



Stress - Strain Analysis and Deformation Behavior of Fiber Reinforced Styrene - Ethylene - Butylene - Styrene Polymer Hybrid Nano Composites

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Abstract

Composite materials are replacing traditional materials, because of their superior physical and mechanical properties. The main objective of the present work is to perform stress-strain analysis on Styrene-Ethylene-Butylene-Styrene (SEBS) - epoxy resin composites under reinforcement of fibers and dispersion of CuO, ZnO, MgO, SiO and TiO₂ nano metal oxides. Combination of glass fiber with particle reinforcement (GFRPs) applications have increased in recent days. In this study, glass fiber reinforced epoxy composites with different nano metal oxides are developed by compression molding method and their mechanical properties such as breaking load, elastic limit, plastic range and fracture point are evaluated. The results indicate that the incorporation of nano phase material with glass fiber can improve the properties of composites.



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Introduction

It is important to calculate the strain and stress distributions to know the mechanical behavior of composites. Composite applications are mostly found in automotive, aeronautical and sports arena. Moreover, they are used in making wind turbines, storage tanks, machinery parts and medical equipment. They become the first choice of the industries because of their unique mechanical

and physical properties. Their composition, their structures and the distribution of the phases define the properties of composites. Glass fiber reinforced with epoxy composites gives an attractive combination of physical and mechanical properties.^{1,2} The mechanical properties of the composites can be improved by reinforcing various nano filler materials. These nano fillers act as additional reinforcing components in the composites. The properties of

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these composites depend on the type, shape and size of the filler material.^{3,4}

Failure mechanism of the polymer composite material is a recent field of study and also one of the important points to discuss in material engineering. Stress-strain analysis is the recent ongoing studies in composite materials to find their breaking points. It is found that the failure mechanism depends on the applied stress. Also, the direction of applied stress is relative to the direction of fiber reinforced in the matrix. Hence it is necessary to study the stress component and its analysis of the composite materials. The properties of polymer composites depend on the constituent material, fiber reinforcement, polymer matrix, size of the fiber and its geometry.

Fiber reinforced polymer (FRP) composites are materials composed of a polymer matrix combined with fiber reinforcements. Polypropylene is one of the toughest thermoplastic materials. Due to its low cost, low density, high heat distortion temperature, process ability and extraordinary versatility in terms of tailored properties, it is widely used. Tensile loading of the specimen have produced different failure types and researchers have studied the inhomogeneity of the matrix.⁵ Research interest has been focused towards fiber-reinforced polymeric composites as these composite materials exhibit excellent mechanical properties. Parvanesh *et al.*⁶ studied the mechanical behavior of PVC nano composites. They have studied the Young's Modulus and tensile strength of polymer composites and the result suggested that good stress transfer can be obtained at an amorphous interface, depending on the polymer.

As a composite material is subjected to various stresses, the load is transformed from the polymer matrix to the fiber through the interfacial bonding interaction. The reinforcing composites may be in the form of fibers, particles or flakes. Continuous matrix materials are generally used in composites.⁷ It was found that the adhesion bond of the resin matrix increases the mechanical properties of polymer composites. Jagannatha and Harish⁸ have studied the effect of glass and carbon fiber reinforced with epoxy polymer matrix. They studied the breaking load and tensile properties of fiber reinforced composites. They concluded that addition of carbon fiber reinforcement in the polymeric composite enhanced the ultimate tensile strength, yield strength and maximum load of the composite. Zhang *et al.*⁹ have also studied the mechanical behavior of hybrid carbon/glass reinforced composites and they compared the flexural stress-strain data of different composites and they concluded that the composite system exhibited more failure under the flexural loading. Jarukumjorn Kasama, Suppakarn Nitinat and W.H. Leonard *et al.*¹⁰⁻¹¹ investigated the mechanical properties and fracture behavior of glass fiber-reinforced polyester composites. The comparative investigations of these new nano composites were performed in order to estimate their competitiveness.

