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ORIGINAL PAPER

Comparison of the Mechanical and Thermo-Mechanical Properties of Unfilled and SiC Filled Short Glass Polyester Composites

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Abstract This paper presents a comparison between particulate filled (SiC particles) and unfilled glass polyester composites on the basis of their mechanical and thermo-mechanical properties. The results show that particulate filled composites have a decreasing trend in mechanical properties when compared to the unfilled glass polyester composites. In particulate filled composites, the tensile and flexural strength of the composites decrease with the addition of 10 wt.-% SiC particles but increase with 20 wt.-% SiC particles. In the case of the unfilled glass polyester composite, the tensile and flexural strength of the composites increase with an increase in the fiber loading. However, higher values of tensile strength and flexural strength of particulate filled glass polyester were found than that of the unfilled glass polyester composite. In the case of thermo-mechanical and thermal properties, the particulate filled composites show better dynamical and thermal properties when compared to the unfilled glass polyester composites. The mechanical and thermal properties (i.e. thermal conductivity) are also calculated using FE modeling (ANSYS software) and the results from this simulation shows good agreement with the experimental results.

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1 Introduction

Polymer composites are steadily replacing conventional materials for improving performance and durability. These polymer composites have become the replacement of conventional structural materials, such as metals, steel or wood, in many applications [1]. Polymers are finding ever-increasing applications as engineering systems and structural materials in various components. High specific strength-to-weight ratio and stiffness of polymers are primarily responsible for their popularity. The behavior of polymer matrix composites (PMC) for long-term use is a major issue for many modern engineering applications such as biomedical, aerospace and civil engineering infrastructure [2]. The primary concerns in long-term performance of PMC are in the screening for final material selection, and in obtaining critical engineering properties that extend over the projected lifetime of the structure. Knowing the mechanical properties of the composite materials has gained significant importance in the design of new systems. The mechanical properties of polymers, such as tensile strength, compressive strength, modulus and impact strength, has been found to be very low when compared to the conventional materials. A possible way to overcome such an issue to introduce a second phase in the polymer to form PMC. In order to obtain the desired material characteristics for a particular application, it is important to know how the changes in performance characteristics of composites occur with filler content under given loading conditions. In a fiber reinforced composite, the fibers carry the bulk load and the matrix serves as the medium for the transfer of the load. These mechanical properties can be increased further by the addition of a third phase in the polymer (as filler materials) to become a multi-component composite system. Such a multi-component composite system consisting of matrix, fiber and particulate filler is called a hybrid composite [3]. Various kinds of polymers and polymer matrix composites reinforced with metal particles have a wide range of industrial applications such as heaters, electrodes [4], and composites with thermal durability at high temperature [5]. These engineering composites are desired due to their low density, high corrosion resistance, ease of fabrication, and low cost [6–8]. The inclusion of inorganic fillers into polymers for commercial applications is primarily aimed at cost reduction and stiffness improvement [9, 10].

In electronic packaging, widely used polymer composites are thermal conductive and electrical insulating in nature. In modern times, demands require smaller size of packages and higher power of electronic devices. Nevertheless, both of them imply a higher generation of heat which may affect the reliability and electrical performance of devices. According to this, high thermal conductivity polymeric composites are demanded. The thermal conductivity of polymers can be enhanced by molecular orientation [11–13] or by the addition of high thermal conductive fillers [14–22] in polymers. However, it is not easy to manufacture polymer composites with specific orientation and required shape. Therefore, to overcome such a problem, the addition of high thermal conductive fillers, such as particles or fibers, seems to be a more realistic solution. A lot of work has been presented on the subject of heat conductivity in polymers by Hansen and Ho [23], Peng and Landel [11], Choy and Young [12], and Tavman [24]. However, these studies were mostly restricted to the thermal behavior of neat polymers only, not to polymer composites. Some reports are available in the existing literature on experimental as well as numerical and analytical studies on thermal conductivity of some filled polymer composites [25–27]. The literature reports many approaches at enhancing thermal conductivity of polymers such as the addition of high thermal conductive fillers [16, 18–20, 28] or hybrid fillers [29], adjustment of size distribution of the filler [30], use of different shapes of fillers [20, 31–34] and use of surface-treated fillers [16]. Beyond experimental studies, numerical and analytical models have also been developed to predict the thermal conductivity of composites as well as to optimize the structure of polymeric composites. Finite element analysis has been the most popular tool of those theoretical approaches.

Studies on the viscoelastic properties of fiber reinforced polymer materials are of great importance [35] because these materials undergo various types of dynamic stressing during service. From the literature, a large amount of work has been presented on the viscoelastic properties of fiber and particulate-filled composites [36, 37]. In unidirectional polymer composite materials, the dynamical mechanical properties are dependent on the fiber orientation in the composite [38, 39]. Due to this, the performance of a structural material can be analyzed by dynamic mechanical thermal analysis in fiber alignment direction with different volume fraction of fibers. Generally, the dynamic mechanical analysis has been widely used for investigating the viscoelastic and structural behavior of polymeric materials and for determining their relevant stiffness and damping characteristics in various applications. The dynamic properties of polymeric materials are of considerable practical significance for several reasons; these properties give insight into various aspects of the structure of the materials, provide information about transition temperatures of polymers and may influence other important properties such as fatigue and impact resistance. Generally, the introduction of a filler in a polymeric matrix leads to a reduction in mobility of the macromolecular chains in the vicinity of fillers. This is evident from the increase in the temperature of the main relaxation associated with the glass transition. Also, the dynamic properties are of direct relevance to a range of unique polymer applications, concerned with the isolation of vibrations or dissipation of vibrational energy in engineering components. The dynamic properties are generally expressed in terms of storage modulus, loss modulus and damping factor (tan δ) which are dependent on time and temperature. Ghosh et al. [40] reported the dynamic mechanical properties of jute/glass hybrid fiber reinforced polymer composites. Gassan and Bledzki [41] studied the influence of surface treatment on dynamic mechanical properties of jute reinforced polypropylene. They showed that the maleic anhydride polypropylene co-polymer increases the level of adhesion between polypropylene and jute fiber. Recently, Kumar et al. has reported the viscoelastic interpretation [42] and thermo-mechanical [43] performance of short aramid and short carbon fiber reinforced vinyl ester composite.

Therefore, the aim of present study is to investigate the mechanical and thermo-mechanical properties of particulate filled and unfilled glass polyester composites and to present the comparison between them on the basis of these properties. Another intention is to compare the experimental results of the mechanical and thermal properties with the finite element (FE) modeling results obtained by using ANSYS software.

