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Tensile and Viscoelastic Properties of Epoxy - Carbon Nanotube Nanocomposites

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ABSTRACT

In this study, multi-walled carbon nanotube (MWCNT) - epoxy nanocomposites were prepared using sonication method. Different percentages of MWCNTs (0.1, 0.2, 0.5, and 1.0 wt.%) were randomly dispersed in epoxy resin. Static tensile and viscoelastic property were characterized on both epoxy and MWCNT-epoxy nanocomposites. The dispersion of MWCNT in epoxy Shape Memory Polymer (SMP) was evaluated using field emission scanning electron microscopy (FESEM). Tensile strength and failure strain have increased significantly by the addition of CNT. In addition, nanocomposites containing 0.5 wt.% MWCNT shows the best storage modulus value. FESEM images show that MWCNTs were uniformly dispersed and distributed.

Key words: *Tensile, Epoxy, Multi-walled carbon nanotube, Viscoelastic, Nanocomposites.*

1. INTRODUCTION

During the past several years, tremendous efforts have been made to modify epoxy resins for particular applications in high performance industries by adding fillers/nanofillers [1,2]. Owning to their exceptional properties, carbon nanotubes (CNTs) are considered ideal reinforcing agents for polymers and they have been widely used to enhance the mechanical, thermal, and electrical properties of epoxy polymers [3-5]. Many researchers have observed substantial improvements in the epoxy composite properties as a result of introducing CNTs [6-8]. Mitchell *et al*. [9] examined the linear viscoelastic properties of composite prepared with pristine single-walled CNT (SWCNT) and organically modified SWCNT in polystyrene matrix. It was found that the composite filled with functionalized CNTs had better dispersion and showed higher modulus. Abdalla *et al*. [10] showed that using carboxylic and fluorinated nanotubes the storage modulus in the glassy state and the rubbery plateau modulus were higher compared to the neat epoxy. Salam *et al*. [11] studied the mechanical and thermal properties of two types of functionalized multi-walled CNTs (MWCNTs) dispersed in an epoxy resin system (SC-15). Flexural and thermomechanical results demonstrated maximum improvement in 0.2 wt.% MWCNT-COOH modified epoxy samples. Arash Montazeri *et al*. [12] investigated the viscoelastic properties of MWCNT/epoxy composites using two different curing cycles and found that the mechanical and viscoelastic properties of pure epoxy and composite samples have been affected by the condition curing process. In addition, results show a good agreement between the Perez model and the viscoelastic behavior of the composite.

In this study, the tensile and viscoelastic behavior of epoxy and MWCNT-epoxy nanocomposites have been investigated as a function of different % of MWCNT loading.

2. EXPERIMENTAL

2.1. Materials and Methods

The MWCNTs used in this study were supplied by the M/s Chemapol Industries Pvt. Ltd., Mumbai. Its diameter 10-20 nm, length 20-30 µm, and purity is not <95%. Epoxy resin LY5052 and HY5052 hardener were supplied by Huntsman Co Pvt. Ltd. The resin and the hardener were based on diglycidyl ether bisphenol-A and polyamine, respectively.

2.2. Preparation of Nanocomposites

MWCNTs (0.1, 0.2, 0.5, and 1.0 wt.%) were mixed with epoxy resin. The mixture was then sonicated (Model No. VCX 130, Sonics & Materials Inc., Newtown, CT) for 45 min at 40% amplitude. The MWCNT dispersed epoxy resin and hardener were completely vacuum degassed at 80°C for 1 h to remove the air bubbles.

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After cooling to room temperature (RT), hardener was added to this mixture and again sonicated for 3 min. The prepared resin/hardener mixture was poured slowly into the sealed mould and kept for 24 h to cure at RT. After 24 h, the casting was removed from the mould, and postcured in temperature oven at different temperatures of 50°C for ½ h, 70°C for 1 h followed by 85°C for 2 h (Figure 1).

2.3. Methods

Static tensile tests were carried out using Instron Universal Testing Machine (model 5500R having load cell capacity of 10 tons). The samples were tested at a cross head speed of 0.5 mm/min and gauge length of 40 mm to record the displacement. An Advanced Rheometric Expansion System (ARES - M/s. Waters Inc., USA make) was used to determine the viscoelastic properties of epoxy nanocomposites. The samples were tested using torsion rectangular geometry at a heating rate of 5°C/min and a strain of 0.1% with 1% frequency. A flat rectangular strip of 45 mm × 10 mm was used for testing. The fractured surface was examined under a field emission scanning electron microscope (FESEM, SUPRA 40 VP with Gemini column, Carl Zeiss, Germany) for visualizing the morphological features.

