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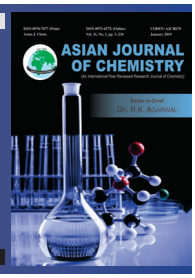

Mechanical and Thermal Properties of Fiber Reinforced Styrene-Ethylene-Butylene-Styrene (SEBS) Composite Doped with CuO, MgO and ZnO Nanoparticles

S. RAVICHANDRAN[1], S. MURUGESAN[1,*] and G. RAMALINGAM[2]

[1]Department of Physics, Sathyabama Institute of Science and Technology, Jeppiaar Nagar, Chennai-600119, India
[2]Department of Nanoscience and Technology, Alagappa University, Science Campus, Karaikudi-630003, India

*Corresponding author: E-mail: binunair.phd@gmail.com

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In the present study, the mechanical properties of nano-metal oxides on styrene-ethylene-butylene-styrene (SEBS) fiber nanocomposites fabricated using thermal compression method. SEBS reinforced fiber nanocomposites exhibit better mechanical properties to develop a polymeric composite which shows various prospective applications in construction of buildings, automotive, aerospace and packaging industries. The mechanical properties of composites are influenced by the adhesion between polymer matrix, fiber and nano filler. It is found that the addition of CuO metal oxides on SEBS-epoxy resin-fiber composite improves the tensile strength whereas it decreases with ZnO nano-phase system.

Keywords: Mechanical properties, Photocatalysis, SEBS-Resin, Composites, Metal oxide powder.

INTRODUCTION

Fibre reinforced polymer composite is a new material in the various applications such as construction, shipping, sports and building industry. Generally, they possess higher specific Young′s modulus and high specific strength enabling them as a valuable material in huge number of industrialized requirements in features. In the context of metal based polymer based composites and their development has resulted from an attempt to achieve an improvement in structural efficiency, reliability and overall performance through either reductions in weight or increases in strength to weight ratio of the material. A reduction in material density and mass can be directly translated to reduction in structural weight. This leads to the aerospace industry to develop new composite materials with combinations of low density, hardness, improved stiffness and high strength as alternatives. These materials have enhanced properties than the existing high strength aluminium alloys. Automation along with high standard for filament and polymer matrix materials will decrease fabrication costs and weight of the material [1,2]. Styrene-ethylene-butylene-styrene (SEBS) is a compound to produce polymer composite materials which improve the grip, feel, appearance, shape and convenience of various applications. SEBS improves performance in pressure sensitive and other adhesive applications. The fiber reinforced polymer nanocomposite material is fabricated for their good mechanical properties, light weight, high strength, modulus of elasticity, low density, relatively high impact strength, good dynamic strength and cracks growth resistance, good oxidative, corrosion resistance, and favourable cost of material and productions [3,4].

The direction of reinforcing of fiber provides the strength and stiffness of the material. The reinforcement becomes harder, stronger and stiffer than the matrix in the most of the cases. The reinforcement is usually a fiber or a particulate. The dimensions of particulate composites approximately equal in all directions. They may be spherical, platelets, disc or any other regular or irregular geometry. Fibers produce high-strength composites because of their less diameter. They contain fewer defects when compared to the other material produced in bulk. But generaly, the smaller the diameter of the fiber, the higher its strength. The type and the quantity of reinforcement results the final properties of composites. Fibre reinforced polymer composite material has been a tremendous advancement in recent days. Polymeric composites have many advantages as higher fatigue strength, higher corrosion resistance and lower weight [5-7]. Different nano fillers have been dispersed in to

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the polymer-matrix composites. These fillers include oxides, carbide and nitride materials, which are thermally conductive but they are electrically insulator [8]. The effect of SEBS isn't exactly great, when it is utilized as a polymer lattice. One of the tendencies is to enhance the impact energy of SEBS without a reduction of the viscosity. Rubber-toughened plastics have been widely used to improve the impact properties of materials. This type of polymer matrices are having two-phase system. One is rubber particles are dispersed in a polymer matrix and another is dispersed particles act as stress concentrators and inducers of energy dissipation by both crazing and shear yielding of the composites. To solve these problems, a rigid-inorganic-nano filler has reinforced by toughening method.