2 Experimental Details

2.1 Preparation of Composites

Short glass fibers (elastic modulus of 72.5 GPa, and possessing a density of 2.59 gm/cc) (Twaron, Teijin) of 6 mm length were used to prepare the composites. The unsaturated isophthalic polyester resin (elastic modulus 3.25 GPa, density 1.35 gm/cc) was manufactured by Ciba Geigy and locally supplied by Northern Polymers Ltd., New Delhi, India. The composites were made by a conventional hand lay-up technique. Two percent cobalt nephthalate (as accelerator) was mixed thoroughly in isophthalic polyester resin and then 2% methyl-ethyl-ketone-peroxide (MEKP) as hardener was mixed in the resin prior to reinforcement. The composites were fabricated in two different sets. The first part having different fiber loading varying the weight of fibers from 10 wt.-% to 50 wt.-%. In the second part, SiC particulate was mixed with glass fiber reinforced polyester resin with three different filler percentages (0 wt.-%, 10 wt.-% and 20 wt.-% SiC particle), 50 wt.-% of fiber loading was taken as fixed. The filler material SiC was provided by NICE Ltd, India. The castings were put under load for about 24 h for proper curing at room temperature. Specimens of suitable dimension were cut using a diamond cutter for different properties characterization and erosion testing.

2.2 Mechanical and Thermo-Mechanical Characterization of the Composites

The tensile test was performed on flat specimens (length of the test section 200 mm) as per ASTM D3039-76 standards on the universal testing machine Instron 1195. The tensile test was also simulated using FE modeling (ANSYS Software). The two-dimensional model for particulate filled glass polyester (10 wt.-% and 20 wt.-% SiC contents) shown in Fig. 1 and unfilled glass polyester composite (10 wt.-% to 50 wt.-% fiber loading) shown in Fig. 2 was made by using 8 node 82 element. The material properties used were: Polyester resin with Young's Modulus = 3.25 GPa, Poisson's ratio = 0.32; short glass fiber with Young's Modulus = 72.5 GPa, Poisson's ratio = 0.27; and the particulate filler SiC with Young's Modulus = 450 GPa, Poison's ratio = 0.14, respectively. During the tensile test simulation of the model, the degree-of-freedom of one side was kept zero, while applying the axial tensile force on its opposite side. Similarly, the flexural test was performed on the specimen (span length of 100 mm; crosshead speed of 5 mm/min) by simulation keeping both ends fixed (all degrees-of-freedom restricted) and also by applying point load at the specimen span length center.

2.3 Theoretical Models

In the present study, the effective thermal conductivity was predicted using various theoretical models (parallel, series, effective medium theory (EMT) equation, and geometric mean) and compared with both the developed numerical analysis (FEA) and the conducted experimental results. Many theoretical and empirical models have been proposed to predict the effective thermal conductivity of two-phase mixtures. Comprehensive review articles have discussed the applicability of many of these models [17]. For a two-component composite, the simplest alternatives would be with the materials arranged in either parallel or series with respect to heat flow, which gives the upper or lower bounds of effective thermal conductivity. The upper and lower thermal conductivity predictions were done using either in parallel or in series models [44]. The parallel model is described below:

$$k_e = k_f \frac{V_f}{V_t} + k_m \frac{V_m}{V_t} + k_p \frac{V_p}{V_t} \tag{1}$$

or

$$k_e = k_f v_f + k_m v_m + k_p v_p \tag{2}$$

where k_e, k_f, k_m, k_p, v_f, v_m, v_p, V_f, V_m, V_p and V_t are the effective thermal conductivity, fiber thermal conductivity, matrix thermal conductivity, particulate thermal conductivity, volume fraction of fiber, volume fraction of matrix, volume fraction of particulate, volume of fiber, volume of matrix, volume of particulate and volume of composites, respectively.

The series conduction model can be written as in Eq. 3.

$$\frac{1}{k_e} = \frac{v_m}{k_m} + \frac{v_f}{k_f} + \frac{v_p}{k_p} \tag{3}$$

The effective medium theory (EMT) [45] for thermal conductivity prediction is given by Eq. 4:

$$v_m \frac{k_m - k_e}{k_m + 2k_e} + v_f \frac{k_f - k_e}{k_f + 2k_e} + v_p \frac{k_p - k_e}{k_p + 2k_e} = 0 \tag{4}$$

The thermal conductivity of the composites as calculated by geometric mean model (GMM) [46] is given by Eq. 5:

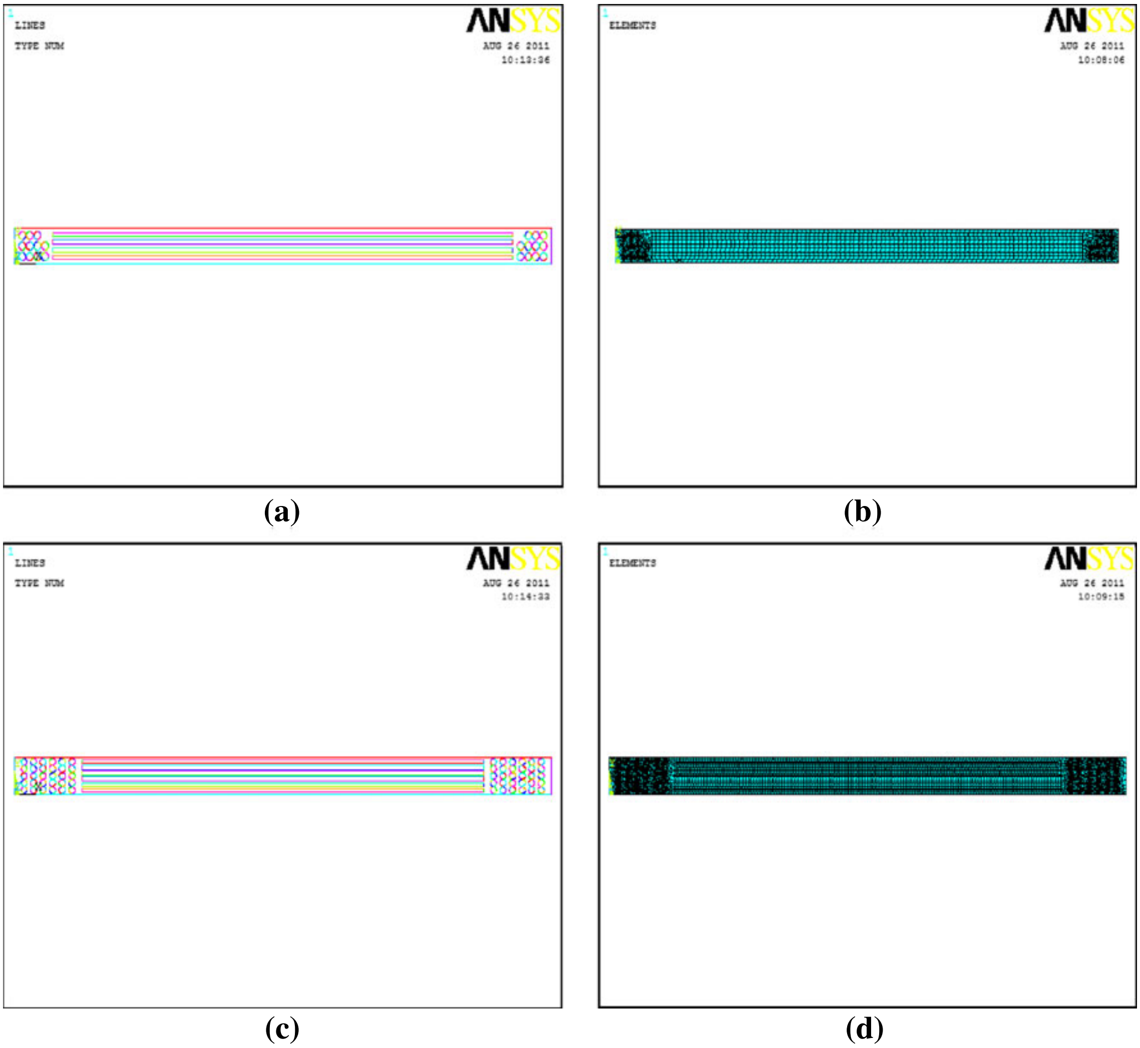
$$k_e = k_f^{v_f} + k_m^{v_m} + k_p^{v_p} \tag{5}$$

