

**A Study on Effective Thermal Conductivity  
of Copper Slag Particle Filled Epoxy  
Composites**

A Project Report Submitted in Partial Fulfillment of the Requirements for the  
Degree of

**B. Tech.**  
(Mechanical Engineering)

By  
**AAMIR SHAMS**  
Roll No. 109ME0420



Department of Mechanical Engineering  
**NATIONAL INSTITUTE OF  
TECHNOLOGY ROURKELA**  
MAY, 2013

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Department of Mechanical Engineering  
**NATIONAL INSTITUTE OF  
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MAY, 2013

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**C E R T I F I C A T E**

This is to certify that the work in this thesis entitled *A Study on Effective Thermal Conductivity of Copper Slag Particle Filled Epoxy Composites* by *Aamir Shams*, has been carried out under my supervision in partial Fulfillment of the requirements for the degree of **Bachelor of Technology** in *Mechanical Engineering* during session 2012 - 2013 in the Department of Mechanical Engineering, National Institute of Technology, Rourkela. To the best of my knowledge, this work has not been submitted to any other university/Institute for the award of any degree or diploma.

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# A C K N O W L E D G M E N T

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# ABSTRACT

To measure the thermal conductivity of Copper slag filled epoxy composites, guarded heat flow meter test method is used using an instrument Unitherm™ Model 2022 in accordance with ASTM-E1530. In the numerical study, the finite-element package ANSYS is used to calculate the conductivity of the composites. Three- dimensional spheres-in-cube lattice array models are used to simulate the microstructure of composite materials for various filler concentrations. This study reveals that the incorporation of copper slag particulates results in enhancement of thermal conductivity of epoxy resin and thereby improves its heat transfer capability. The experimentally measured conductivity values are compared with the numerically calculated ones and it is found that the values obtained for various composite models using finite element method (FEM) are in reasonable agreement with the experimental values.

**Key Words:** *Polymer Composite, Ceramic Powder Reinforcement, Thermal Conductivity*

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# CHAPTER 1

## Introduction

**Introduction:**

Composite materials are materials that are made from two or more constituent materials with different physical or chemical properties which when combined, produce a material with characteristics different from the individual components. The discrete components remain separate and distinct within the finished structure. One of the materials which is known as the reinforcing phase, is in the form of fiber sheets or particles and they are embedded in other material which is called the matrix phase. The prime functions of the matrix are to transfer stresses between the reinforcing fibers/particles and to protect them from mechanical and/or environmental damage whereas the presence of fibers/particles in a composite improves its mechanical properties such as strength, stiffness etc. A composite is therefore a synergistic combination of two or more micro-constituents that differ in physical form and chemical composition and which are insoluble in each other. The main objective is to take advantage of the superior properties of both materials without compromising on the weakness of either. Several light weight and high strength applications have successfully substituted the traditional materials by composite materials. High toughness, high strength-to-weight ratio, high creep resistance, and high tensile strength at elevated temperatures are the reasons why composites are selected for such applications. In a composite, a matrix is usually a ductile or tough material while the reinforcing materials are strong with low densities. If the composite is designed and fabricated correctly it combines the strength of the reinforcement with the toughness of the matrix to achieve a combination of desirable properties not available in any single conventional material. The strength of the composites depends primarily on the amount, arrangement and type of fiber and /or particle reinforcement in the resin. [1]

Types of composites, mainly are divided into:

1. Polymer Matrix Composites
2. Metal Matrix Composites
3. Ceramic Matrix Composites

Other forms include:

1. Carbon Matrix Composites
2. Glass Matrices
3. Elastomers

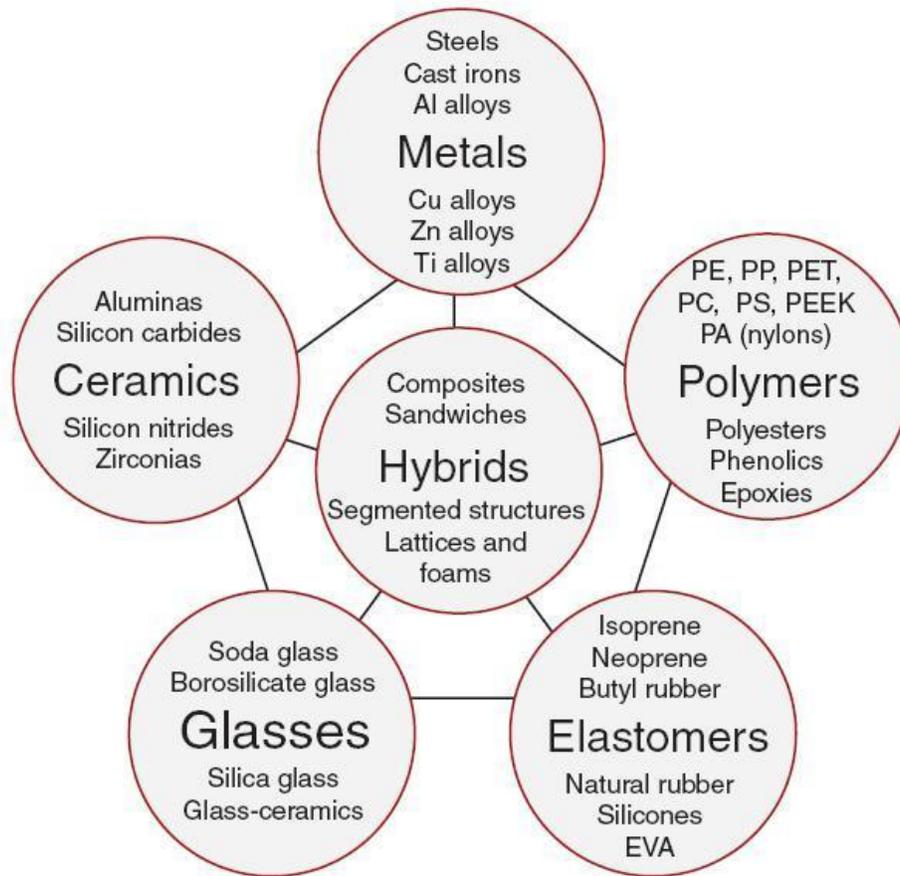


Fig 1.1: Conventional classification of composite materials in accordance to matrix material

### **Polymer Matrix Composites:**

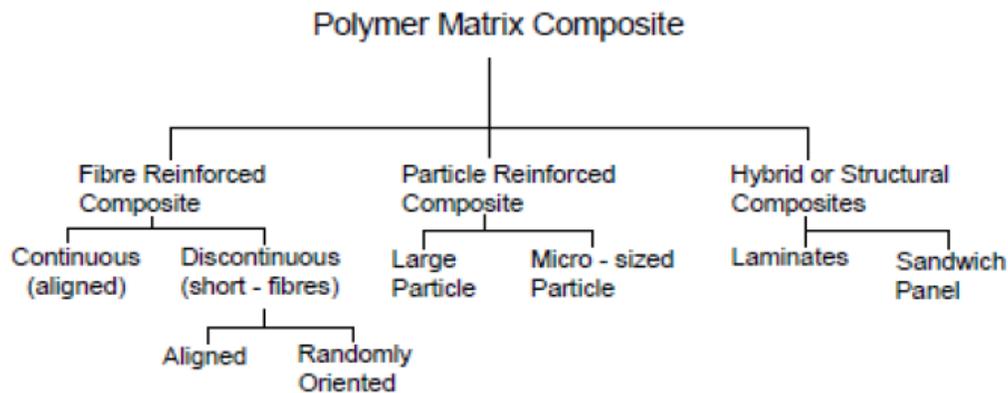
Polymers make ideal materials as they can be processed easily, possess lightweight, and desirable mechanical properties. These high temperature resins are extensively used in aeronautical applications.

