Investigating the Mechanical and Thermal Behavior of Glass Fiber Reinforced Epoxy Composites with SiC and TiO_2: A Comparative Study

Mark Taylor[1], Dr. John Anderson[2], Emily Clark[3]

[1]Department of Mechanical Engineering, University of Oxford, Oxford, UK
[2]Department of Mechanical Engineering, University of Cambridge, Cambridge, UK
[3]Department of Mechanical Engineering, Imperial College London, London, UK

ABSTRACT

This work deals with preparation of epoxy composites with high content of micro-fillers up to 10 wt%. Experimental thermal conductivity tests are evaluated in each specimen and compared with FEM Analysis. This study was mainly focused on spherical particles of Silicon Carbide (SiC) and titanium oxide (Tio2) micro-fillers separately in an effective way to enhance both thermal conductivity and sufficient mechanical endurance. A numerical solution using finite element package ANSYS will be used to explain heat transfer process within epoxy matrix filled with micro silicon carbide particles and titanium oxide separately and its effective thermal conductivity values are validated with experimental results and theoretical model correlations.

KEYWORDS: Micro Fillers, Sic, Tio, Thernal Conductivity, ANSYS

I. INTRODUCTION

In recent years, the interest in composite materials is increasing due to its advantages as compared to monolithic metal alloys. Composites materials can be defined as engineered materials which exist as a combination of two or more materials that result in better properties than when the individual components are used alone. Composites consist of a discontinuous phase known as reinforcement and a continuous phase known as matrix. In operation, many composites consist of a material (the matrix), and a reinforcement of some kind, added primarily to enhance the strength and stiffness of the matrix

The future materials are expected to possess high heat dissipation capacity, high conductivity, low coefficient of thermal expansion etc. Thus, so many advanced materials have been drawn for encountering such problem. These materials may be metal matrix composites, ceramic matrix composites, carbon-carbon composites, polymer matrix composites (PMCs) [1] Polymer matrix composites are using extensively in many industries because of their characteristics being fitting in different application. These characterizes high thermal conductivity, high corrosion resistance, increase in mechanical properties like wear resistance and hardness [2] ease of process-ability, durability at elevated temperature [3], are high corrosion resistance, low density, low cost [4-6] etc. Different types of filler material are included in polymer matrix to get the desirable properties. Particles generally used for reinforcing are magnetic powder [7], mineral powder, ceramic particles, metal powder like aluminium, copper, zinc, amorphous material etc. Some of the particulates used to increase the thermal conductivity of the composite material required in the various application like in electronic packaging but sometimes it is also required to decrease the thermal conductivity to use the material as an insulating material.

Bonner [8] found that when the polymer matrix included with the micro-sized particulate, the positive effect is seen when the filler content i.e. volume fraction is greater than 20% but it is also seen that above this volume fraction some of the important properties of polymer matrix composites like aging performance, density, process ability also affected.

In so many literature [9, 10], it is found that with the inclusion of silica particulate into polymer matrix leads to increase in mechanical, electrical and thermal properties. The effect of variation of size, shape, specific surface area and volume fraction has seen in the variation of mechanical properties of composite materials by many researchers. Adachi et al. and Moloneyat al. [11-12] described the variation of mechanical properties with the variation of volume fraction of particlesm.

Most of the studies is done regarding the heat transfer in polymer by Hansen and Ho [13], Peg and Landel [14], Henning and knappe [15]. Some of the work is done on heat transfer in polymer is done to increase the thermal conductivity by varying the molecular orientation but it is not always favorable to increase the thermal conductivity by varying the orientation. Thus addition of thermally conductive filler material and fibre in polymer is the simplest and practical means to improve the thermal conductivity.Some of the studies are done to study the effect of fillers shape and size and orientation on thermal conductivity of the composite material [16].

Banjare et al. [17] described the physical and thermal characterization of composite material reinforced with red mud particulates. They studied the effect of filler particle's volume fraction on the effective thermal conductivity of these composite materials. By the addition of 25vol% of red mud filler, there is 135% increase in the thermal conductivity of these composite materials.