2.4 Experimental Measurement of Effective Thermal Conductivity

The measurement of thermal conductivity is performed using the guarded heat flow meter method, Unitherm Model 2022 supplied by ANTER Corp., Pittsburgh, PA. This unit is supplied with a mid range flux module covering a thermal resistance range from 0.01 to 0.05 m^{2}K/W and is able to measure the thermal conductivity of materials in the range of 0.1–40 W/m-K following standard ASTM E1530 (2 inch diameter circular discs with thickness depending on the materials thermal conductivity). The detail of experimental procedure was explained in the authors previously published research work [47]. The generalized one-dimensional heat conduction equation was used to evaluate the thermal conductivity is as follows:

$$Q = kA\frac{(T_1 - T_2)}{x} \tag{6}$$

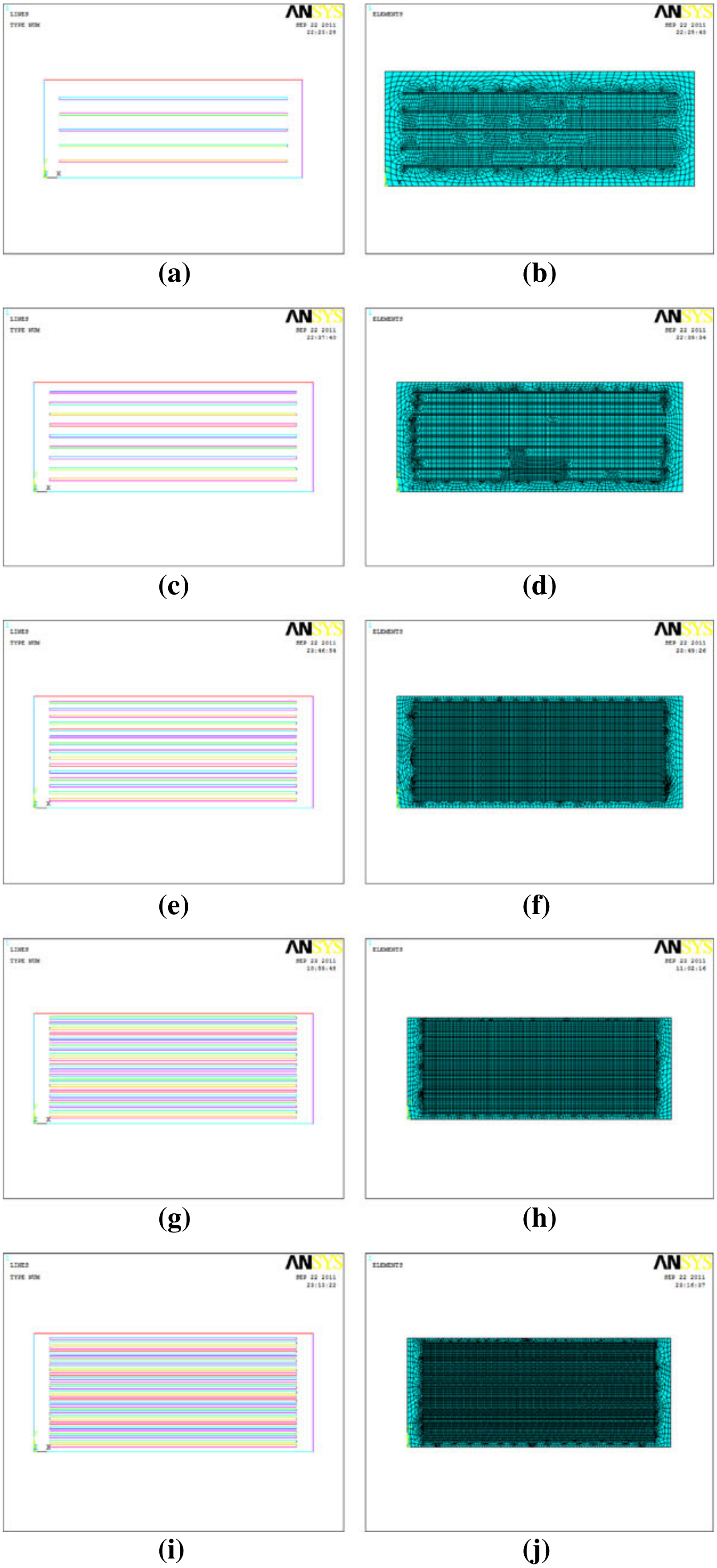
Where Q is the heat flux (W), k is the thermal conductivity (W/m-K), A is the cross-sectional area (m^2),



(a) (b) (c) (d)

Fig. 1 FE modeling for SiC filled glass polyester composite. **a** schematic model for 10 wt.-% SiC filled composite. **b** schematic model for 10 wt.-% SiC filled composite after meshing. **c** schematic model for 20 wt.-% SiC filled composite. **d** schematic model for 20 wt.-% SiC filled composite after meshing

Fig. 2 FE modeling for unfilled glass polyester composite. **a** schematic model for 10 wt.-% fiber loading. **b** schematic model for 10 wt.-% fiber loading after meshing. **c** schematic model for 20 wt.-% fiber loading. **d** schematic model for 20 wt.-% fiber loading after meshing. **e** schematic model for 30 wt.-% fiber loading. **f** schematic model for 30 wt.-% fiber loading after meshing. **g** schematic model for 40 wt.-% fiber loading. **h** schematic model for 40 wt.-% fiber loading after meshing. **i** schematic model for 50 wt.-% fiber loading. **j** schematic model for 50 wt.-% fiber loading



(a) (b)

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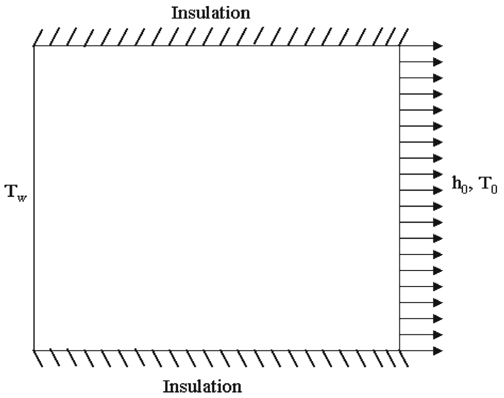


Fig. 3 Thermal boundary conditions. * h_0 convective heat transfer coefficient. * T_w and T_0 temperatures at the nodes along the two surfaces

$T_1 - T_2$ is the difference in temperature (K), and x is the thickness of the sample (m).