Polymeric matrix composites are the most commonly used matrix materials. The reasons for this are two-fold. Normally, the mechanical properties of polymers are insufficient for many structural

purposes. In particular their strength and stiffness are low compared to metals and ceramics. By reinforcing other materials with polymers these difficulties can be overcome.

Secondly high pressure and high temperature are not required in the processing of polymer matrix composites. Also simpler equipment is required for manufacturing polymer matrix composites. For this reason polymer composites developed rapidly and became popular for structural applications within no time. Since, overall properties of the composites are superior to those of the individual polymers, they find their uses in various places. They have a greater elastic modulus than the neat polymer but are not as brittle as ceramics.

### Types of polymer composites:



Hierarchical representation of Polymer Matrix Composite

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) Structural polymer composites (SPC)

### Fiber reinforced polymer:

Fibers and matrix is the main constituent of common fiber reinforced composites. Fibers are the strengthening material and the main source of strength while matrix sticks all the fibers together in shape and transfers stresses between the reinforcing fibers. Fibers carry loads along the longitudinal directions. Occasionally, for smoothing of the manufacturing process, filler might be added to it, to reduce the product cost and/or impart special properties to the composites. Common fiber reinforcing agents include beryllium carbide, beryllium oxide, molybdenum, asbestos, carbon/ graphite fibers, beryllium, Copper oxide, natural fibers, glass fibers, polyamide

etc. Similarly epoxy, phenolic resin, polyester, polyurethane, vinyl ester etc. are the common matrix materials. Polyester is most widely used among these resin materials,. Epoxy, which has higher adhesion and less shrinkage than polyesters, comes in second for its high cost.

### **Particle reinforced polymer:**

Ceramics and glasses such as small mineral particles, metal particles such as Copper and amorphous materials, including polymers and carbon black Particles used for reinforcing.

Particles are used for increasing the modulus and to decreasing the ductility of the matrix. Particles are also used for reducing the cost of the composites. Matrices and reinforcements can be common, inexpensive materials and are easily handled. High strength, stiffness, high melting temp., low density, corrosion resistance, and wear resistance are some of the useful properties of ceramics and glasses. Many ceramics are good thermal and electrical insulators. Some ceramics have special properties, some are piezoelectric materials, some ceramics are magnetic materials, and a few special ceramics are also superconductors at very low temperatures. However, glass and ceramics have one major drawback: they are brittle. An example of particle – reinforced composites is an automobile tire, which has carbon black particles in a matrix of poly-isobutylene elastomeric polymer.

### **Structural Polymer Composites:**

These are laminar composites composed of layers of materials held together by matrix. Sandwich structures also fall under this category. Over the past few decades, it has been found that polymers have replaced many of the conventional metals/materials in various applications. Because of the advantages polymers offer over conventional materials, this has been possible. The ease of processing, productivity and cost reduction are the most important advantages of using polymers. They have generated wide interest in various engineering fields, particularly in aerospace applications. New researches are underway worldwide to develop newer composites with varied combinations of fillers and fibers so that they can be usable under all operational conditions. In most of these applications, the properties of polymers are modified using fillers and fibers to suit the high strength/high modulus requirements. Fiber-reinforced polymers offer advantages over

other conventional materials when specific properties are compared. That's the reason for these composites finding applications in diverse fields from appliances to spacecraft's.

A lot of work has been carried out on various aspects of polymer composites, but a not so many researchers have reported on the thermal conductivity modification of particulate filled polymers. In view of this, the present work is undertaken to estimate and measure the effective thermal conductivity of epoxy filled with metal powders.

## **2. Metal Matrix Composites:**

Metal Matrix Composites have several advantages over monolithic metals, such as higher specific modulus, higher specific strength, better properties at elevated temperatures and lower coefficient of thermal expansion. These characteristics of metal matrix composites have led to consideration for various applications viz. combustion chamber nozzle (in rocket, space shuttle), housings, tubing, cables, heat exchangers, structural members etc.

## **3. Ceramic matrix Composites:**

One of the main objectives in producing ceramic matrix composites is to increase the toughness. Naturally it is hoped and indeed often found that there is a concomitant improvement in strength and stiffness of ceramic matrix composites. High compressive strength, good corrosion resistance, stability at elevated temperatures and high melting points render ceramic matrix composites, a preferred method for applications requiring a structural material that can withstand temperatures above 1500°C. Naturally, ceramic matrices are the obvious choice for high temperature applications.

## **4. Carbon Matrices**

Carbon and graphite have a special place in composite materials options, both being highly superior, high temperature materials with strengths and rigidity that are not affected by temperature up to 2300°C. This carbon-carbon composite is fabricated through compaction of carbon or multiple impregnations of porous frames with liquid carbonizer precursors and subsequent pyrolyzation. They can also be manufactured through chemical vapour deposition of pyrolytic carbon.

**About Copper slag:**

Copper slag is produced during pyro-metallurgical production of copper from copper ores contains materials like iron, alumina, calcium oxide, silica etc. For every ton of metal production about 2.2 ton of slag is generated. Dumping or disposal of such huge quantities of slag cause environmental and space problems. During the past two decades attempts have been made by several investigators and copper producing units all over the world to explore the possible utilization of copper slag. The favorable physico-mechanical characteristics of copper slag can be utilized to make the products like cement, fill, ballast, abrasive, aggregate, roofing granules, glass, tiles etc. apart from recovering the valuable metals by various extractive metallurgical routes. [2]

Favorable physico-mechanical and chemical characteristics of copper slag lead to its utilization to prepare various value added products such as cement, fill, ballast, abrasive, cutting tools, aggregate, roofing granules, glass, tiles etc. These materials have been found to be possessing superior mechanical properties and they may be of cheaper varieties than the similar conventional materials. The utilization of copper slag in such manners may reduce the cost of disposal. This may also leads to less environmental problems. Improvement in plant economics may also be expected. Metals and alloys can also be produced from the copper slag by various pyro, hydro and pyro-hydrometallurgical routes. Therefore, it is evident that judicial utilization of different types of copper slag is of prime importance in the present days. [2]

# CHAPTER 2

## Literature Review

## LITERATURE REVIEW

This literature review serves as a medium to provide a background information on the issues to be dealt in this thesis and to articulate the relevance of the present study. This review encircles some of the related aspects of polymer composites with special reference to their thermal conductivity characteristics.