II. MATERIALS AND METHODS

2.1 Reinforced Material

Glass fibre was the first modern fibres to be used in composites. Many different glass fibers are now in production. The best known of these are S-glass (which is a high strength magnesia-alumino-silicate composition) and E-glass (a non-alkali metal boro-silicate glass developed originally for its electrical insulation properties). Whilst glass fibre is strong and relatively cheap, it is less stiff than carbon fibre, the relative density of which is lower than that of glass. High-quality glass fibre is spun at a high temperature and then cooled very rapidly before being given a coating of 'size'. This is a mixture, the main object of which is to protect the glass surface from contamination which would lead to a loss in strength. It also contains a derivative of silane SiH_4 which acts as a bonding agent between glass and matrix.

Glass fiber is a generic name like carbon fiber or steel. A variety of different chemical compositions is commercially available. Common glass fibers are silica based (50-60% SiO_2) and contains a host of other oxides of calcium boron, sodium, aluminium, and iron. Table 3.2 gives the composition of some common used glass fibers. The designation 'E' stands for electrical because E-glass is a good electrical insulator in addition to having good strength and a reasonable Young's Modulus. 'C' stands for corrosion because C-glass has a better resistance to chemical corrosion; 'S' stands for high silica content that makes S-glass withstand higher temperature than other glasses. Most of the continuous glass fiber produced is of the E-glass type but, although the designation E, electrical use of E-glass fiberis only small fraction of the total market**.**

Limitation of glass fiber

Glass fiber reinforced composites suffer from three important limitations

1. Comparatively low modulus of elasticity (the specific modulus of unidirectional fiber glass composites being of same order as aluminium, titanium, magnesium and steel).
2. Low inter laminar shear strength in relation to tensile strength.
3. Low compressive properties in relation to tensile properties (the comparison allowable for unidirectional layup being less than one half of tensile strength).

Composition	E-glass	C-glass	S-glass
SiO_2	55.2	65.0	65.0
Al_2O_3	8.0	4	25.0
CaO	18.7	14.0	-
MgO	4.6	3.0	10
Na_2O	0.3	8.5	0.3
K_2O	0.2	- -	- -
B_2O_3	7.3	5.0	- -

Table-1: Approximate chemical composition of some glass fibers (wt. %)

In the present work, woven roving E-glass fibers (supplied by Saint Gobain Ltd. India) have been used as the reinforcing material in all the composites. Glass fibers are the most common of all reinforcing fibers for polymeric (plastic) matrix composites (PMCs). The principal advantages of glass fiber are low cost, high tensile strength, high chemical resistance and excellent insulating properties. The two types of glass fibers commonly used in the fiber reinforced plastics industries are E-glass and S-glass. Another type known as C-glass is used in chemical applications requiring greater corrosion resistance to acids than is provided by E-glass. A fiber has a length that is much greater than its diameter. The length-to-diameter (l/d) ratio is known as the aspect ratioand can vary greatly. Continuous fibers have long aspect ratios, while discontinuous fibers have short aspect ratios. Continuous-fiber composites normally have a preferred orientation, while discontinuous fibers generally have a random orientation. The major constituents of E-glass are silicon oxide (54 wt %), aluminum oxide (15 wt %), calcium oxide (17 wt %), magnesium oxide (4.5 wt %) and boron oxide (8 wt %). E-glass fiber has an elastic modulus of 72.5 Gpa and possess a density of 2.59 gm/cc. The pictorial views of bi-directional roving bamboo and E-glass fiber mats used for composite fabrication for this study are given in Figure 3.3.

Fig: 1 Bidirectional roving E-glass fiber mats

2.2 Filler Materials

Polymer matrix composites are used in greatest diversity considering their less cost, ease of fabricability, higher specific strength, design flexibility and lightweight. Reinforcement of polymer matrix with glass fiber leads to general improvement of mechanical properties. Filler materials are generally the inert materials which are used in composite materials to reduce material costs, to improve mechanical properties to some extent and in some cases to improve process ability.