Dispersion of nanoparticles and their homogeneous distribution is an important factor affecting the properties of a polymer nano-composite, apart from the type and properties of nanofiller and polymer types. These conditions are difficult to technically fulfil because of their small size, nanoparticles have a strong tendency to form agglomeration, bounding mainly by van der Waals forces. Nanoparticle dispersion increases the adhesiveness of compositions with polymers. Semiconducting nanocomposites containing SEBS are becoming increasingly important. Suitable polymer can be utilized to achieve dispersion in the resin of nanoparticles created in the process of disintegration of the crystalline structure of semiconductors. Epoxy resin as one of the most commonly-used thermosets, has been widely applied in various engineering applications due to its excellent mechanical properties, chemical resistance and electrical insulation. This strategy for assembling nanocomposites is valuable since it permits keeping away from vitality serious procedures of acquiring nanoparticles, agglomeration and security issues.

In the past two decades, a wide range of research has been carried out to study the preparation of polymer nano-composites, their structure-property relationship and characterization of composites. Scientists discussed the polymer nanocomposites by considering various potential nanofillers such as carbon nanotubes, silica, talc, nano-biofillers, layered silicates and natural fibers. Recently, many researchers also focussed on nanoparticles as fillers to modify epoxy to prepare thermal conductive composites. Inorganic compounds such as aluminium oxides, zinc oxides, silica oxides, *etc*. were used as the fillers of fabric composites and polymers to improve the thermally conductive property [9,10]. In this study, mechanical and thermal behaviour of styrene-ethylene-butylene-styrene (SEBS)-glass fiber with nano metal oxide hybrid composites were characterized and discussed. Polymer materials are usually considered as thermal insulators. They have low thermal conductivity. However, studies have shown that certain polymers have high thermal conductivity. Herein, the experimental achievements of thermal transport and mechanical properties in polymer materials and their nanocomposites are outlined. Also, it is has been observed from the literature that a very less number of work is carried out on mechanical properties and thermal conductivity behaviour of SEBS composites. Thus, the aim of the present work is to study the effect of different filler loading on mechanical properties and thermal behaviour.

EXPERIMENTAL

Sampling: High pure styrene-ethylene-butylene-styrene (Kraton Ltd., Mumbai) and AR grade 99.5 % pure toluene was used to make the composite material. Resin (LY 556) and 10 % of hardener (HY 917) was added with 97 % pure polymer matrix. High pure bidirectional glass fiber (Mat-WRM 610 GS) material was used as a reinforcing material.

Copper(II) oxide nanopowders were prepared by sol-gel method. The aqueous solution of $CuCl_2 \cdot 6H_2O$ (0.2 M) was prepared in cleaned bottom flask. Sodium hydroxide (8 mL) is added to above solution till pH reached to 6-8. The colour of the solution turned from blue to black immediately and the large amount of black precipitate was formed. The precipitate was centrifuged and washed 3-5 times with distilled water. The obtained precipitate was dried in air for 4 h. CuO nanopowder was obtained and used for the characterization of the material.

Similarly, magnesium oxide and zinc oxide nano crystals are prepared by sol-gel process as usual method. The reaction mixture was dried at room temperature, centrifuged and washed with distilled water and ethanol for removal of impurities. The final product was dried at 100 ºC for 4 h and calcinated at a particular temperature [11].

Fabrication of fiber reinforced polymer metal oxide composites: The SEBS/resin/glass fiber composites were prepared with different nano-metal oxides like ZnO, CuO and MgO. SEBS was first dissolved in toluene for 30 min, then nanoparticles and hardener was mixed by magnetic stirrer for 10 min. The fabrication of composites is carried out through the hand casting technique. Glass fiber (WRM 610 GS woven roving mat) bi-directional, is reinforced with SEBS/resin polymer matrix with nanopowder at 80 ºC and pressure of 0.2 bar for 2 h. Finally, the fiber reinforced polymer laminate is prepared with the thickness 2.0 mm and curing the material for 24 h [12,13]. Three different types of composites (Table-1) have been fabricated with three different types of nano metals such as ZnO, MgO and CuO. Each composite consisting of 20 wt.% of nanophase materials. The cast of each composite is cured under a load of about 25 kg for 24 h before it removed from the mould and the same is again cured in the air for another one day after removal. CuO, MgO and ZnO with glass-fiber composite materials of dimensions 250 mm × 25 mm × 2.5 mm were prepared for mechanical testing. Testing of samples for mechanical properties was done on computerized universal testing machine (UTM) by compressing moulding (Model-DARRAGON, Type-DA100, 100-T).