From the beginning of the era of industries, slags that are left over when metals are pyro-metallurgically extracted from ores, have been considered waste. One of them is copper slag which is produced during the matte smelting and steps of pyro-metallurgical production of copper. In the process of matte smelting, two phases of liquid: copper-rich matte (sulphides) and slag (oxides) are formed. Slags containing <0.8% copper are either discarded as waste or sold as products with properties similar to those of natural basalt (crystalline) or obsidian (amorphous). Utilization and recovery of these metal depends on the types of slag. Current methods of management of this slag are recovering of metal, recycling, production of value added products and disposal in stockpiles or slag dumps. Processed air-cooled and granulated copper slag have number of favorable mechanical properties for collective use, including excellent soundness characteristics, good abrasion resistance and good stability.[2]

A lot of work is being done in this area to maximize the output by using slags as composites in materials such as concrete. For this, knowing the physical and chemical properties of these slags is very important. One such property is its thermal conductivity.

F C Chen, C L Choy and K Young calculated the thermal conductivity of composite materials containing thinly dispersed spheroidal inclusions by solving the associated problem of heat flow across one such inclusion embedded in an infinite matrix in the presence of thermal boundary resistance. The theory showed good agreement with experimental data for different composites containing inclusions of various substances, geometry and size, at temperatures from 2K to 300K. By considering the thermal boundary resistance in a treatment closely paralleling that of Meredith and Tobias , they also extended the calculation to composites with densely packed spherical inclusions, which was yet again found to be in close agreement with experiment.[3]

Hansen and Ho [4], Peng et. al [5], Tavman [6] and others have also contributed in this subject of finding and studying the characteristics of composites.

While copper slag is generated of the granulated slag of copper refineries, red mud is the solid waste product of the Bayer process, the means to refine bauxite in generating alumina. These smelting processes produce large volume of non-metallic dust and soot with red mud bearing the ability to be a major environmental hazard among the three varieties of slags. However waste elimination techniques have been the savior to an extent as evident from the various solid waste reusable applications. Red mud for instance has been used in aluminium metal matrix composites for wear resistance applications, along with studies of tribological properties [7, 8] that have successfully cut part of the wastage. Red mud composite coatings [9] have improved wear resistance. Similarly synergistic effect of copper slag and red mud happen to improve physical and mechanical properties of bamboo fiber reinforced composites [10]. Again Biswas and Satpathy [11] justified the possible utilization of copper slag as filler material for the preparation of composite materials and value added products such as abrasive and cutting tools and railroad ballast. Also as copper slag is highly stable and non-leachable, it is boasted of as an alternative material for concrete applications which is evident from Sterlite Industries India's recent stake in waste management. Various copper matrix composite materials strengthened with alumina particulates are engineered by means of pressure molding and sintering. The compactness of composites increased with the sintering temperature and increase in pressure, and decreased with the alumina content increasing. The hardness of composite materials increased with the increase of sintering temperature, pressure and alumina particulates [12]. Among all slags discussed in this paper, blast furnace (BF) slag is quite the most consumed solid waste which is apparent from its numerous numbers of usages. Jian Zhou, Shunzhi Qian et al [13] studied cementitious composites from blast furnace slag and limestone powder which have high compressive strength and improved tensile strain capacity. For usage in construction purposes, Cheng and Chiu [14] researched the usage of granulated BF slag as a filler material in making of geo-polymers. Of diversified research work, remediation of chromium contaminated soils studied by O.A.B Hassan [15] claims of stabilizing chromium contaminated soils by presence of iron slag in the resulting leachate. In the present work focus has been in studying the ability of BF slag as a filler material. As this is a relatively new area of study, groundbreaking work by Padhi and Satpathy [17] and again Padhi et.al. [16] has emphasized on the erosion study of epoxy resins and hybrid epoxy composites respectively filled with blast furnace slag.

# CHAPTER 3

## Materials & Methods

## MATERIALS AND METHODS:

This chapter describes the materials and methods used for processing of the selected composites under this research. It presents the details of the characterization and thermal conductivity tests which the composite samples are subjected to. The numerical methodology related to the determination of thermal conductivity based on finite element method is also presented in this chapter of the thesis.

## MATERIALS

### Matrix Material:

Epoxy LY 556 resin, chemically belonging to the “epoxide” family is used as the matrix material. Common name of this resin is Bisphenol-A-Diglycidyl-Ether. The low temperature curing epoxy resin (Araldite LY 556) and the corresponding hardener (HY 951) are mixed in a ratio of 10:1 by weight as recommended. Both, the hardener and the epoxy resin are supplied by Ciba Geigy India Ltd. Epoxy is chosen primarily because it is the most commonly used polymer and because of its insulating behavior (a low value of thermal conductivity, which is about 0.363 W/m-K).

### Filler Material (Copper Slag):

Composition of Copper Slag:

Typical Chemical Composition			
Fe%	45	Tin %	0.08
SiO <sub>2</sub> %	>31	Antimony %	0.07
Al <sub>2</sub> O <sub>3</sub> %	>4	Chromium %	0.02
Zn%	<1	Cobalt %	0.02
CaO%	<7	Nickel %	0.02
Cu%	<1	Cadmium %	0.04
MgO%	>1.5	Arsenic %	Not Detected

TiO <sub>2</sub> %	<2	Beryllium %	Not Detected
Free Silica	<1	Trace elements %	<0.5
Lead%	0.1	Moisture %	<1

Properties of Copper Slag:

Appearance	Black, glassy, more vesicular when granulated
Unit weight	2800–3800(kg/m <sup>3</sup> )
Absorption, %	0.13
Bulk density	144–162 lbs per cubic feet
Conductivity	500 μs/cm, 43.48 W/m-k for this project
Sp. gravity	2.8–3.8
Hardness	6–7 Moh
Moisture	<5%
Water soluble chloride	<50 ppm
Abrasion loss, %	24.1
Sodium sulphate soundness loss, %	0.90
Angle of internal friction	40–53
Density	3.2

**Composite Fabrication:**

The low temperature curing epoxy resin (LY 556) and corresponding hardener (HY951) are mixed in a ratio of 10:1 by weight as recommended. Copper slag with average size 100-200  $\mu\text{m}$  are reinforced in epoxy resin (density 1.1 gm/cc) to prepare the composites. The dough (epoxy filled with copper slag powder) is then slowly poured into the cups, which are coated beforehand with a uniform thin film of silicone-releasing agent and wax. The composites are cast by conventional hand-lay-up technique in cups so as to get cylindrical specimens. Composites with different compositions (1.4, 3.35, 5.23, 7.85, 9.4 and 11.3 vol % of copper slag respectively) are made. The castings are left to cure at room temperature for about 24 hours after which the cups are broken and samples are taken out. Specimens of required dimension are cut using a diamond cutter for further physical characterization and thermal conductivity test.