2.5 Finite Element Analysis Calculation of Effective Thermal Conductivity Comparison

A finite element method was used to calculate the stiffness matrix with thermal loading and boundary conditions. The effective characteristic matrix was calculated using ANSYS software. The 3-D heat conduction condition can be represented in the form of a matrix, given by Eq. 7.

$$\begin{pmatrix} q_x \\ q_y \\ q_z \end{pmatrix} = \begin{bmatrix} k_{xx} & k_{xy} & k_{xz} \\ k_{yx} & k_{yy} & k_{yz} \\ k_{zx} & k_{zy} & k_{zz} \end{bmatrix} \begin{pmatrix} \frac{\partial T}{\partial x} \\ \frac{\partial T}{\partial y} \\ \frac{\partial T}{\partial z} \end{pmatrix} \tag{7}$$

The generated model is assumed to represent a unit cell in the composite. Hence, a homogenization scheme can be used to define the effective thermal conductivity of the composite along the x-direction.

$$k_e = q_x \frac{\Delta x}{\Delta T} \tag{8}$$

Where the temperature difference $\Delta T = T_1 - T_2$ and the heat flux (q) were measured with reference to the global coordinate system. The thermal boundary condition that consists of the characteristic matrix, is shown in Fig. 3.

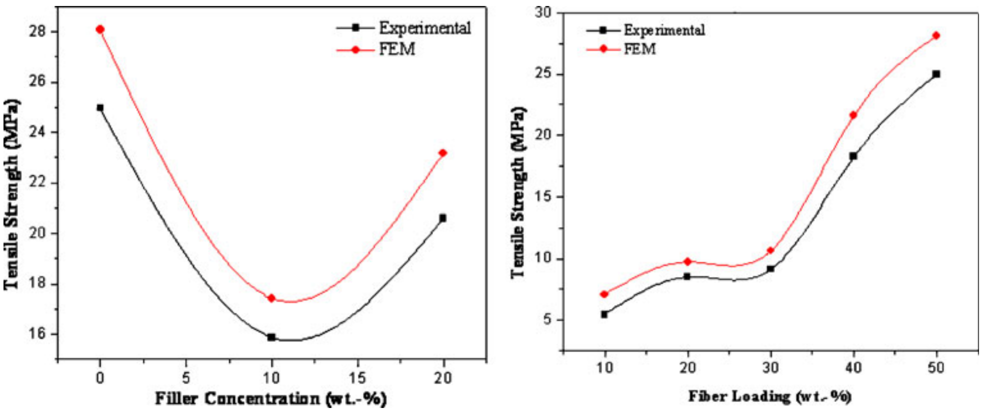
2.6 Thermo-Mechanical Analysis of the Composites

The thermo-mechanical properties of the composites were measured using Dynamic Mechanical Analysis (DMA). The DMA was conducted in an oxygen atmosphere at a fixed frequency of 1 Hz, a heating rate of 5°C/min, with a temperature range of 25–250°C for particulate filled composite and 25–350°C for unfilled glass polyester composite, and a strain of 1% on rectangular samples with dimensions of $25 \times 4 \times 1$ mm^3 using the Q800 DMA instrument in bending mode.

3 Results and Discussion

3.1 Comparison of Tensile Strength, Flexural Strength and Tensile Modulus of the Particulate Filled and Unfilled Glass Polyester Composite

Figures 4 and 5 show the comparison of tensile strength and flexural strength of particulate filled and unfilled glass polyester composites. From Figs. 4 and 5 it is seen that in the case of particulate filled composite, with the addition of a small amount (10 wt.-%) of SiC particles, the tensile strength and flexural strength decreases; however, on further addition (20 wt.-%) of SiC particles, the tensile strength and flexural strength improves. Whereas in the case of unfilled glass polyester composite, the tensile strength as well as the flexural strength increases simultaneously with an increase in the fiber loading. This is due to the fact that the chemical reaction at the interface between the fiber and the matrix may be too strong to transfer the tensile stress. Similar observations have been reported by Harsha et al. [48] for other fiber reinforced thermoplastics such as polyaryletherketone composites. It may be mentioned here that both tensile and flexural strengths are important for recommending any composite as a candidate for structural applications. Also, it is seen that in the case of particulate filled composites, the value of tensile and flexural strength is higher than that of unfilled glass polyester composites. This means that, with the addition of these hard particles, the composites becomes harder and the load applied on the composites is shared by the particles, due to which the strength of the composite increases. However, with the addition of 10 wt.-% SiC filler contents, the tensile and flexural strength show a decreasing trend which is an indication of poor adhesion between the fiber, filler and the matrix, and that the stress can't be transferred from the matrix to the fiber and filler. The FEM results show the higher tensile and flexural strength when compared to the experimental results. This is due to the pores and voids that take place in the composites during fabrication. These pores and voids reduce the strength properties of the composite. The Figs. 6 and 7 show the



(a) (b)

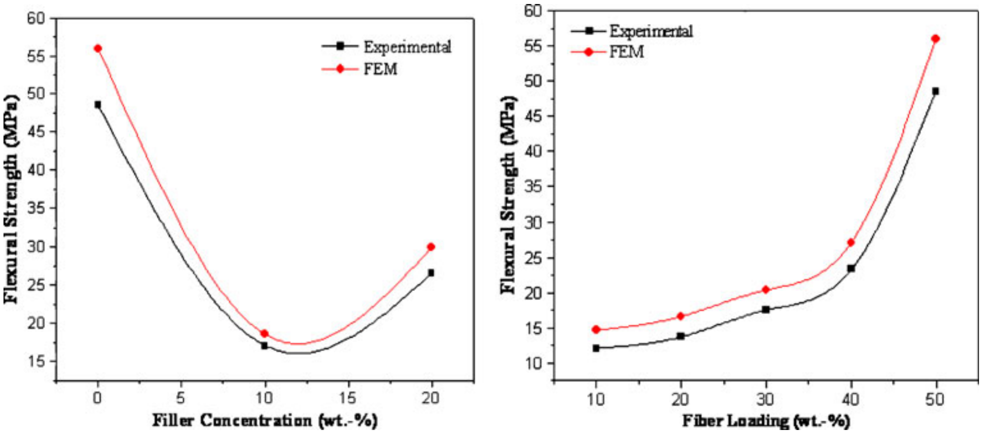
Fig. 4 Tensile strength for particulate filled and unfilled glass polyester composite. **a** variation of tensile strength with SiC filler percentage. **b** variation of tensile strength with fiber loading

Von Mises stresses for filled and unfilled glass polyester composites by FE modeling.