TABLE-1
COMPOSITION OF FRP NANOCOMPOSITE MATERIAL

Sample	Composition
1	SEBS + 60 Wt % glass fiber + 20 Wt % CuO
2	SEBS + 60 Wt % glass fiber + 20 Wt % MgO
3	SEBS + 60 Wt % glass fiber + 20 Wt % ZnO

RESULTS AND DISCUSSION

The tensile test in longitudinal direction was performed on all three specimens of each FRP nanocomposites materials.

The mechanical analysis is very important tool to study the behaviour of FRP nanocomposite. The mechanical properties of polymer nanocomposites depend on the nature of polymer matrix, orientation of fiber reinforce, distribution of nano-crystals and the inter phase region between fibers and matrix. Tensile strength is the maximum stress that a material can withstand while being stretched before breaking and it is used in structural applications [14,15].

The properties of composites depend upon the dispersion, aggregation and interaction of the particles and mainly two factors influencing the tensile strength of the composites *viz*., (a) reinforcing particles increase the strength of the material by simple load transfer, which is dependent on the bond integrity at the particle/matrix interface and by retarding dislocation motion; and (b) inhibition of plastic relaxation at the particle/matrix interfaces [16-18].

The values of maximum force (P_{max}), tensile strength (R_m) and modulus of elasticity (E) were measured and the values are listed in Table-2. It can be observed that the addition of nano metal oxide powder to polymer matrices can significantly influence their mechanical properties. Maximum force at break (P_{max}), modulus of elasticity (E) and tensile strength (R_m) of CuO composite is more than MgO and ZnO composite materials and the variations are shown in Fig. 1.

TABLE-2
MECHANICAL PROPERTIES OF FRP OF SEBS COMPOSITE WITH NANO PHASE MATERIALS

Type of specimen	Max force at break (%)	Max force at break P_{max} (N)	Tensile strength (R_m) Mpa	Modulus of elasticity (E) GPa
SEBS with CuO	302.61	635	108.08	2.160
SEBS with MgO	110.99	550	69.33	1.980
SEBS with ZnO	322.66	250	52.24	1.689

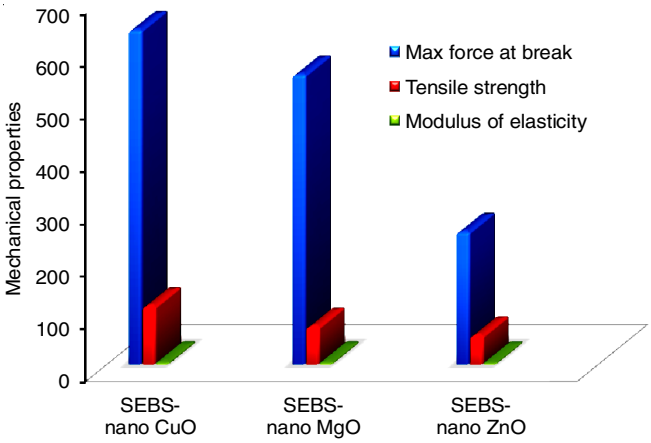

Fig. 1. Variation of tensile strength, modulus of elasticity and strength of FRP with nano phase materials

The tensile modulus and tensile strength of FRP composites were improved significantly in the presence of nano metal oxides. The stiffness of SEBS-glass fiber composite with CuO nanophase material is remarkably higher than that of the other composites. This may be attributed to the stiffness and reinforcing effect of glass fiber and nano metal oxides. It can be observed from Figs. 2 and 3 from which the presence of fiber

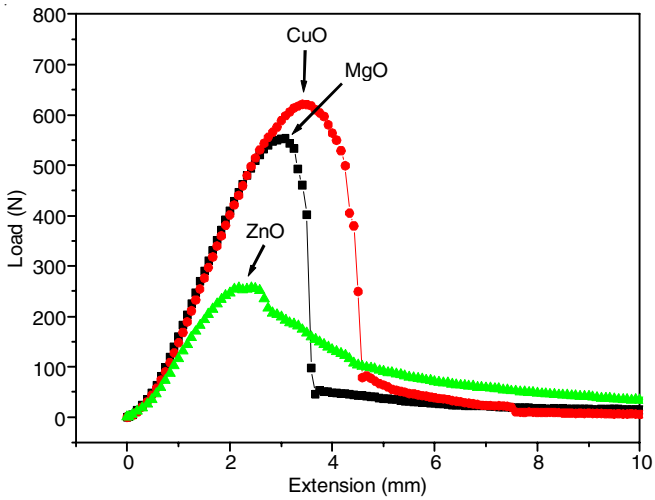

Fig. 2. Graph between the load and extension of different SEBS polymer nanocomposites