Samples	Composition (for copper slag filled epoxy)
<b>1</b>	Epoxy + 1.4 vol% (1.04 wt %) Filler
<b>2</b>	Epoxy + 3.35 vol% (2.49 wt %) Filler
<b>3</b>	Epoxy + 5.23vol% (3.89 wt %) Filler
<b>4</b>	Epoxy + 7.85 vol% (5.84wt %) Filler
<b>5</b>	Epoxy + 9.4 vol % (6.99 wt %) Filler
<b>6</b>	Epoxy + 11.3 vol% (8.40 wt%) Filler

**THERMAL CONDUCTIVITY CHARACTERIZATION****Determination of Thermal Conductivity Experimentally:**

Unitherm™ Model 2022 is used to measure thermal conductivity of a variety of materials. They include ceramics, polymers, glasses, composites, rubbers, some metals and other materials of low to medium thermal conductivity. Only a small test sample is required relatively. Non-solids, like liquids or pastes can be tested using some special containers. By using a multi-layer technique, thin films can also be tested accurately.

The tests are in conformance with **ASTM E-1530** Standard.

**Operating principle of Unitherm™ 2022:**

A sample of the material is held under a uniform compressive load between two polished surfaces, each controlled at a different temperature. The bottom surface is part of a calibrated heat flow transducer. Heat flows from upper surface, through the specimen, to the lower surface, establishing an axial temperature gradient in the stack. After reaching thermal equilibrium, the temperature difference across the specimen is measured along with the output from the heat flow transducer.



**Fig. 3.1** Determination of Thermal Conductivity Using Unitherm™ Model 2022

These values together with the thickness of sample are then used to calculate the thermal conductivity. The temperature drop through the specimen is measured with temperature sensors that are placed in the highly conductive metal surface layers on both sides of the sample.

**Numerical Analysis: ANSYS and Concept of FEM (Finite Element Method):**

The Finite Element Method (FEM) was formerly introduced by Turner et al. in 1956. It is a great computational technique for near solutions to a variety of "real-world" engineering problems having complex fields subjected to general boundary conditions. FEM has become a vital step in

the modeling or design of a physical phenomenon in various fields of engineering. A physical phenomenon usually occurs in a continuum of matter (solid, liquid, or gas) involving some field variables. They vary from point to point, thus having an infinite number of solutions in the domain.

FEM relies on the fragmentation of the domain into a predetermined number of subdomains or elements for which the systematic approximate solution is constructed by applying variational or weighted residual methods. The problem is reduced to that of a finite number of unknowns by FEM. This is done by dividing the domain into elements and by articulating the unknown field variable in terms of the assumed approximating functions within each element. These functions (which are also known as 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. Its ability to discretize the irregular domains with finite elements makes this method a valuable and practical analysis tool for the solution of boundary, initial and Eigen value problems arising in various engineering disciplines.

Hence, FEM is a numerical procedure that can be used to obtain solutions to a large class of engineering fields involving heat transfer, fluid flow, stress analysis, etc. ANSYS is a general purpose finite element modeling software for numerically solving a wide range of mechanical problems such as structural analysis (both linear and nonlinear), heat transfer, static/dynamic and fluid problems. Acoustic and electromagnetic problems can also be solved using ANSYS.

### **Basic Steps in FEM:**

The finite element method involves:

The governing differential equation of the problem is converted into an integral form at first. There are two techniques to accomplish this:

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

In variational technique, the calculus of variation is used to obtain the integral form corresponding to the given differential equation. This integral needs to be minimized to obtain the solution. For structural mechanics problems, the integral form turns out to be the expression for the total potential energy of the structure.

In weighted residual technique, the integral form is made as a weighted integral of the governing differential equation where the weight functions are known and arbitrary, except that they satisfy certain boundary conditions. To reduce the continuity, this integral form is often modified using the divergence theorem. This integral form is set to zero to obtain the solution. For structural mechanics problems, if the weight function is considered as the virtual displacement, then the integral form becomes the expression of the virtual work of the structure.

The second step involves dividing the domain of the problem into a number of parts, called as elements. For one-dimensional or 1-D problems, these elements are nothing but line segments having only length but no shape. For problems of higher dimensions, the elements have both size and shape. For two-dimensional (2D) or axi-symmetric problems, the elements used are triangles, rectangles etc. having straight or curved boundaries. Curved sided element is a better choice when the domain boundary is curved. For three-dimensional or 3D problems, the shapes used are tetrahedron and parallelepiped (prism whose faces are all parallelograms) having straight or curved surfaces.

The division of the domain into elements is called a mesh. In this step, a suitable estimate is chosen for the primary variable of the problem, over a typical element, using interpolation functions (also called shape functions) and the unknown values of the primary variable at some pre-selected points of the element, called as 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. Whereas in the case of 2-D and 3-D elements, the nodes are placed at the vertices (atleast 3 nodes for triangles, and atleast 4 nodes for rectangles, quadrilaterals as well as tetrahedral and a minimum of 8 nodes for parallelepiped shaped elements). Further, additional nodes are placed either on the boundaries or in the interior. The values of the primary variable at the nodes are called as the degrees of freedom.

To get the exact solution, the expression for the primary variable must contain a complete set of polynomials (i.e., infinite terms) or if it contains only finite number of terms, then the number of elements has to be infinite. In either case, it results into an infinite set of algebraic equations. To make the problem amenable, only a finite number of elements and an expression with only finite number of terms are used. Hence, we get only an approximate solution. (Therefore, the expression for the primary variable chosen to obtain an approximate solution is called an approximation).

However, the accuracy of the approximate solution can be improved either by increasing the number of terms in the number of elements or approximation.

In the fourth step, the approximation for the primary variable is substituted into the integral form. If the integral form is of the weighted residual type, it is set to zero to obtain the algebraic equations. 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. In each case, the algebraic equations are obtained element wise first (called as the element equations) and then they are assembled over all the elements to obtain the algebraic equations for the whole domain (called as the global equations). In this step, the algebraic equations are modified to take care of the boundary conditions on the primary variable. The modified algebraic equations are solved to find the nodal values of the primary variable.

Last step is 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.