The tensile modulus of both the filled and unfilled glass polyester composite increases reasonably with an increase in the SiC contents and fiber loading as shown in Fig. 8. This increase may be attributed to the low strain rate of the composite during the tensile test.

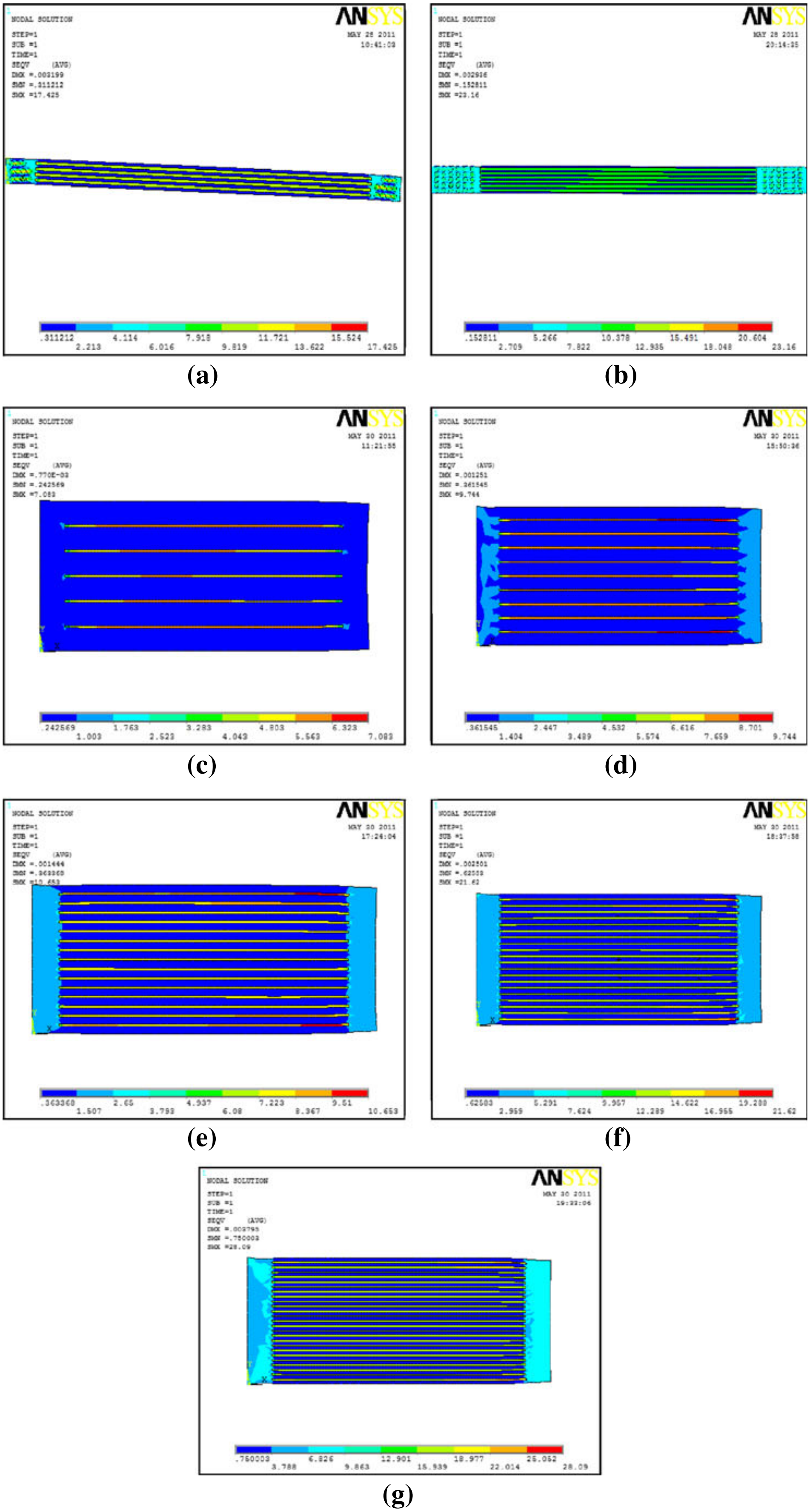
3.2 Effect of Thermal Conductivity on the Particulate Filled and Unfilled Composites

In the thermal analysis, the effective thermal conductivity for unfilled and particulate filled glass polyester composite is calculated theoretically (using different theoretical models), experimentally and FE modeling. Figure 9 shows the comparison of thermal conductivity obtained from different approaches between SiC filled (10 wt.-% and 20 wt.-%) and unfilled glass polyester composites (10, 20, 30, 40, 50 wt.-% of fiber loading). It is observed that SiC filled composite shows a higher thermal conductivity value when compared to the unfilled glass polyester composites. This is due to the inclusion of high thermally conductive SiC filler in the composite [44]. Figure 10 shows the temperature distribution in the composites filled with 10 wt.-% and 20 wt.-% of SiC particles and unfilled glass polyester composite. The thermal constraint of 300 K was applied to the right hand side and a heat flux of 150 W/m^2 (boundary conditions) was applied to the left hand side. Figure 9 shows that, the parallel model graph has the upper bound of thermal conductivity and the lower bound of thermal resistance while the series model graph has the lower bound of thermal conductivity and the upper bound of thermal resistance in all composites. The other models solution bounds between the parallel model and the series model. From this comparison it could be stated that the thermal conductivity can be increased by the addition of filler contents in the composites.