In this present work, two metallic fillers i.e. titanium oxide and silicon carbide are chosen to be used as particulate fillers in predetermined proportions in various composites prepared for this investigation. Here the fillers taken in this study are in the range of 70-100µmapproximately.

Filler Material	Density (Kg/m^3)	Hardness (M Pa)	Tensile Strength (M Pa)	Thermal Conductivity (W/m-K)
Aluminium oxide	3.98	22050	665	38.5
Titanium di oxide	4.05	10290	367.5	11.8
Silicon carbide	4.84	3800	1625	20.7

Table-2: Properties of Filler Materials

2.3 Composites Fabrication

2.3.1 Preparation of epoxy composite without fillers

In the present investigation, composite materials are fabricated by hand layup process. A mould of size 450 x 450 x 3 mm^3 is prepared and the work side of the mould was coated with a mansion wax which is acted as releasing agent. E- glass fiber was cut into the dimensions of length and breadth is of 400×400 mm was used to prepare the specimen. The composite sheet for specimens are consists of totally 8 layers of glass fiber, Resin and Hardener were mixed and stirred mechanically in a Ratio of 10:1 by weight. With the help of a brush the mixture of epoxy resin and hardener are applied inside the mould surface after the application of mansion wax. One layer of E-Glass fiber of size 400X400 mm^2 is placed in the mould. E-glass cloth is coated with the resin and mild steel Roller is used to remove the entrapped air bubbles and to get uniform distribution of resin and another layer of E-glass fiber is placed on it and the process is continued up to eighth layer and it is cured at room temperature for 72 hours.

2.3.2 Preparation of epoxy composites with fillers

Hand lay-up technique is used to fabricate E-Glass reinforced epoxy based hybrid metallic filled composites. Those filler materials are titanium oxide and silicon carbide 5 wt%, and 10 wt%. respectively. The designation and composition of Epoxy, Glass fiber, Fillers and hardener are shown in Table-3.3. Where C1 is pure Glass fiber reinforced epoxy composite without filler material and C2 to C5 different wt% of different filler reinforced epoxy composites respectively.

The composition and designation of the composites prepared for this study are listed in table 3.3. The fabrication of the composite slabs is done by conventional hand-lay-up technique followed by light compression moulding technique. The fillers are mixed thoroughly in the epoxy resin before the respective fiber mats are reinforced into the matrix body. The low temperature curing epoxy resin and corresponding hardener (HY951) are mixed in a ratio of 10:1 by weight as recommended. Each E-glass fiber is of dimension 400 × 400 mm^2 and wooden sunglass mould having dimensions of 450 × 4500 × 4 mm^3 is used. Prepared epoxy filled hybrid composites are shown in Fig: 2

Fig- 2 composite mould with fillers

Designation of Composite	Composition
C1	60 wt % Epoxy + 40wt % G. F
C2	55 wt% Epoxy + 40 wt % G.F + 5 wt % TiO2
C3	50 wt % Epoxy + 40 wt % G.F + 10 wt % TiO2
C4	55 wt% Epoxy + 40 wt % G.F + 5 wt % SiC
C5	50 wt % Epoxy + 40 wt % G.F + 10 wt % SiC

Table-3.: Designation and Composition of Epoxy Composites

2.4. Specimen preparation

From the moulds, the fabricated E-Glass reinforced particulate filled epoxy based hybrid composites were taken out and as per ASTM standards they are cut in to the specimens of perfect dimensions from the composite slabs for mechanical characterization (i.e. Tensile test, flexural and impact tests) by using hack saw and various tools in engineering work shop, various specimen's shapes and sizes are shown Fig.3

- Tensile test- sample was cut into dog bone shape as per ASTM D638ASTM D1708 Tensile Strength (TENSILE).
- Flexural test- sample was cut into flat shape as per ASTM D790 (FLEXURAL)ASTM D7264-15 Standard Test Method for Flexural Properties of Polymer Matrix Composite Materials
- Impact Test- sample was cut into flat shape with notch at the Centre as per ASTM D256
- Hardness Test – sample was cut into flat shape as per ASTM D 2240