#### **Advantages of FEM over other numerical methods:**

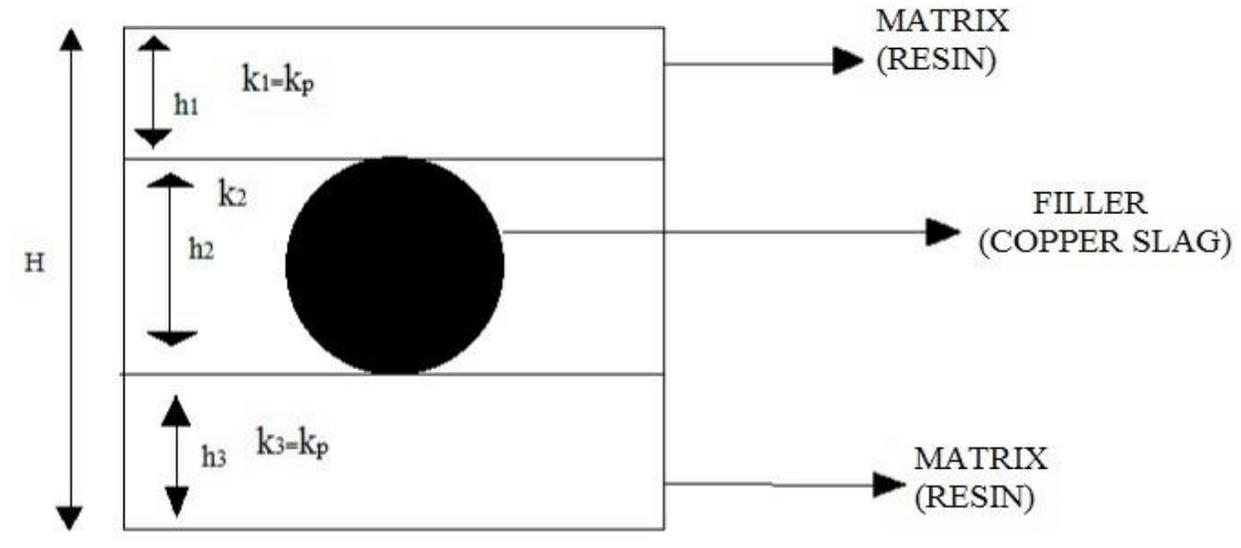
- This method can be used for any irregular-shaped domain and all types of boundary conditions.
- Domains consisting of more than one material can be easily analyzed.
- The algebraic equations can be easily generated and solved on a computer. In fact, a general purpose code can be developed for the analysis of a large class of problems.
- Accuracy of the solution can be improved either by proper refinement of the mesh or by choosing approximation of higher degree polynomials.

#### **Determination of $k_{\text{eff}}$ using ANSYS:**

The thermal model of ANSYS was used to determine the thermal conductivity of the particle filled composites. After solid modeling, property assignment and meshing were done load was applied in the form of temperature on one of the faces of the cube. The opposite face of the cube was kept at ambient temperature and the rest of the surfaces were kept in adiabatic condition. The solution

to the model along with the post processing results helped us to obtain the effective thermal conductivity of the composite.

### Analytical Model (Sphere in Cube):



**Fig 3.2** SPHERE-IN-CUBE-MODEL

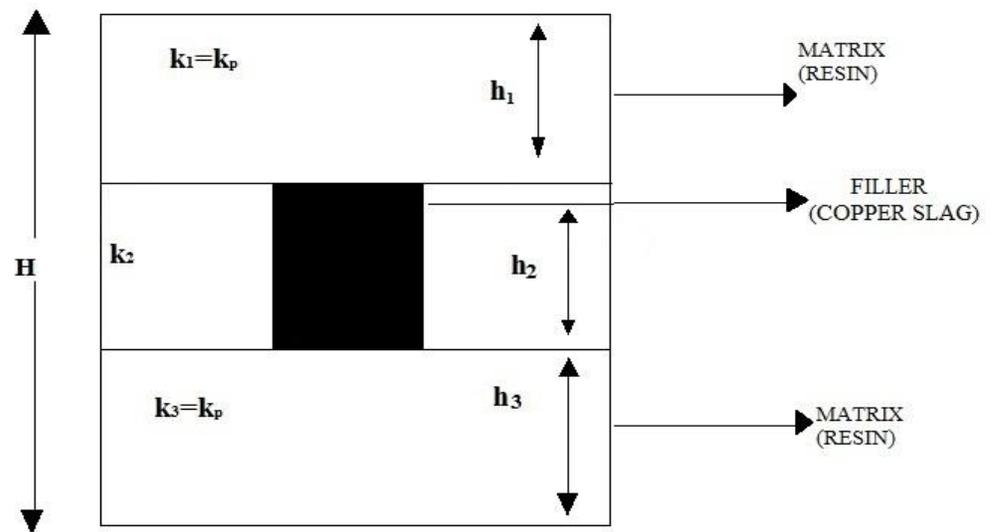
The effective thermal conductivity of the sphere in cube model has been derived from the existing sphere in cube model proposed by J.Z. Liang and G.S.Liu. The final expression of this model is

$$k_{\text{eff}} = \frac{1}{\frac{1}{k_p} - \frac{1}{k_p} \left( \frac{6\phi}{\pi} \right)^{1/3} + \frac{4}{k_p \left( \frac{4\pi}{3\phi} \right)^{2/3} + (k_f - k_p) \left( \frac{16\pi^2}{9} \right)^{1/3}}$$

where  $k_p$  = Thermal conductivity of epoxy polymer

$k_f$  = Thermal conductivity of filler material

$\phi$  = volume fraction of filler material



**Fig 3.3** CUBE-IN-CUBE-MODEL

Here  $k_{\text{eff}} = \frac{m}{\frac{(m-1)}{k_p} + \frac{m^2}{k_p(m^2-1) + K_f}}$

, where  $m = \left(\frac{1}{\phi}\right)^{\frac{1}{3}}$

# CHAPTER 4

## Results & Discussion

## RESULTS AND DISCUSSION

### Description of the problem:

For functional design and application of composite materials the most important parameter is the effective properties of composite. The important factors that regulate the effective properties is the microstructure of the composite and it can be controlled to an appreciable level. Microstructure of composite includes the size, shape, spatial distribution and orientation of the reinforcing inclusion in the matrix. Although most inclusions have random distributions, periodic structure can provide the details of the effect of microstructure on the effective properties can be. System with periodic structures is easy to analyze because of the high degree of symmetry.

Thermal analysis is carried out for the conductive heat transfer through the composite body using the finite-element program ANSYS. For the thermal analysis purpose, three-dimensional physical models with spheres-in-a-cube and cube in cube lattice array have been used to simulate the microstructure of composite materials for six different filler concentrations. Further the effective thermal conductivities of these composites filled with copper slag powder up to about 11.3% by volume is numerically determined by using ANSYS.

### Assumptions:

For the ideal case thermal analysis it will be assumed that:

1. The composites are considered to be macroscopically homogeneous.
2. Both the matrix and filler are homogeneous and isotropic.
3. The thermal contact resistance between the matrix and the filler is assumed to be negligible.
4. Voids are not present in the composite lamina.
5. The problem considered is based on 3D physical model.
6. The filler are arranged in a square periodic array/uniformly distributed in matrix.