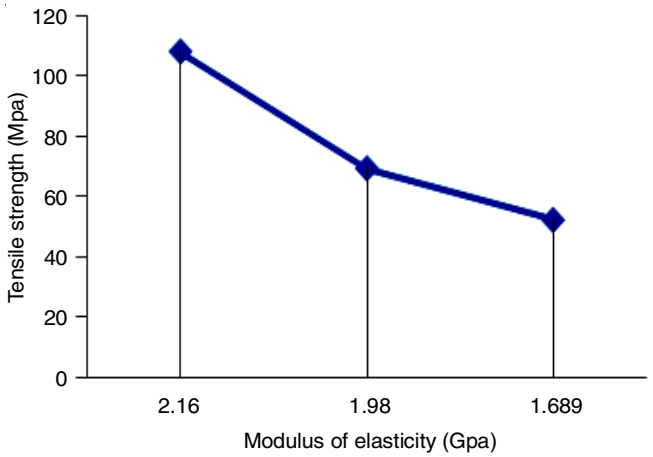

Fig. 3. Variation of tensile strength with modulus of elasticity of SEBS-polymer nanocomposites

resulted in a marked anisotropy of tensile properties. According to Kornmann *et al*. [19], epoxy samples showed a large plastic deformation with more than 5 % strain and the nanocomposite samples appeared more brittle but their Young′s modulus was higher than that of epoxy matrix. The nanophase crystals adhere to the surface of glass fiber and subsequently contribute to the improvement in interfacial bonding of the resultant polymer composites. It is well documented that good interfacial adhesion can provide better stress transfers to the glass fiber. This will improve the modulus and strength of the respective composites [20,21].

The mechanical properties of composites are improved by doping of nano-metal oxides. The inclusion glass fiber leads to decrease in the elongation of the material. Tensile strength of SEBS-glass fiber composites with zinc oxide nanoparticles is decreased due to the weak bonding interaction between the matrix and nano-phase materials. But, it has low tensile modulus with a breaking load of 250 N. It is very lower for SEBS-glass fiber ZnO nanocomposites. The decreasing trend was observed in the elastic modulus of composites materials. Loss of modulus is the capacity of material to dissipate energy, when it is stressed and this is due to the mechanical interlocking with bulk chains. The lower mechanical behaviour of zinc oxide nanocomposites

may be due to an imperfection in the interface nanocomposite surface and agglomeration of zinc oxide nanoparticles. Ash and Rogers [22] showed that PMMA-Al_2O_3 system of composite materials has 15 % decreased elastic modulus due to the reinforcement.

Thermal conductivity: As electronic devices tend to become slimmer and more integrated, heat conduction become a central task for design and application of the devices. Similar issues are faced in several other applications, including electric motors, generators and other devices, heat exchangers in power generation, automotive applications, *etc*. Metallic materials are used as heat dissipation materials, but there have been many attempts to replace the metallic materials with highly conductive polymer based composites due to their light weight, corrosion resistance, easy processing and lower production cost. Thermally conductive polymer based composites are prepared by the incorporation of conducting nano fillers.

The outstanding thermal conductivity of reinforced composite makes them a promising candidate to obtain highly thermal conductive polymer based composites. The thermal conductivity of composite depends on their morphology, size and impurities. To obtain well-structured composites with good thermal conductivity, purification are necessary. Thermally conductive polymer composites offer new dimensions for replacing metal parts in several applications. Current interest to improve the thermal conductivity of polymers is focused on the addition of nanofillers with high thermal conductivity. The volume fraction and fiber distribution are to be more important factor than selection of polymer materials for enhancement thermal property. Thermal conductivity of composite is a function of temperature and fiber orientation. Phonons are the quanta frequency of atomic vibrations. Phonons transfer heat energy through interactions with themselves and sub-atomic particles [23]. Phonon scattering also occurs in the multi-phase polymer nanocomposite material and it is propagate from one phase to another [24]. Particles′ nature, size, shape and geometry are also considered in the thermal conductivity of composites. Following equations are used to measure thermal conductivity of fibre reinforced polymer composite materials.