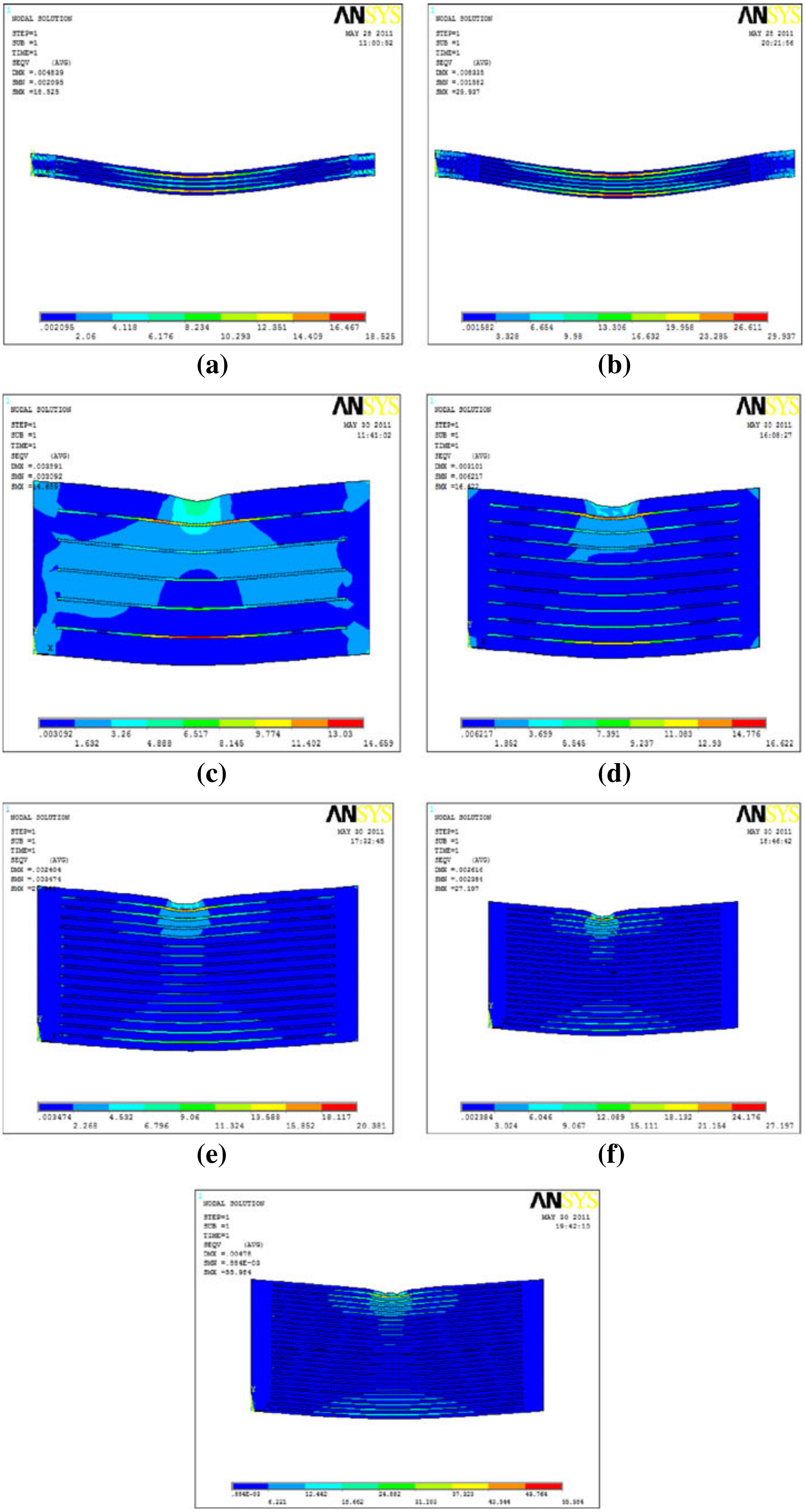
(a) (b)

Fig. 5 Flexural strength for particulate filled and unfilled glass polyester composite. **a** variation of flexural strength with SiC filler percentage. **b** variation of flexural strength with fiber loading



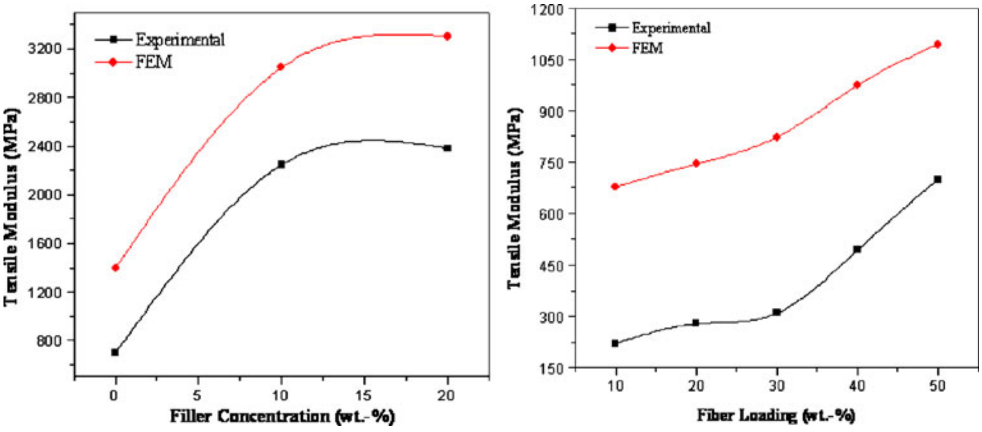
(a) (b) (c) (d) (e) (f) (g)

Fig. 6 Von Mises stress for filled and unfilled glass polyester composite. **a** Von Mises Stress for 10 wt.-% SiC filled composite. **b** Von Mises stress for 20 wt.-% SiC filled composite. **c** Von Mises Stress for 10 wt.-% fiber loading composite. **d** Von Mises stress for 20 wt.-% fiber loading composite. **e** Von Mises stress for 30 wt.-% fiber loading composite. **f** Von Mises stress for 40 wt.-% fiber loading composite. **g** Von Mises stress for 50 wt.-% fiber loading composite



(a) (b) (c) (d) (e) (f) (g)

Fig. 7 Von Mises stress for flexural test with particulate filled and unfilled glass polyester composite. **a** Von Mises stress for flexural test with 10 wt.-% of SiC filled composite. **b** Von Mises stress for flexural test with 20 wt.-% of SiC filled composite. **c** Von Mises stress for flexural test with 10 wt.-% of fiber loading composite. **d** Von Mises stress for flexural test with 20 wt.-% of fiber loading composite. **e** Von Mises stress for flexural test with 30 wt.-% of fiber loading composite. **f** Von Mises stress for flexural test with 40 wt.-% of fiber loading composite. **g** Von Mises stress for flexural test with 50 wt.-% of fiber loading composite

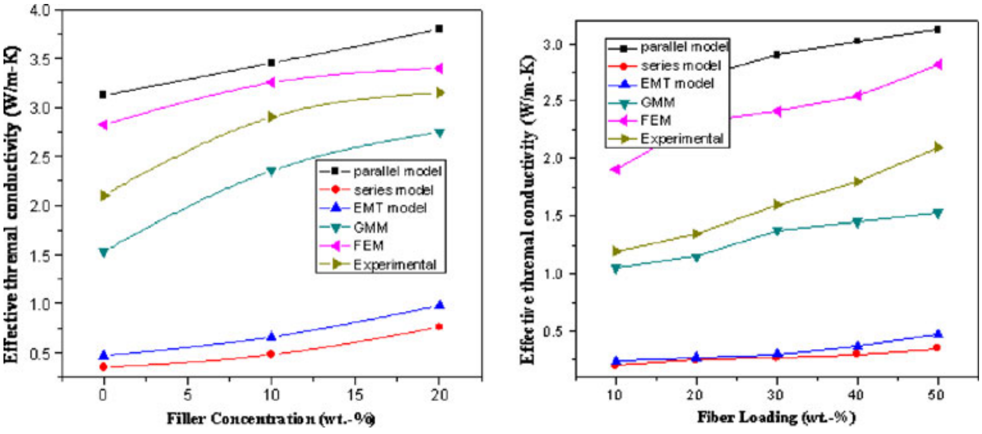


(a) (b)