Nano metal oxide reinforcement also controls the strength and stiffness of fiber composites. Current fracture mechanism based on stress-strain analyses and the mechanical behavior are found to be suitable for describing the behavior of composites at different loads. In the present work, the elastic ranges, plastic ranges, and deformation/fracture points are measured by the stress-strain analysis of

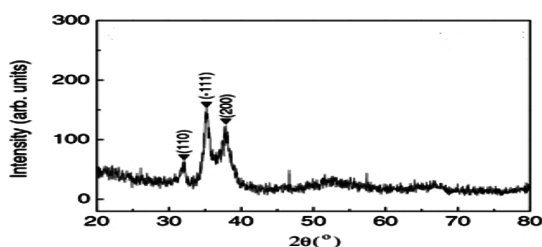


Fig. 1: (a) X - Ray diffraction patterns of CuO nanoparticles

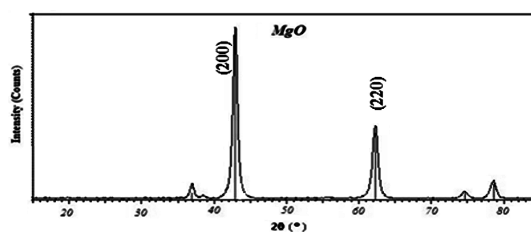


Fig.1: (b) X - Ray diffraction patterns of MgO nanoparticles

Styrene-Ethylene-Butylene-Styrene (SEBS)-epoxy resin polymer composites reinforced with CuO, ZnO, MgO, SiO₂ and TiO₂ nano phase materials. It is found that the composite in each case showed a nonlinear elastic relation between stress and strain and its behavior varies depending on the reinforcements.

Materials and Methods

Materials

Commercial styrene-Ethylene-Butylene-Styrene (SEBS), epoxy resin (LY 556), hardener (HY 951), glass fiber (MATWRM 619 GSM) were used to make a composite. Epoxy Resin is a base material on the glass plate, which is purchased from M/s. Om Sakthi Techno Services. SEBS was used to make composite film, which is purchased from M/s Kraton polymers. Mumbai. Nano powders were synthesized by sol-gel method in our physics Laboratory, Sathyabama University. Bidirectional Glass fiber- WRM 610 GS woven roving mat was used for reinforcement in polymer matrix.

Synthesis of Nano Phase Material by Sol Gel Method

CuO nano-powders were prepared by sol-gel method. Aqueous solution of CuCl₂·6H₂O (0.2 M) was prepared in clean round bottom flask. 8 Ml NaOH is added to above solution till the pH reached to 6 - 8. The color of the solution turned dark blue immediately and large amount of black precipitate was formed at the bottom of the flask. The precipitate was centrifuged and washed 5 times with distilled

water. The obtained precipitate was dried in air for 4h. CuO nano powder was obtained and it was used for the characterization of the material.

MgO nano crystals were prepared by reaction of aqueous solution of 0.1 M of Mg(NO₃)₂ and 0.51M NaOH using deionized water. White precipitation was induced by adding NaOH into the Mg(NO₃)₂ solution by continuous stirring for 3 h in room temperature. The resultant mixture was cooled to room temperature, centrifuged and washed with distilled water and ethanol for removal of impurities. The final product was dried at 100 °C for 4 h and calcinated at a particular temperature.

Size of the particles were measured by XRD analysis using the Debye-Scherrer equation and average size of the particle were confirmed between 45 - 65 nm. XRD pattern of CuO and MgO are given in Fig.1 (a) and 1(b), respectively.