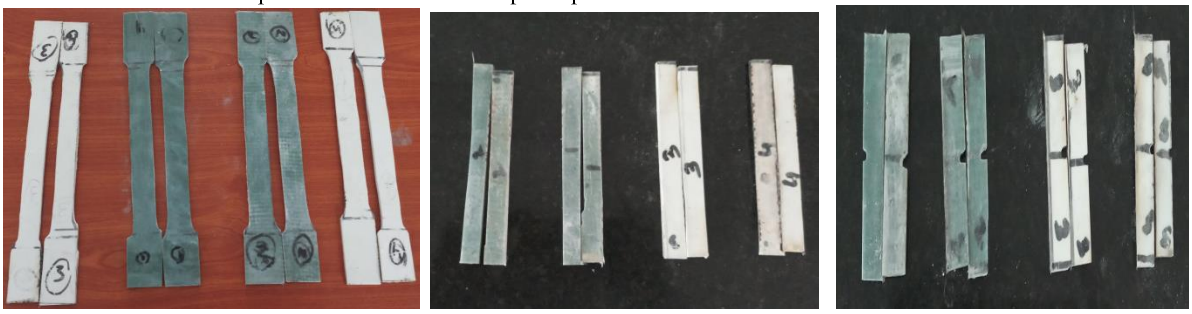

Fig: 3: Tensile, flexural and Impact test Specimens

2.5. Physical Properties

2.5.1Density and Volume Fraction of Voids

The actual density (ρ_{ce}) of the composite can be obtained experimentally by water immersion technique. The theoretical density of composite materials can easily be obtained as per the following equations given by Agarwal and Broutman [2-1].

$$\rho ct = \frac{1}{\left(\frac{wf}{\rho f} + \frac{wm}{\rho m}\right) + (wm + \rho m)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .2.1$$

Where, w and ρ represent the weight fraction and density respectively. The suffix m, f, and ctstand for the matrix, fibre and the composite materials respectively.

The volume fraction of voids (V v) in the composites is calculated by the following equation:

$$Vv = \frac{\rho ct - \rho cm}{\rho ct} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots ..2.2$$

2.5.2 Density and Volume Fraction of Voids of Epoxy Composites

The presence of void content in the composites significantly reduces the mechanical and physical properties of the composites. Table: 4 presents the theoretical density, experimental density and their corresponding void content of all the composite specimens. It may be noted that the composite density values calculated theoretically from weight fractions using Eq (2.1) are not equal to the experimentally measured values. This difference is a measure of voids and pores present in the composites.

Composites	**Theoretical Density(gm/cc)**	**Experimental density (gm/cc)**	**Volume Fraction of Voids (%)**
C1	1.569	1.509	3.828401
C2	1.604	1.701	6.02745
C3	1.449	1.571	8.41461
C4	1.507	1.631	8.25807
C5	1.348	1.449	7.54597

Table-4: Void Fraction of Epoxy Composites

The theoretical and actual densities along with the corresponding volume fractions of voids are presented in Table 4.. The void content is the cause for the difference between the values of true density and the theoretically calculated one. This difference is a measure of voids and pores present in the composites. It is observed from Table 3.5 that in C1 the volume fraction of voids is negligible and this is due to the absence of particulate fillers. With the addition of filler materials more voids are found in the composites. As the filler content increases from 5 wt% to 10wt% the volume fraction of voids is also found to be increasing. This is due to the irregular shape of the fillers and presence of empty spaces near sharp edges of the filler particles.

III. RESULTS AND DISCUSSION

3.1 Mechanical Characterization

The characterization of the composites discloses that inclusion of any particulate filler has influenced strongly on the physical and mechanical properties of composites. The specimen designation, composition and their experimentation values of the properties of the particulate filled glass-fibre hybrid composites under this investigation are presented in Table 5

Designation	Tensile Strength (Mpa)	Flexural Strength (Mpa)	Impact Strength (Joules)	Micro Hardness (shore)
C1	232.6	321.8	8	80
C2	286.8	348.6	12	86
C3	265.7	326.9	14	88
C4	246.2	471.4	16	90
C5	204.2	405.8	12	92

Table-5: Mechanical properties of the composites

The tensile strength of the composite decreases with increase in filler material has a strength of 232.6MPa in tension, this value drops to 204.2MPa with the addition of 10wt% of silicon powder compared to pure composite respectively.