Fig. 8 Tensile modulus for particulate filled and unfilled glass polyester composite. **a** variation of tensile modulus with SiC filler percentage. **b** variation of tensile modulus with fiber loading

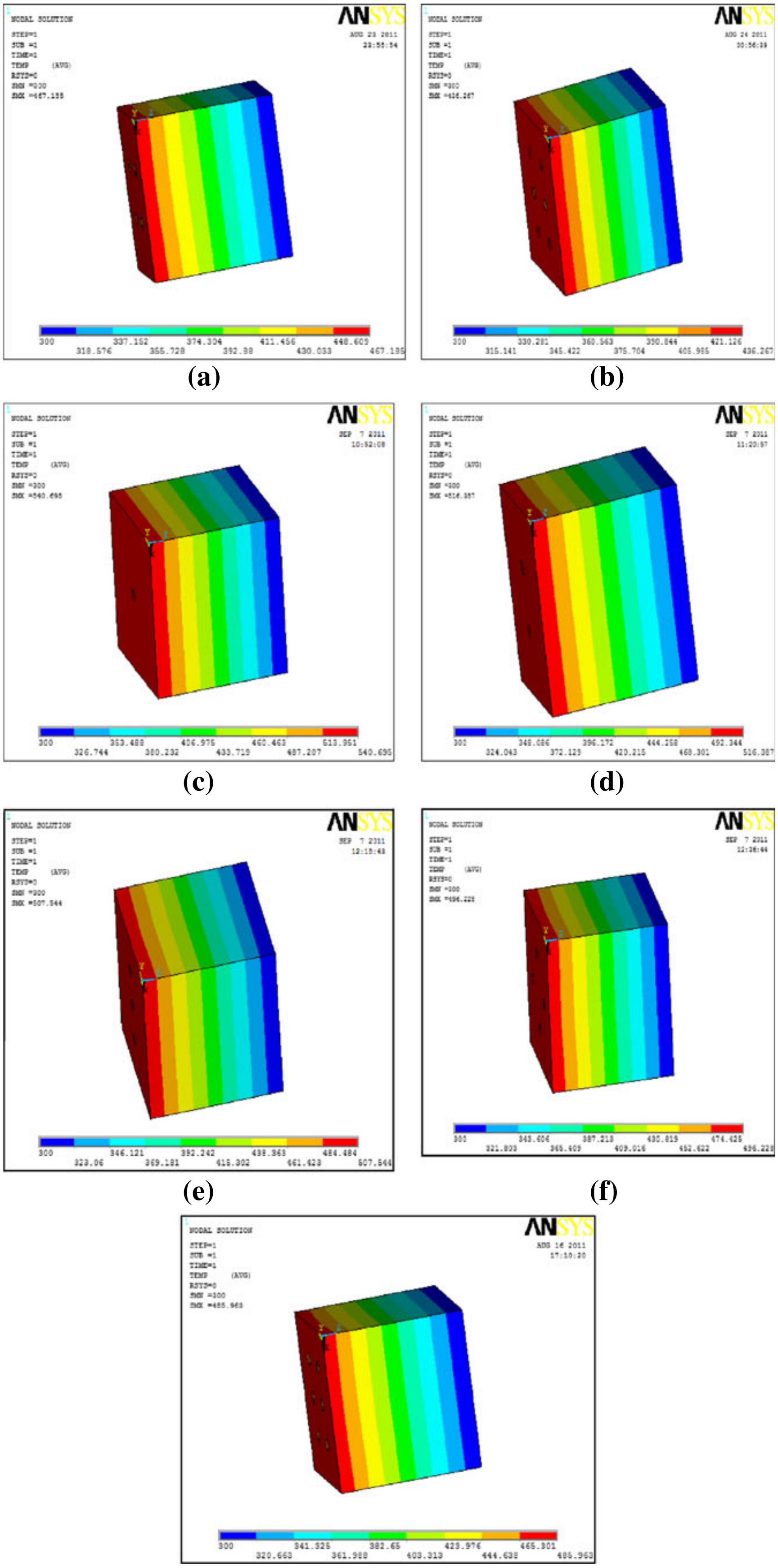
3.3 Effect of Dynamic Mechanical Analysis on the Particulate Filled and Unfilled Composites

The DMA is a high precision technique for measuring the viscoelastic properties of materials. Viscoelasticity is about the elastic behaviors of the materials. Most real-world materials exhibit mechanical responses that are a mixture of viscous and elastic behavior. In this paper, the viscoelastic properties and damping capacity of the SiC filled and unfilled glass fiber reinforced polyester composites have been studied using DMA. The variation of storage modulus (E'), loss modulus (E") and damping factor (tan δ) as a function of temperature for the composites, and the comparison between the SiC filled and unfilled glass polyester composite are shown in Fig. 11. It is seen from the figure that the SiC filled composite shows better dynamic mechanical properties when compared to the unfilled glass polyester composites, i.e. the higher value of storage modulus, loss modulus and damping factors. The storage modulus (E') represents the stiffness of a viscoelastic material. It has been observed, in Fig. 11a and b, that the slope corresponding to the temperature dependent decay of the storage modulus (E') for particulate filled, i.e. 10 wt.-% and 20 wt.-% SiC, is much higher when compared to unfilled glass/polyester composite in the temperature range 27–80°C. However, the storage modulus for 10 wt.-% and 20 wt.-% filler exhibits a sharp decrease in the storage modulus in the range ~60–80°C, whereas in the unfilled composite, it decreases sharply in the range 40–60°C. The loss modulus (E") represents the energy dissipation ability of the material that has theoretical correspondence to the toughness of the composites. The SiC particulate filled



(a) (b)

Fig. 9 Comparison of effective thermal conductivities of FE results and theoretical models for particulate filled and unfilled glass polyester composite. **a** comparison of effective thermal conductivities of FE results and theoretical models (particulate filled composite). **b** comparison of effective thermal conductivities of FE results and theoretical models (unfilled glass polyester composite)