3. RESULTS AND DISCUSSION

3.1. SEM Study

Figure 2a-d show FESEM images of the fracture surfaces of epoxy and randomly dispersed CNT-epoxy nanocomposites at RT. The fracture surface of epoxy displayed small river-like patterns along the crack propagation direction with a relatively smooth surface, representing typical brittle fracture behavior as shown in Figure 2a. The surface features of CNT-epoxy nanocomposites are rough as compared with those of epoxy SMP (Figure 2b and c). The presence of well-dispersed CNTs indicates that cracks bypassed these CNTs, creating a fracture surface rougher than that of the neat epoxy (Zhou). The voids were observed in the sample containing 1.0 wt.% CNTs (Figure 2d) which are the sign of pulled nanotubes from the epoxy matrix [13,14].

3.2. Static Tensile Properties

Figure 3 shows the stress-strain curves for epoxy and nanocomposite specimens at RT. The measured tensile properties are listed in Table 1. As indicated in the table, there was an increase in the tensile strength, failure strain, and modulus values with the addition of MWCNTs. At 1.0 wt.% MWCNT, the tensile strength and modulus improved by 29.31% and 8.45%, respectively.

3.3. Viscoelastic Behavior

Figures 4-7 show the ARES plot of epoxy and CNT-epoxy nanocomposites. The glassy storage modulus is increased by the addition of CNT and it shows maximum modulus value was obtained for 0.5 wt% CNT (Figure 4). In addition, addition of CNT improves the elastic properties of the epoxy at elevated temperatures (Figure 5). An increase in modulus could be observed in the rubbery region for the sample containing 0.2% and 0.5 wt.% MWCNT. In fact, in this state, the molecular motion and its amplitude are very high and the macromolecule is practically not in contact with particles. Hence, there is no shear force acting between them [15]. When the CNT content increased to 1.0 wt.%, the rubbery modulus decreased.

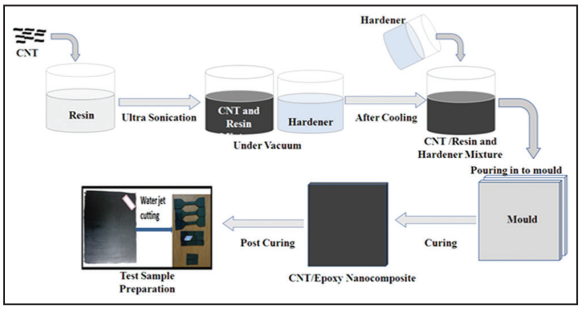

Figure 1: Preparation of randomly dispersed carbon nanotube - epoxy SMP nanocomposites.

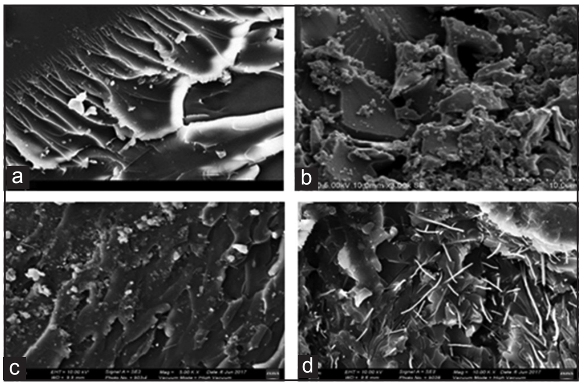

Figure 2: Field emission scanning electron microscopy images of the fractured surfaces of (a) 0%, (b) 0.2%, (c) 0.5% and (d) 1% carbon nanotube – epoxy SMP nanocomposite.

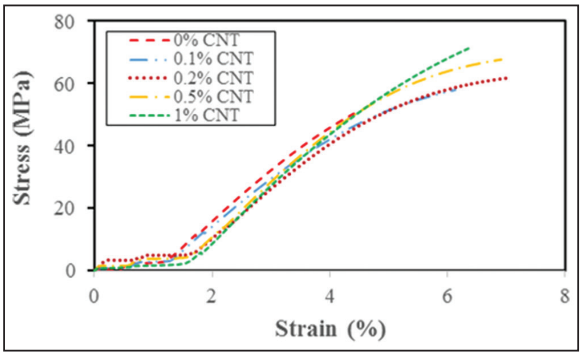

Figure 3: Tensile stress versus strain curves for epoxy and carbon nanotube-epoxy nanocomposites.

Table 1: Tensile properties of epoxy and CNT-epoxy nanocomposites.

