Polymer Nanocomposites for Mechanical Properties

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Nanoscience paves new avenues in the field of the scientific community as well as industry. In the case of civil engineering, a substantial interest can be observed in nano-sized materials, such as nano-silica powder, nanofibers, and nanotubes intended for structural applications. Nanofibers and nanotubes are used to introduce nano-reinforcements in polymer matrices that enable a decrease in the required amount of steel reinforcement and reduce corrosion problems affecting engineering structures.

multi-walled carbon nanotube | epoxy nanocomposites | flexural test
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1. Overview

Epoxy resins, due to their high stiffness, ease of processing, good heat, and chemical resistance obtained from cross-linked structures, have found applications in electronics, adhesives coatings, industrial tooling, and aeronautic and automotive industries. These resins are inherently brittle, which has limited their further application. The emphasis of this study is to improve the properties of the epoxy resin with a low-concentration (up to 0.4% by weight) addition of Multi-Walled Carbon Nanotubes (MWCNTs). Mechanical characterization of the modified composites was conducted to study the effect of MWCNTs infusion in the epoxy resin. Nanocomposites samples showed significantly higher tensile strength and fracture toughness compared to pure epoxy samples. The morphological studies of the modified composites were studied using Scanning Electron Microscopy (SEM).

2. Nanoscience

Nanoscience paves new avenues in the field of the scientific community as well as industry. In the case of civil engineering, a substantial interest can be observed in nano-sized materials, such as nano-silica powder, nanofibers, and nanotubes intended for structural applications [1]. Nanofibers and nanotubes are used to introduce nano-reinforcements in polymer matrices that enable a decrease in the required amount of steel reinforcement and reduce corrosion problems affecting engineering structures [2]. Diamond-like carbon material (DLC), such as carbon nanotubes (CNTs), possesses outstanding mechanical properties, exceptional stiffness, and high strength-weight ratios and toughness; these outstanding properties result in the potential of CNTs as ultimate reinforcing materials for the development of nanocomposites [3]. One of the major problems with polymer-based composite is its intrinsically brittle type of failure, which is due to their minuscule tensile strength compared to their compressive strength and high fracture toughness [4]. In appreciation of this flaw and to enhance polymer-based composites, extensive experimentation with filler reinforced composites has been carried out and encouraged [5]. The fillers can affect properties such as toughness, impact resistance, fatigue endurance, and the onset of crack initiation, in addition to the strength of the composite [6]. Today's world demands multi-functionality, reduced cost, increased durability, and much more for composite materials [7]. The promise of being lighter, thinner, and stronger, with durability, makes CNT reinforced composites one of the most attractive types of filler reinforced composite [8]. Garg et al. [9] studied the effect of functionalized nanoparticles (NPs) in influencing the mechanical properties under study. The resin transfer method was employed to fabricate polymer nanocomposites consisting of Glass fiber/epoxy/MWCNTs and reported an increase in flexural strength by 155% [10]. A nano-thin film composed of MWCNTs showed improved strength of metallopolymer systems [11]. An attempt was made to investigate the mechanical/electrical properties of MWCNTs/epoxy composites. The optimum mechanical properties were observed at 0.1 wt.% and 0.25 wt.% for tensile strength and flexural modulus of modified composites. An increase in tensile modulus and decrease in strain to failure was observed with the increase in CNT content. The maximum performance in flexural strength was noticed at 0.05%, and the electric response of the modified composites was noted to a threshold value of 0.5% multi-walled carbon nanotube addition. A fine distribution of MWCNTs remains essential to improving mechanical properties under study. Poor distribution of nanoparticles fails the specimen because of the agglomeration of the CNTs. The agglomeration has less influence on the electrical properties of modified composites [12]. The mechanical/electrical properties of MWCNT-modified composites were investigated. Based on the results obtained, it was noticed that tensile strength and flexural modulus were optimum at MWCNT contents of 0.1% and 0.25% (mass fraction). With the increase in MWCNT dosage increase in tensile modulus and a decrease in the strain to failure, the ratio was noticed. This phase shift from plastic to the brittle mode of failure was noticed because of the upsurge of the MWCNT ratio. The optimum flexural strength of the MWCNT modified sample was found to be optimum at 0.05 wt.% of the base matrix. Compared to other reinforcement proportions, the electrical percolation threshold of the modified composites was found to occur at 0.5 wt.% of MWCNT addition. The homogeneous dispersion of the reinforcement filler is an important parameter in improving the mechanical properties of the modified composites. Homogeneous dispersion of nanoparticles is very much essential for enhancing the strength of the polymer composites. Agglomeration of infused reinforcement leads to the early failure of modified composites. The agglomeration has the least influence on the electrical properties of the modified composites [13][14]. The effect of incorporating the MWCNTs bucky paper (CNTBP) and MWCNTs bucky paper/Epoxy (CNTBPE) on flexural strength of three-ply glass fiber/epoxy (3GF) was investigated. CNTBPE samples exhibited an improvement in flexural strength by 50% and 30% compared to 3GF and four-ply glass fiber composite, respectively. An increase in the specific modulus and strength by 30% and 70% compared to 3GF was observed [15]. The influence of varying MWCNTs (0.15, 0.25, 0.50, and 0.75 wt.%) on mechanical and thermal properties of multi-scale Carbon Fiber-Reinforced Plastic (CFRP) were investigated. Mechanical tests were conducted to study the influence of NPs on mechanical properties (tensile strength, modulii, and flexural strength) of CFRP. Thermal tests such as differential scanning calorimetry, thermo-gravimetric analysis, and dilatometry were conducted to investigate the effect of NP on glass transition temperature, the coefficient of thermal expansion (CTE), and the thermal stability of CFRP. SEM and the optical microscope were utilized to observe the dispersion of MWCNT in the holding matrix. The broken particles of the specimen were utilized for SEM observation. An improvement in the tensile, flexural strength, and Young′s modulus by 60%, 54%, and 26%, respectively, was observed with the addition of 0.25 wt.% of MWCNT in the CFRP composite. The optimum performance of the developed composite could be due to the NPs acting as nano-stitches holding the matrix together, thereby inhibiting the development of microcrack propagation during failure. The CTE of CFRP was reduced due to the addition of MWCNTs; the composites were thermally stable up to 350 °C. From the spectrographic observation, MWCNTs were homogeneously dispersed in the epoxy matrix until a certain dosage beyond which agglomeration of the fillers was observed [16].