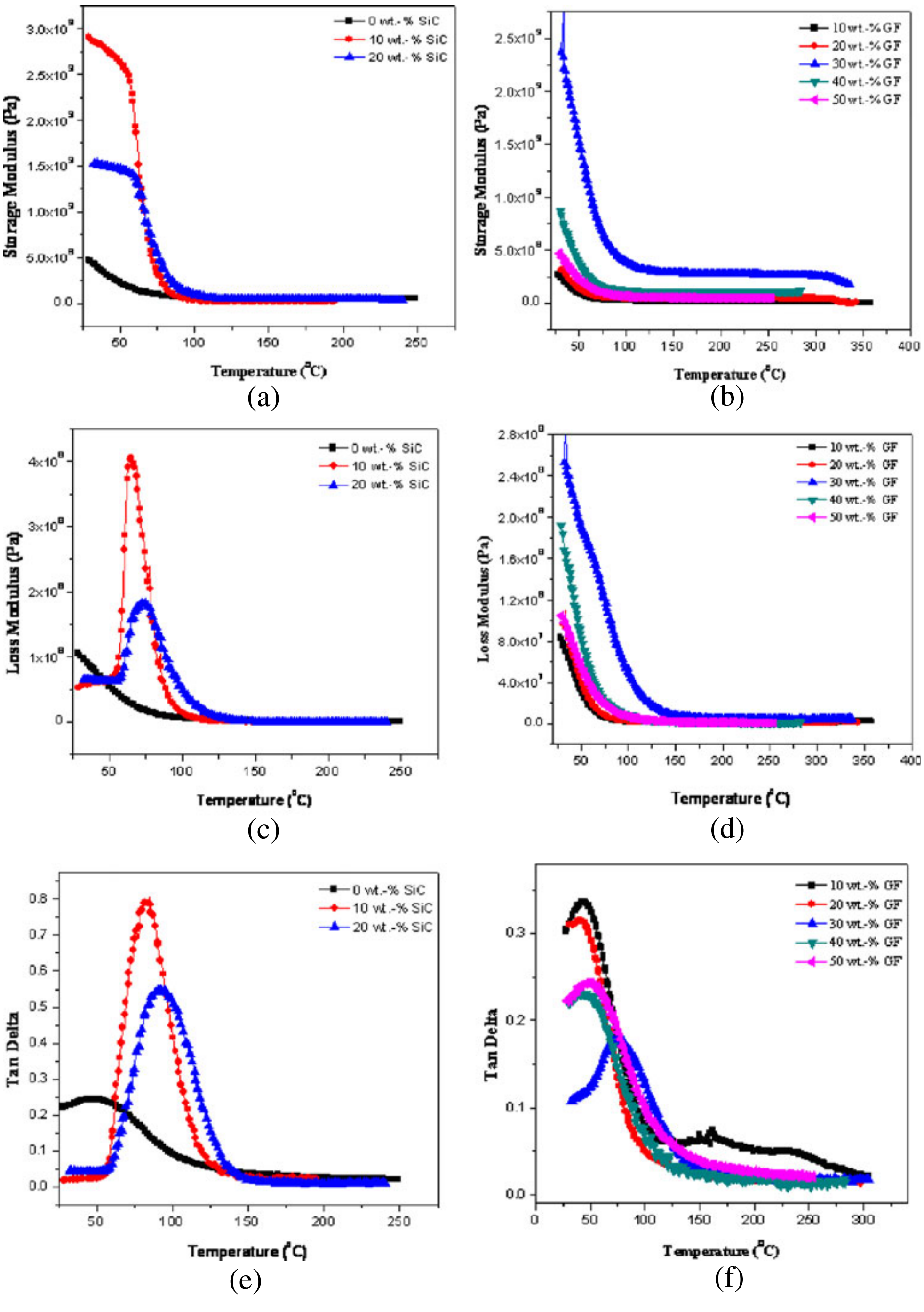
(a) (b)

(c) (d)

(e) (f)

(g)

Fig. 10 Temperature distribution for particulate filled and unfilled glass polyester composite. **a** temperature distribution for 10 wt.-% SiC filled composite. **b** temperature distribution for 20 wt.-% SiC filled composite. **c** temperature distribution for 10 wt.-% fiber loading composite. **d** temperature distribution for 20 wt.-% fiber loading composite. **e** temperature distribution for 30 wt.-% fiber loading composite. **f** temperature distribution for 40 wt.-% fiber loading composite. **g** temperature distribution for 50 wt.-% fiber loading composite



(a) (b) (c) (d) (e) (f)

Fig. 11 Dynamic mechanical analysis for particulate filled and unfilled glass polyester composite. **a** variation of the storage modulus (E') as a function of temperature for particulate filled composite. **b** variation of the storage modulus (E') as a function of temperature for unfilled glass polyester composite. **c** variation of the loss modulus (E") as a function of temperature particulate filled composite. **d** variation of the loss modulus (E") as a function of temperature for unfilled glass polyester composite. **e** variation of the damping parameter (tan δ) as a function of temperature for particulate filled composite. **f** variation of the damping parameter (tan δ) as a function of temperature for unfilled glass polyester composite

composite indicates a higher viscous energy dissipation ability than that of the unfilled fiber reinforced composites. In the case of unfilled glass polyester composite, the glass is regarded as an elastic material which can store energy and avoid energy dissipation. Polyester is considered to be a viscoelastic material; it has both viscosity and elasticity. When the polyester is deformed, one part of the energy may be stored in the form of the potential energy; while another would be dissipated in the form of the heat energy. The damping factor (tan δ) indicates the recoverable energy in terms of mechanical damping or internal friction in a viscoelastic system. The variation of the tan δ of the filled and unfilled glass polyester composites as a function of temperature is shown in Fig. 11e and f. A maximum in the tan δ has been observed for particulate filled (10 wt.-% and 20 wt.-% of SiC particles) occurring at 90°C; whereas for unfilled glass polyester composite, it occurs at 60°C. This means that, with the addition of SiC particulate in fiber reinforced composites, the damping performance of the composite can be enhanced. Usually, the interaction between the polymer matrix and glass fiber is affected by the temperature. At lower temperatures, molecular chains are fixed in a small space, holding the glass fiber. However, at higher temperatures, the molecular chains can move freely in a large space and the interaction between the matrix and glass fiber becomes weak. Damping is the rate at which something dissipates energy; the higher the damping, the higher the rate of energy dissipation. It is reasonable to anticipate that the increased damping in the investigated composites was caused by the energy dissipation of the matrix.

4 Conclusions

The composites were fabricated successfully by using a hand lay-up technique. Comparisons between particulate filled and unfilled glass polyester composite were presented on the basis of mechanical and thermo-mechanical properties. It was noticed that, with an increase in the filler content, the mechanical properties (tensile strength and flexural strength) decreased. In the case of the unfilled composites, an increase in the fiber loading increased the mechanical properties simultaneously. However, in the case of dynamical mechanical analysis and thermal analysis (thermal conductivity), the particulate filled glass polyester composites showed better properties when compared to the unfilled glass polyester composites. This means that, with the addition of hard ceramic fillers, the stiffness, energy dissipation and damping properties of the composite can be increased; whereas due to the high conductive nature of these particulates, the thermal conductivity of particulate filled composites will also increase.

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