### Numerical Analysis

In the numerical analysis of the problem, the temperatures at the nodes of the surface ABCD is prescribed as  $T_1 (=100^{\circ}\text{C})$  and the convective heat transfer coefficient is assumed to be  $2.5 \text{ W/m}^2\text{-K}$  at ambient temperature of  $27^{\circ}\text{C}$ . The heat flow direction and the boundary conditions are shown in Fig. 4.1(heat flow from face ABCD to EFGH). The other surfaces are all assumed to be adiabatic. The unknown temperatures at the nodes in the interior region and on the adiabatic boundaries are obtained with the help of finite-element program package ANSYS.

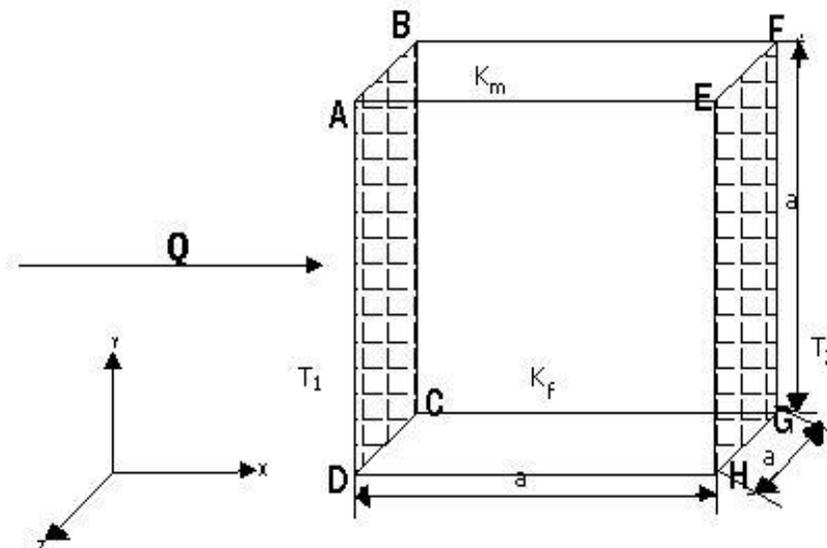


Fig.4. 1 Boundary conditions

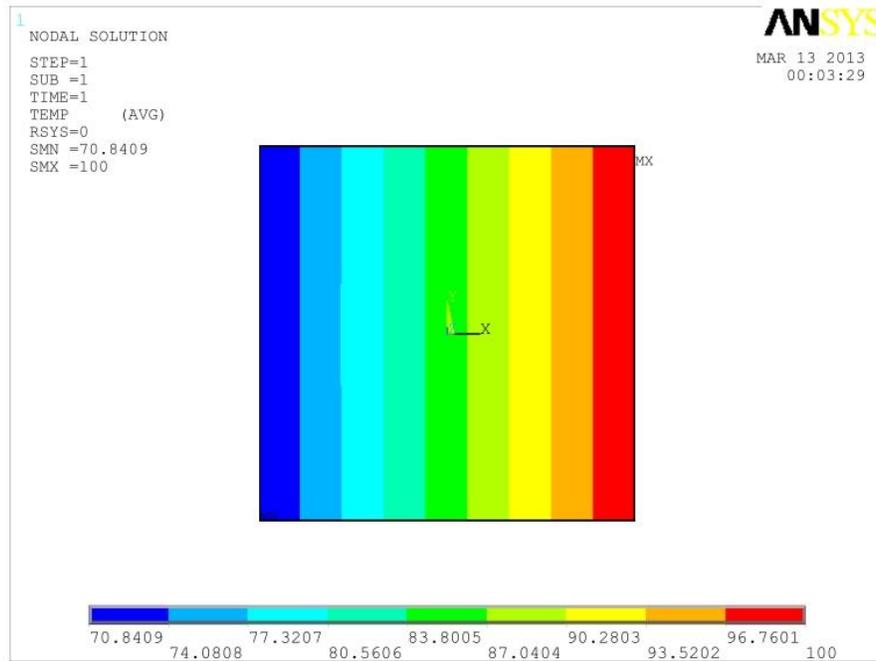


Fig.4.2.1 Temperature profile for copper slag filled epoxy composite of 1.4 % filler concentration

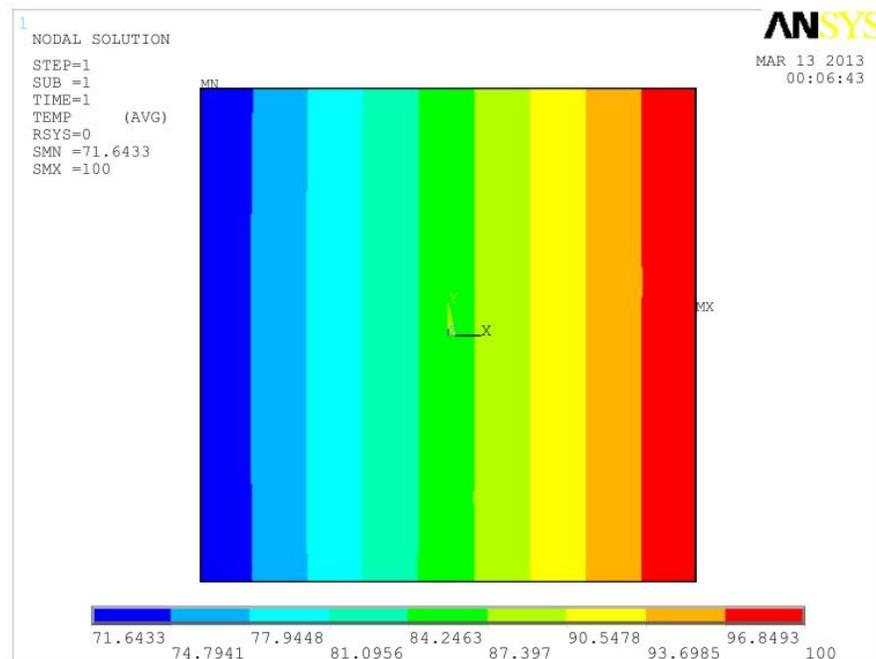


Fig. 4.2.2 Temperature profile for copper slag filled epoxy composite of 3.35 % filler concentration