Gantayat et al. [17] developed the nanocomposites by infusing functionalized MWCNTs (F-MWCNTs) in varying contents of 0.4, 0.6, and 1 wt.% into the epoxy. Nanocomposites were characterized by X-ray diffraction and Fourier Transform Infrared Spectroscopy (FTIR). The field emission scanning microscope was used to study the morphology of developed composites. Nanocomposites loaded with 0.6 wt.% functionalized MWCNTs exhibited higher tensile strength and Young′s modulus compared to other composites. This enhancement can be attributed to the good dispersion of the NPs in epoxy. An intimate bonding between the filler and the matrix was also responsible for the enhancement of the mechanical properties. Swam et al. [18] studied the effect of F-MWCNTs against MWCNTs into the epoxy matrix. The F-MWCNTs composites were prepared by varying compositions of MWCNTs of different weight percentages (0.4, 0.6, and 1 wt.%) into the epoxy resin. Thermal mechanical and electrical properties were improved because of the incorporation of MWCNTs. Zabini et al. [19] studied the effect of amine-functionalized and pure CNTs infusion into the epoxy matrix to study the effect of F-CNT influence on thermal, mechanical, and morphological properties. Based on the results, it can be obtained that amine-functionalized CNTs showed improved glass transition temperature, tensile properties, and thermal stability of modified composites. Jin et al. [20] prepared MWCNTs based Carbon/Carbon composites by employing the chemical vapor infiltration technique. The electrical conductivity and compressive strength reached 191 S/cm and 148.6 MPa, respectively. This research aims to improve the properties of Epoxy resin with the direct addition of MWCNTs in low concentrations. Epoxy samples blended with MWCNTs are prepared, and the effect of NPs on epoxy properties is investigated with fracture and mechanical characterization.

3. Conclusions

From the above experiment, we can conclude that the highly flexible behavior of CNTs has made them an ideal reinforcing phase. In the case of a tensile test, comparing the results of plain polymer with composites reinforced with epoxy/MWCNTs, that is, in the case of specimen A3 (0.3 wt.%), it is observed that an increase in tensile strength by 61% as compared to the unfilled epoxy resin. This could be due to the aspect ratio of MWCNTs, flexibility, and rehybridization capacity of the planar graphene sheet that makes up MWCNTs. Composites with a higher percentage of CNTs showed declining trends of tensile strength, which can be attributed to the non-homogeneous dispersal of MWCNTs. In the case of flexural strength, comparing the results of plain polymer with composites reinforced with epoxy/MWCNTs, that is, in the case of specimen A4, it is observed that an increase in flexural strength by 60% as compared to the PE specimen is observed. This is due to the hindrance of the crack growth at the micro-level by bridging the crack at the nano-level itself. The reinforcement beyond A3 (0.3 wt.%), that is, A4, has shown deteriorating trends in the strength features. This may be because of nanotube waviness with the increase in filler content. Composites with a higher % of CNTs showed declining trends of tensile and flexural strength. SEM analysis shows the dispersion of MWCNTs in the polymer matrix, and EDX shows the presence of other elements in the sample, which will affect the strength of the composites.

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