100 ml of Zn(NO₃)₂·6H₂O aqueous solution and 100 ml of NaOH aqueous solution were mixed to obtain Zn(OH)₂ precipitate. The precipitate was separated from the solution by a centrifuge at 3000 rpm for 5 min. The obtained Zn(OH)₂ was dispersed in distilled water and was again separated by a centrifuge. This procedure was repeated 3 times, and the impurities in the precipitate were removed. The Zn(OH)₂ was then dispersed in 50 ml of H₂O₂ aqueous solution whose concentration was 1 mol/l. The dispersed solution was heated at 348 K in a closed glass vessel

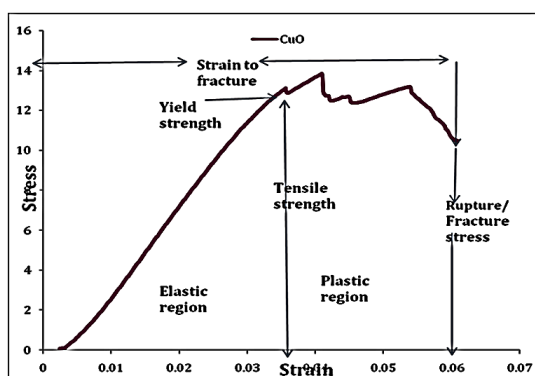


Fig. 2: (a) Stress-Strain diagram for SEBS-Epoxy resin-Glass fiber - composites with CuO metal oxides nano phase reinforced material

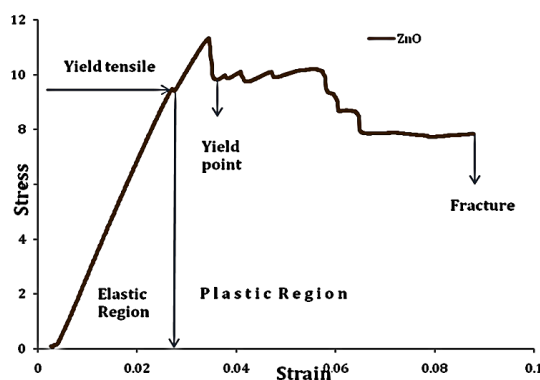
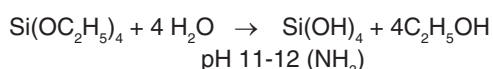


Fig. 2: (b) Stress-Strain diagram for SEBS - Epoxy resin-Glass fiber - composites with ZnO metal oxides nano phase reinforced material

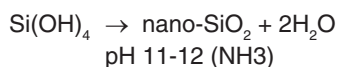
(200 ml). The resultant solution was a translucent sol of the zinc peroxide nanoparticles. The obtained sols were dried at 348 K for 6 h. The obtained powder was kept at 453 K temperatures for 2 h to prepare ZnO particles.

The TiO₂ powder was prepared by sol-gel process using Ti(OC₃H₇)₄ and ethanol as used as a solvent. After dissolution of 11.4 ml of Ti(CO₃H₇)₄ in ethanol solvent, a solution of 0.75 ml water in ethanol was mixed and 1.5 ml C₄H₁₁NO₂ added dropwise method under continuous stirring to realize a transparent sol gel. The sol was digested for 24 h and dried subsequently at 100° C for 8h and calcinated for 2h and cooled.¹²⁻¹⁵

Nano SiO₂ was prepared through hydrolysis of Si(OC₂H₅)₄ via the following route



Followed by poly-condensation of Si(OH)₄



Fabrication of Nano Composites

To fabricate the composite film, commercial bi-directional glass fiber, epoxy resin and styrene-ethylene-butylene-styrene were used. Resin was coated on the surface of a glass plate which was used for casting the composite. Nano powders were

weighed and mixed with SEBS in a particular ratio uniformly by magnetic stirring for 1 h continuously. After the uniform mixing with the resin, nano particles were dispersed in solution. The above prepared solution was used for making the film. WRM 610 GS woven roving mat-bi directional glass fiber was reinforced on the film and again the SEBS with nano powder solution was poured on the film. Finally, the fiber reinforced polymer film was prepared with the thickness of 4 mm and curing was done by keeping the material for 24 hrs. During this process, pressure is applied on the composite film (50 Bar) at 80 °C. The final laminates consisted of resin, glass fiber and nano crystals dispersed polymer matrix.