Specimen type	Tensile strength (MPa)	Strain (%)	Tensile modulus (MPa)
0.0	50.38	4.41	1549
0.1	57.96	6.13	1562
0.2	61.77	7.01	1610
0.5	67.70	6.91	1646
1.0	71.27	6.35	1692

CNT=Carbon nanotube

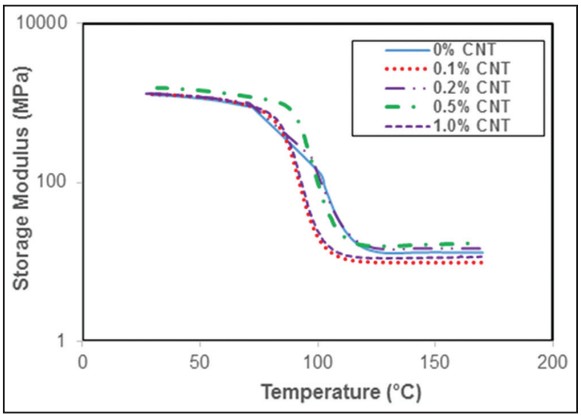

Figure 4: Storage modulus for epoxy and nanocomposites.

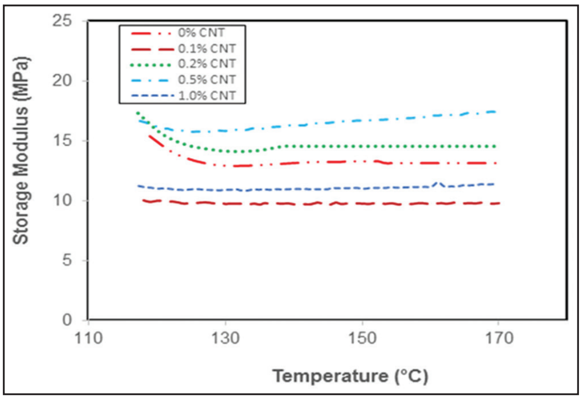

Figure 5: Rubbery modulus for epoxy and nanocomposites.

The damping properties of nanocomposites, such as loss factor and damping ratio, are essential design parameters for many engineering applications. Figure 6 shows the loss modulus for epoxy and CNT-epoxy nanocomposites. As indicated in this figure, the addition of MWCNTs increases the damping capacity. The highest loss modulus is seen in case of 0.5 wt.%, which was followed by a decrease in the peak height at higher MWCNT values.

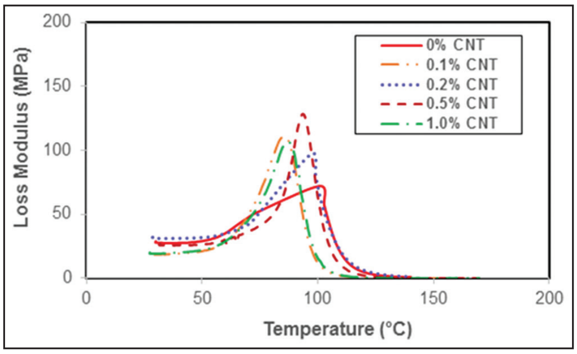

Figure 6: Loss modulus for epoxy and nanocomposite samples.

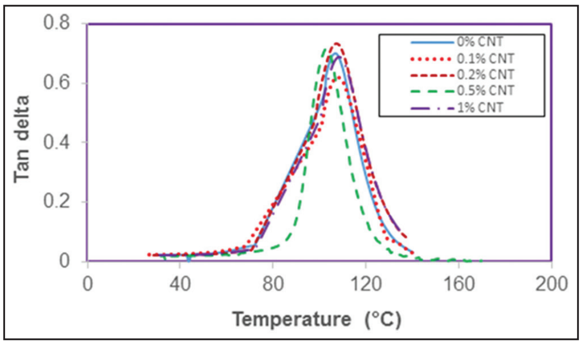

Figure 7: Glass transition temperature of epoxy and nanocomposites.

The glass transition temperature T_g was taken at the maximum of tan d versus temperature plots shown in the Figure 7. According to Figure 7, the T_g values were remained almost same except for 0.5 wt.% MWCNT was slightly reduced than that of pure epoxy.

4. CONCLUSION

MWCNT - epoxy nanocomposites containing different weight percentages of MWCNT were fabricated in this study. The tensile and viscoelastic properties of the samples were evaluated. The results showed that the tensile strength and modulus improved by 29.31% and 8.45%, respectively. The viscoelastic properties of the nanocomposite samples indicated a general increase in the elastic properties and damping of energy in the presence of MWCNTs.

5. ACKNOWLEDGMENTS

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