] Goyel RK, Tiwari AN, Negi YS. (2013) "High performance polymer/AlN composites for electronicsubstrate application", *Composites Part : B Engineering*, 47 70-74.

[99] Agrawal A, Satapathy A. (2013) "Thermal and dielectric behaviour of epoxy composites filled with ceramic microparticle", *Journal of Composite Materials*. DOI.10.1177/0021998313513205

[100] Madhusmita Sahu . (2014) "A study on thermal characteristics of polymer composites filled with micro-sized tiO2 particles", *A thesis submitted to NIT,* Rourkela.

[101] Hou YH, Zhang MQ, and Rong MZ. (2004) "Thermally induced performance decay in conductive polymer composites", *Polymer Composites*, 25(3) 270–279.

[102] Sun C (2010) "Controlling the rheology of polymers/silica nanocomposites", *PhD thesis, Eindhoven University of Technology, Netherlands*

[103] Barbero Ever J. (1999) "Introduction to Composite Materials Design", *Taylor & Francis, Philadelphia, PA.*

[104] Agarwal BD and Broutman LJ.(1990) "Analysis and performance of fiber composites: Second Edition", *John Wiley and Sons*,Inc

[105] Turner MJ, Clough RW, Martin HC and L.J. Topp. (1956) *"Stiffness and Deflection Analysis of Complex Structures", J. Aeronaut Sci*, 23 805-823.