There are two reasons for dropping strength compared to filled composites to unfilled composites.

1. The interfacing adhesion is too weak to transfer the tensile stress, due to the presence of pores at interface between filler particles and the matrix.
2. The corner points of the irregular shaped particulates result in stress concentration in the matrix base

The test results for flexural strength observed that the unfilled composites exhibited flexural strength of 321.8 Mpa which is lower than all filled composites. In this test results C4 exhibited maximum flexural strength (471.4 Mpa) compared to other filler composites due to good adhesive strength of matrix and glass fiber reinforcement.

The reduction in the flexural strengths of the composites with filler content is probably caused by an incompatibility of the particulates and the epoxy matrix, leading to poor interfacial bonding. The lower values of flexural properties may also be attributed to fiber to fiber interaction, voids and dispersion problems.

There are two reasons for dropping strength compared to filled composites to unfilled composites

1. The in compatibility of the particulates and the polyester matrix, leading to poor interfacial bonding.
2. The lower values of flexural strength may also be attributed to fiber to fiber interaction, voids and dispersion problems.

However, it also depends on other factors such size, shape, type and loading on filler on material.

The maximum impact strength was observed more in Epoxy modified composite, at 5wt% silicon carbide filled composites, than the other composites. It was found that wt% of the other fillers increases, the energy absorbed on impact decreases. The fall in those ranges are believed to be a result of inter-particle spacing which often tends to slow down the nucleation of cracks by absorbing some fraction of energy.

There can be two reasons for this decline in the impact energies of the particulate filled composites compared to unfilled ones.

1. The incompatibility of the particulates and the epoxy matrix leading to poor interfacial bonding.
2. The corner points of the irregular shaped particulates result in stress concentration in the matrix base.

The test result shows the effect of hardness of the hybrid composite is improved with the addition of filler materials. As far as the composite with 10wt% titanium oxide as well as Silicon carbide used as a filler material shows better hardness value compared to other composites. The increase in hardness value is may be due to the incorporation of brittle fibres in the epoxy resin.

3.2 Thermal Analysis

The determination of effective properties of composite materials is of paramount importance for functional design and application of composite materials. Microstructure represents shape, size distribution, spatial distribution and orientation distribution of the reinforcing inclusion in the matrix. The effect of microstructure on the effective properties can be gained from the investigation of composites with periodic structure.

For numerical analysis, the temperatures at the nodes along the surfaces ABCD is given as T1 (=100^0C) and the convective heat transfer coefficient is given as 2.5 W/m^2K at ambient temperature of 27^0C. The heat flow is unidirectional with suitable boundary conditions are shown in Fig.5.3. The rest surfaces parallel to the direction of the heat flow are assumed heat flux to be zero. The temperatures at the nodes in the interior region and on the adiabatic boundaries are obtained with ANSYS programming.