Tensile Test

Test specimens were taken from the composite sheets. Unidirectional tensile specimens were cut out of the laminates in both fiber and matrix directions according to ASTM D3039. Breaking load of different composites were determined from the stress-strain diagram. Mechanical tests often involve the deformation or breakage of samples of material called test specimens. The specimen size was 260 mm × 24 mm × 4 mm. The different composite specimen samples were tested in the Universal Testing Machine (UTM) and in each case the material was allowed to break to find the ultimate tensile strength.

Results and Discussion

The mechanical properties of a SEBS - Epoxy resin with nanometal oxides are given in Table.1.

Table 1: Experimental data of Maximum Extension, Tensile strength, Elongation and Young's modulus of Styrene - Ethylene-Butylene-Styrene (SEBS) - Epoxy composite Reinforced with different nano metal oxides.

Polymer matrix	Reinforced Nano metal oxides	Max. Force (K/N)	Distance (Fm)	Maximum Extension (mm)	C/S Area	Tensile Strength mm ²	Elongation (%) (kN/mm ²)	Young's Modulus (kN/mm ²)
SEBS	MgO	19.32	7.3	0.592	122.4	0.158	5.533	13.572
SEBS	ZnO	15.74	5.8	0.398	123.75	0.127	3.867	13.68
SEBS	CuO	16.25	7.5	0.438	125.6	0.173	5.35	14.211
SEBS	TiO ₂	15.66	8.7	0.308	114.4	0.137	8.2	15.382
SEBS	SiO ₂	17.2	8.23	0.44	122.3	0.29	7.7	13.433
SEBS	Epoxy Resin	15.52	5.72	0.411	122.5	0.121	4.11	13.699

Young's modulus, also known as the tensile modulus or elastic modulus, is a measure of the stiffness of an elastic material and is a quantity used to characterize materials. Young's modulus may have different values depending on the direction of the applied force with respect to the structure. As tensile stress is applied to the composite material, elongation of a material takes place. Elongation is inversely proportional to hardness, tensile strength and elastic modulus of the material. That is, greater the hardness, tensile strength, and modulus, lesser will be the elongation under stress and it takes more force to stretch a hard material, which is having high tensile strength. Stress-strain curve is drawn to find the ultimate tensile strength and elastic modulus. In general, the stress in a composite material is defined as the change in the internal energy with respect to the strain per unit volume.

The stress-strain graph of the composite shows a ductile/brittle nature. The effect of strain rate on stress-strain behavior of composite material is measured at room temperature and it shows that the mechanical properties of the material strongly depends on the rate of strain. The variation of stress-strain for the glass reinforced SEBS-polymer doped with CuO, ZnO, MgO, SiO₂ and TiO₂ metal oxides nanophase material are shown in Fig.2(a) - 2(e). When a polymer composite has been subjected to tensile test, it passes various stages before fracture.

The stress-strain curves show considerable nonlinearity before reaching the breaking stress, i.e. they show apparently-brittle structure. Each curve shows a maximum stress, which is assumed to be the flexural strength of the material. This should be due to strong adhesive force between the fibers and polymer matrix.¹⁶ The result shows that the composite doped with TiO₂ nanoparticles (NPs) has low tensile strength as compared to other metal oxide reinforcements and that the stress - strain rate is high in the case of MgO doped material. But the composite reinforced with SiO₂ NPs is perfectly linear in variation and it shows characteristics of brittle nature of material. The nanometal oxides and fibers provide bonding sites to the polymer matrix so that the entire load could be transferred to the fibers and prevent separation between the polymer surfaces and matrix.