$$q = \frac{k(T1 - T2)}{L} \quad (1)$$

$$K = \frac{L}{R} \quad (2)$$

$$R = \frac{(T1 - T2)}{q} \quad (3)$$

where q is the heat flux (W m^{-2}), k is the thermal conductivity (W m^{-1} K^{-1}), (T1-T2) is the difference in temperature (K), L is the thickness (m), and R is the thermal resistance of FRP nanocomposite materials (m^2 K W^{-1}). Several researchers reported on the improvement of thermal conductivities of polymers by nano phase materials. The prepared metal oxide nanocomposites were tested with the conductivity range of 0.1 to 100 W/mK and the thermal conductivity of polymer composite is given in Table-3.

Thermal conductivity of fillers is affected by their crystal structure, impurities, structural imperfections, phonon scattering events, *etc*. in polymer composites [28-30]. The behaviour of thermal conductivity of composites is depends on the thermal conductivity of fiber and nano-fillers. The incorporation of nanoparticles improved crystallinity and thermal conductivity simultaneously [31-33]. Thermal conductivity of SEBS-glass fiber composite increases with CuO and is almost the same for MgO and ZnO nano-fillers is shown in Fig. 4. Different nanoparticles have been used to improve thermal conductivity of polymers.

TABLE-3
THERMAL CONDUCTIVITY OF SEBS COMPOSITE REINFORCED WITH GLASS FIBER WITH NANO PHASE MATERIALS

Type of specimen	Conductivity (W/mK)	Conductivity (W/mK)	Ref.
SEBS with CuO nano particles	0.198	0.17 (Epoxy resin-AIN)	[25]
SEBS with MgO nano particles	0.176	0.17 (Epoxy resin MgO)	[27]
SEBS with ZnO nano particles	0.177	0.171 (PMMA/ ZnS)	[26]

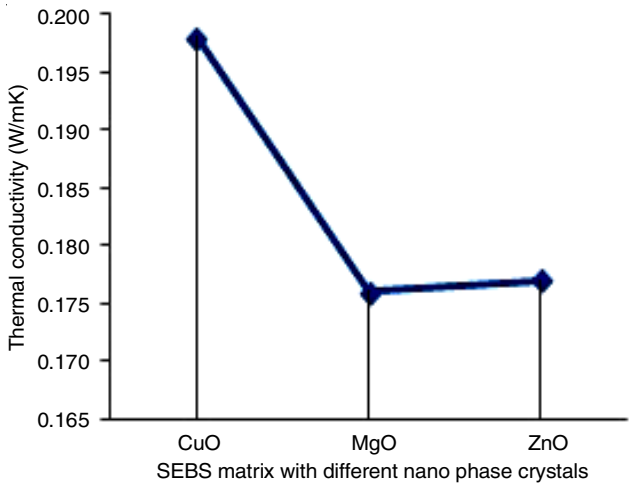

Fig. 4. Variation in thermal conductivity of SEBS-GF composite with nano metal oxides

Conclusion

Effect of nano-materials on the mechanical properties and thermal conductivity of fiber reinforced SEBS-resin composites has been studied. In the present study, glass fibre reinforced styrene-ethylene-butylene-styrene (SEBS) polymer composite with CuO, MgO and ZnO nano materials were fabricated for measuring tensile strength, modulus of elasticity and thermal conductivity. The properties of fiber reinforced polymer matrix have a significant influence on the mechanical properties of nanocomposites. The highest tensile strength was obtained due to incorporation of CuO nanoparticles. It is due to interfacial bonding between SEBS-glass fiber and nano-phase system. In general, the increase of filler increases thermal conductivity of FRP nanocomposite materials. Fiber alignment in the heat flux direction is also shown in a significant change probably increase in thermal conductivity. Mechanical and thermal properties of glass fiber composites are also affected by fiber/matrix interface. But over all nano-CuO/epoxy composites display better mechanical properties as compared to other nano polymer matrix. Doping of nanoparticles is affecting the thermal conduc-

tivity also. The incorporation of CuO nanoparticles is further improving the thermal properties of composites. SEBS-glass fiber with CuO nano phase system has good conductivity than other composites reinforced polymer composites with fiber alignment provided large increases in the thermal conductivity.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this article.

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