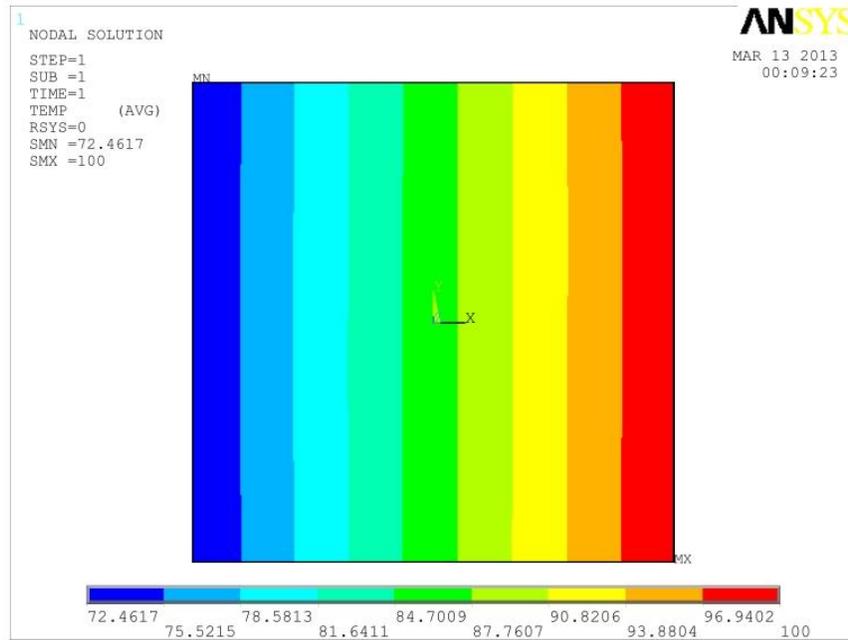


Fig. 4.2.3 Temperature profile for copper slag filled epoxy composite of 5.23 % filler concentration

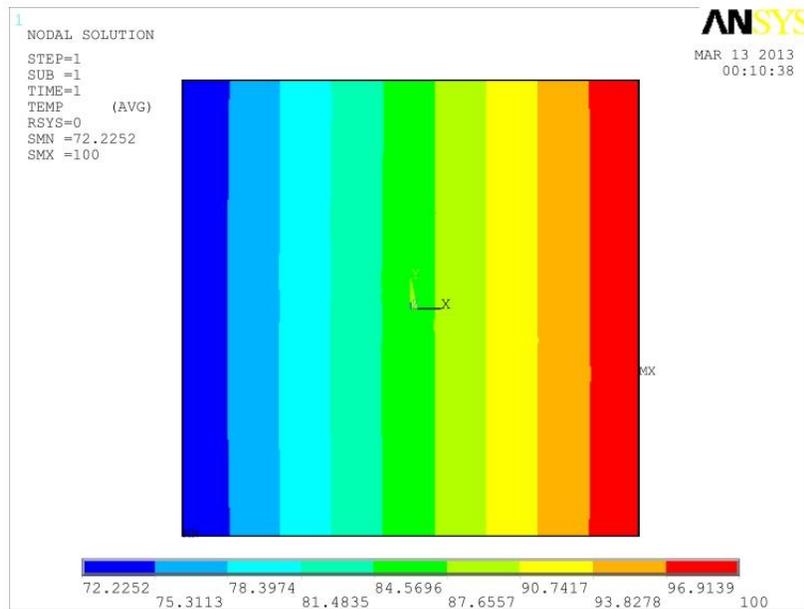


Fig. 4.2.4 Temperature profile for copper slag filled epoxy composite of 7.85 % filler concentration

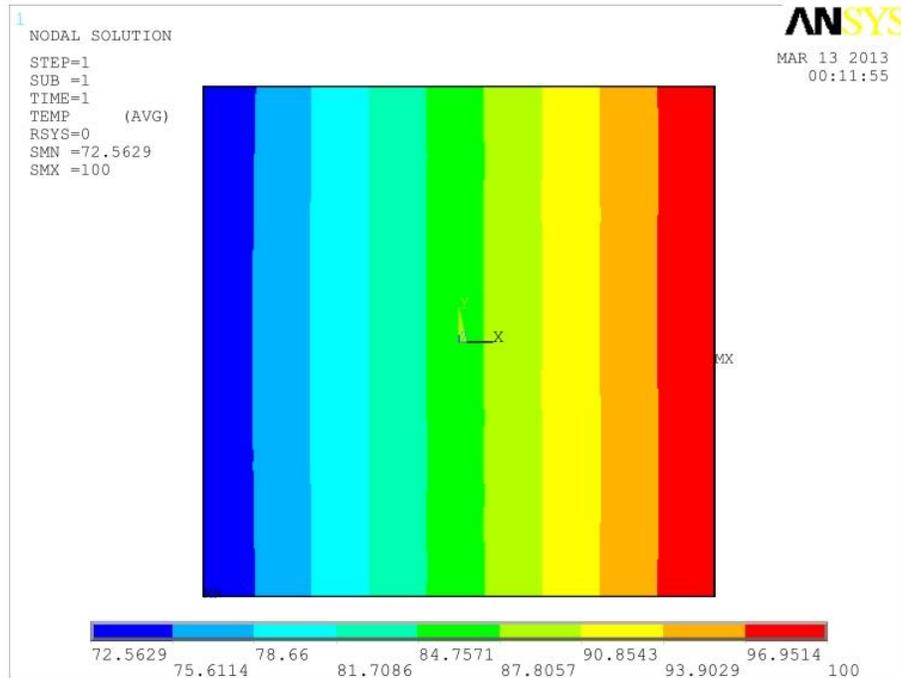


Fig. 4.2.5 Temperature profile for copper slag filled epoxy composite of 9.4 % filler concentration

**Table 4.1** Thermal conductivity for composites obtained from FEM and Experiment

Sample No	Copper Slag Content Vol %	Effective Thermal Conductivity			
		FEM Simulated value (sphere in cube)	FEM Simulated value (cube in cube)	Experimental Measured Value	Analytical Model Value
1	1.4	0.513	0.462	0.528	0.39
2	3.35	0.597	0.52	0.623	0.42
3	5.23	0.667	0.564	0.69	0.425
4	7.85	0.761	0.618	0.775	0.43
5	9.4	0.816	0.648	0.826	0.43
6	11.3	0.887	0.685	0.9	0.44

**Table 4.2** Percentage errors associated with the FEM simulated values with respect to the measured values (for copper slag filled epoxy composites)

Composite Sample	Copper Slag Content (Vol %)	Percentage errors associated with FEM results w.r.t. the experimental value (%)
1	1.4	2.84
2	3.35	4.17
3	5.23	3.33
4	7.85	1.80
5	9.4	1.22
6	11.3	1.44