Fig.3 shows the variation of breaking load with different nanophase materials. From the above graph, it is understood that the SEBS - Epoxy with SiO₂ composites have highest value while the composites reinforced with TiO₂ & ZnO have lowest value of breaking loads. Due to the reinforcement of the SiO₂ nano particles, more hydrogen bonds are formed between SiO₂ and matrix and it is concluded that, the size of the nanophase material can directly affect the behavior of composites. These findings are consistent with earlier researchers, who reported

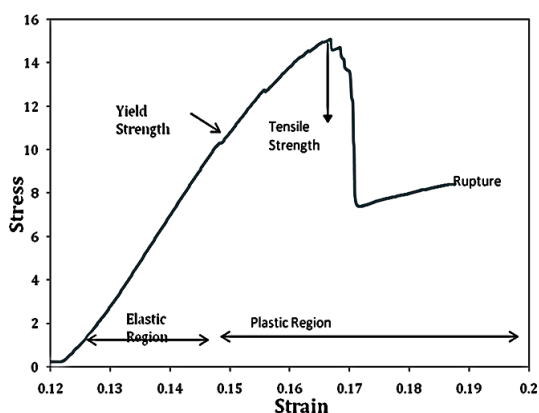


Fig. 2: (c) Stress-Strain diagram for SEBS - Epoxy resin - Glass fiber - composites with MgO metal oxides nano phase reinforced material

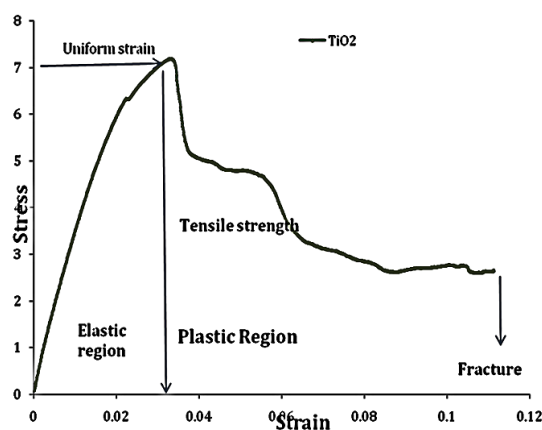


Fig. 2: (e) Stress-Strain diagram for SEBS - Epoxy resinGlass fiber-composites with TiO₂ nano phase reinforced material.

mechanical property has enhanced by addition of various nano fillers in polymer composites.¹⁷⁻¹⁸

Effect of Fiber and Metal Oxide Reinforcement on Deformation

Nanocomposites with CuO, ZnO, and TiO₂ metal oxides had similar stiffness as compared to other materials. The composite with MgO has high stress-strain rate and it has high tensile strength at the stress rate of 14 mps, while the composite with SiO₂ has linear variation and it shows a brittle nature. This tensile strength occurred at the stress rate of 19 mps. This type of behavior is achieved only due to the reinforcement of nano phase material as they could provide bonding sites to the polymer matrix.

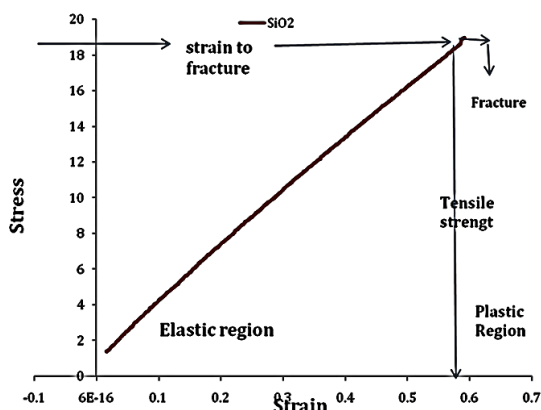


Fig. 2(d): Stress-Strain diagram for SEBS - Epoxy resin Glass fiber-composites with SiO₂ metal oxides nano phase reinforced material

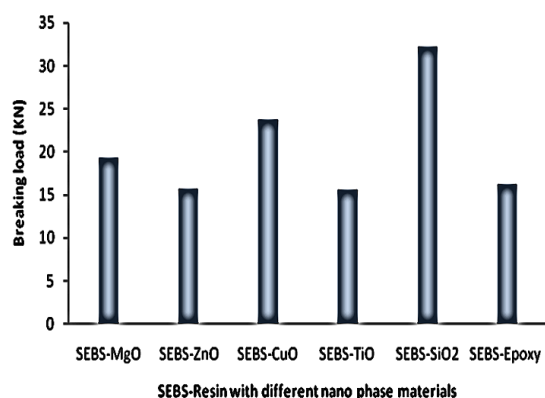


Fig. 3: Graph shows the variation of Breaking Load with different nano phase materials.