3.2.1 Effective Thermal Conductivities obtained from different models and Experimentation

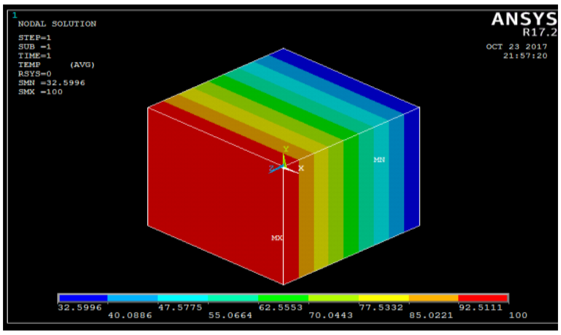

Fig-5: 5 Wt % of Silicon carbide Filler

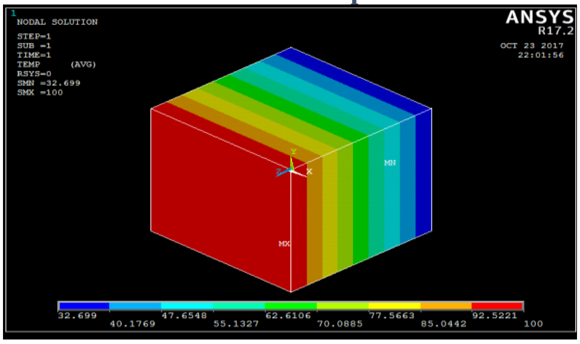

Fig-6: 5 Wt % of Titanium oxide Filler

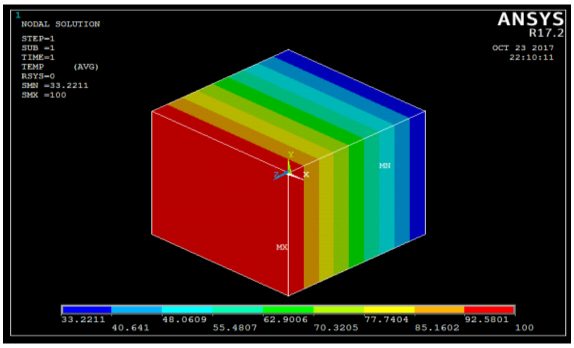

Fig-7: 10 Wt % of Silicon carbide Filler

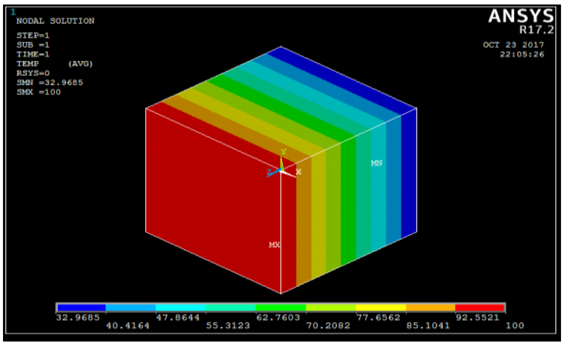

Fig-8: 10 Wt % of Titanium oxide Filler

Sample	**Weight Fraction**	**Effective thermal conductivity of composites K_{ef} (W/m-K)**	
		Experimental	**FEA Values**
1	Epoxy+ 5 wt% filler(TiO2)	0.2067	0.2077
2	Epoxy+5 wt% filler-(SiC)	0.2105	0.2117
3	Epoxy+ 10 wt% filler(TiO2)	0.2212	0.226
4	Epoxy+ 10 wt% filler-(SiC)	0.222	0.2329

IV. CONCLUSION

The conclusions drawn from the present work are as follows.

The glass-epoxy based hybrid composites with modified fillers of TiO2 and SiC have been fabricated successfully by simple hand layup process.

1. In the glass- epoxy composites, the composite (C2) i.e. modified filler of TiO2 of 5 wt% exhibited maximum tensile (286.8 Mpa) compared to other composites.
2. In the glass-epoxy composites, it is observed that the composite C4 i.e. exhibited maximum flexural strength (471.4.7 Mpa) compared to other particulate filled composites. However, it is observed that the both filler i.e. TiO2 &SiC with epoxy resin exhibited better properties compared to based composites.
3. In the thermal analysis the composite filled with titanium oxide varying weight proportions are act as insulator.
4. it is observed that the experimental thermal conductivity of the TiO2 filler at 5 Wt% is0.2067 W/m-K and at 10 Wt % filler is 0.2212 W/m-K. The epoxy composite with SiC filler of 5 wt % experimental value is 0.2105 W/m-K and at 10 wt% filler, the experimental thermal conductivity is 0.222W/m-K. From this observations the TiO2 filler epoxy composite act as insulator material because heat transfer take placed less compared to other filler material. The SiC filler modified epoxy composite based on their thermal conductivity act as a Conductor material.

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