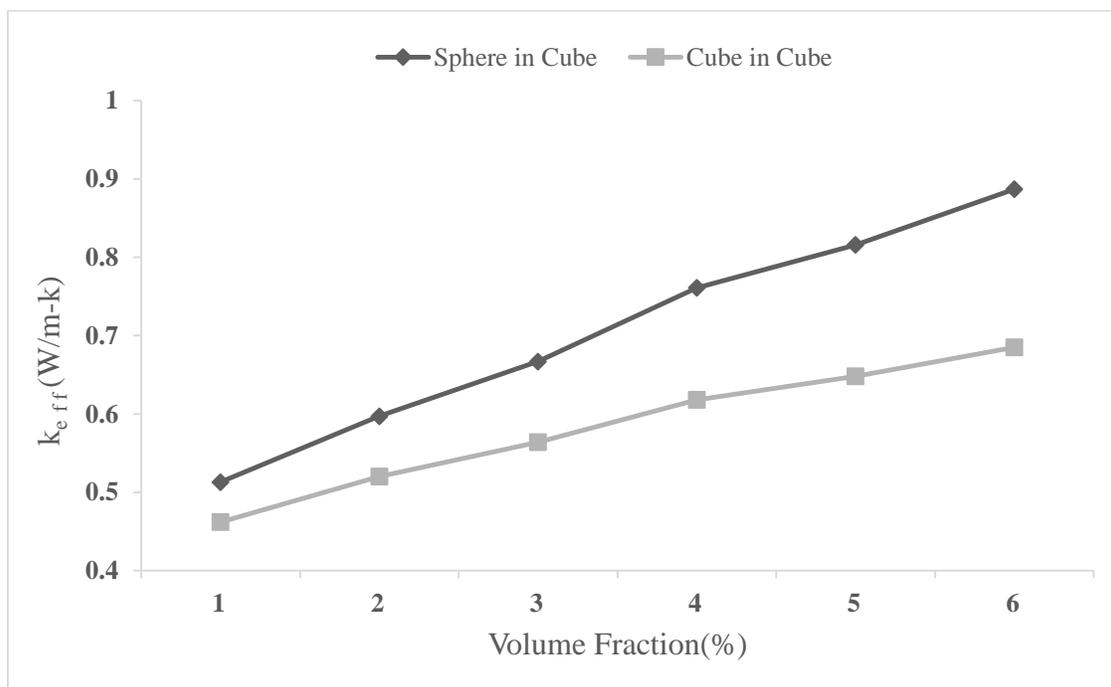


Fig 4.3 Comparison between conductivities of both analytical results (SiC vs CiC)

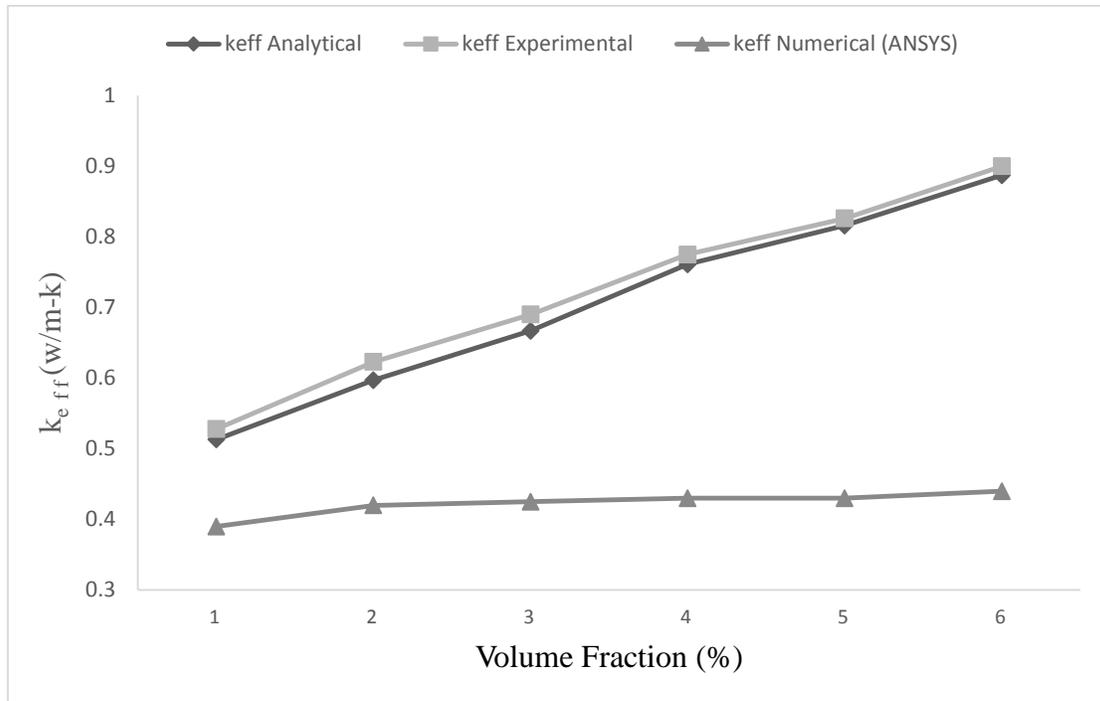


Fig 4.4 Comparison between Experimental results Analytical values and FEM Analysis

Thermal conductivities of epoxy composites filled with copper slag powder particles from 1.4% to 11.4% by volume are numerically estimated by using the finite element package ANSYS (sphere-in-cube model) and the numerical results are compared with the experimental results of the thermal conductivity of samples and also with the analytical model. The temperature profiles obtained from FEM analysis for the composites with filler concentrations of 1.4, 3.35, 5.23, 7.85, and 9.4 vol % are presented in Figures 4.2.1 - 4.2.5 respectively.

This study shows that finite element method can be suitably employed to determine effective thermal conductivity of the polymer composite with different percentage of filler. The value of equivalent thermal conductivity obtained for various composite models using finite element package ANSYS are in reasonable agreement with the experimental values for a wide range of filler contents from about 1.4 vol% to 11.3 vol%. Incorporation of copper slag results in enhancement of thermal conductivity of epoxy resin. With addition of 1.4 % and 11.3% of copper slag the thermal conductivity increases by about 6.61% and 29.75 % respectively when compared with neat epoxy resin.

# CHAPTER 5

## Conclusions & Future Scope

**CONCLUSIONS:**

- ❖ Successful fabrication of copper slag powder filled epoxy composites is carried out by Hand-lay-up technique.
- ❖ The values of the effective thermal conductivity (**keff**) obtained for various composite models from FEM are in reasonable agreement with the experimental values for a wide range of filler content from 1.4 vol% to 11.3 vol%.
- ❖ Finite Element Method (FEM) can be suitably employed to determine the effective thermal conductivity (**keff**) of these particulate filled polymer composites for different volume fractions of copper slag.
- ❖ Inclusion of copper slag results in improvement of thermal conductivity of epoxy resin. With addition of 11.3 vol. % of copper slag, the thermal conductivity improves by about 31.25 % with respect to neat epoxy resin.

**FUTURE SCOPE:**

Copper slag is one of the materials that is considered as a waste material that could have a promising future in construction industry as partial substitute of either cement or aggregates. Studies are already being carried out to increase the output by using copper slags and other materials as composites. From this project, it is evident that copper slag can be used to enhance the characteristics when used with other materials. Hence, it has a huge potential to be used for industrial applications.

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