There are some abnormal changes in the tensile strength and Young's modulus of the polymer composites that have been observed due to the reinforcement of CuO NPs. It is also observed that elongation has also increased due to dispersion of nano material. This is due to the effect of CuO nano fillers as the fillers acts as a plasticizer¹⁹ whereas MgO are multipolar nano particles. More variations in elongation and tensile strength were observed due to polar attractive forces and van der Waals bonding interactions between the fillers and polymer matrix. Tensile strength is only slightly increased due to TiO₂ NPs reinforcement as compared with the ZnO reinforcements. This is probably due to the stronger particle-particle interactions TiO₂ NPs with respect to their bonding to the matrix, leading to agglomeration whereby mechanical properties of the composites were reduced. This is also dependent on the formation of chain entanglement in the matrix.²⁰

The stress-strain curves of CuO, ZnO and MgO and TiO₂ bearing materials show similarities with ductile polymers. After reaching the yield point, the stress drops to the draw stress (σ_d) remains constant in each material while the neck propagated through the entire length of the specimen till the fracture point. However, the variation of fracture strain depends on the nature of the nano fillers. The drop in fracture strain is caused by the transition from ductile to quasi brittle fracture. The draw stress depends on adhesion between the polymer and the particles.²¹ Variations of fracture point of different composites are shown in Fig.4. This variation of mechanical properties of

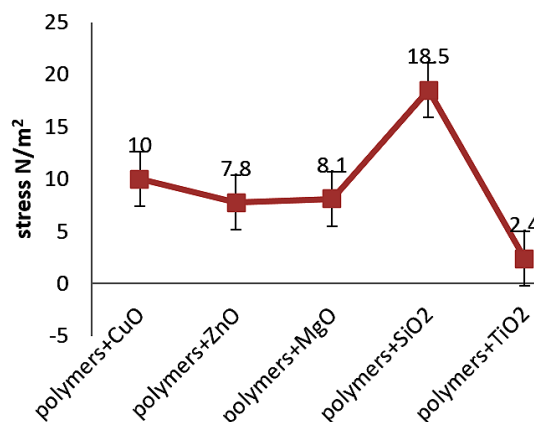


Fig. 4: Graph shows the variation of fracture point of different polymer nano composites.

composites depends mainly on the microstructure and the interface morphology of the polymer matrix and nano materials which includes the interfacial bonding, size and spatial distribution of the particles into the polymer matrix.²² When there is poor bonding interaction between the polymer matrix and particles, the composite becomes brittle as the applied load may not be transferred to the reinforcements.²³

Conclusion

The stress-strain characterization and failure pattern of glass fiber reinforced- SEBS laminates with different nano phase materials under different loading conditions have been investigated. The stress-strain behavior of laminates under different loads are measured until breaking point. It varies depending on the nano filler reinforcements. It is concluded that nano metal oxide reinforcements also controls the strength and stiffness of composites. Young's modulus of SEBS composites increases with TiO₂ nano particles while SEBS-with SiO₂ nano phase material has high tensile strength and low Young's modulus. Elastic region of the composites varied due to the reinforcement of nano metal oxides

and it was measured as 0.01-0.035, 0.01-0.023, 0.12-0.147, 0.1-0.6, 0-0.03% for CuO₂, ZnO, MgO₂, SiO₂, and TiO₂ respectively. Peak stress and strain increases with increasing SiO₂ nano content. It is attributed to the effects of nano phase material on the plasticizer of composites.

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