Thermal Performance Enhancement of Epoxy/MWCNT Nanocomposites

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ABSTRACT

This study investigates the preparation and characterization of epoxy/MWCNT nanocomposites with varying concentrations (0.1, 0.3, and 0.6 wt%) of multi-walled carbon nanotubes (MWCNTs). MWCNTs were dispersed using ultrasonication, and the resulting dispersions were incorporated into the epoxy matrix. The prepared nanocomposites were characterized using X-ray diffraction (XRD), field emission scanning electron microscopy (FESEM), and thermal analysis. XRD analysis revealed information on the alignment, distribution, and crystal structure of MWCNTs within the epoxy matrix, while FESEM images provided insights into the dispersion quality, interfacial interaction, and overall quality of the nanocomposites. Thermal analysis showed that increasing MWCNT concentration led to a general increase in the glass transition temperature (Tg) of the polymeric composite. The results demonstrated that the addition of MWCNTs to epoxy can enhance mechanical, thermal, and electrical properties by forming a rigid network and restricting polymer chain molecular mobility. However, achieving uniform MWCNT dispersion in the epoxy matrix is critical for optimizing these benefits and ensuring the optimal performance of the nanocomposites.

Keywords: Epoxy/MWCNT nanocomposites,Thermal analysis,multi-walled carbon nanotubes

Introduction

Polymer nanocomposites are a class of materials consisting of nanoparticles dispersed within a polymer matrix. The nanoparticles typically have at least one dimension in the nanometer range (1-100 nm), which leads to a high surface area and unique properties. The combination of the nanoparticles' distinct characteristics and the continuous polymer matrix results in enhanced material properties compared to the individual components [1].

Commonly used nanoparticles in polymer nanocomposites include carbon nanotubes, graphene, nanoclays, metal nanoparticles, and metal oxide nanoparticles. These nanoparticles can be incorporated into various polymer matrices, such as thermoplastics, thermosets, and elastomers, to tailor material properties for specific applications [2]

Polymer nanocomposites exhibit a wide range of improved properties, including mechanical strength, electrical conductivity, thermal stability, barrier properties, and flame

retardancy. These enhancements are primarily attributed to the high aspect ratio and large surface area of the nanoparticles, as well as the interfacial interactions between the nanoparticles and the polymer matrix [3].Due to their unique combination of properties, polymer nanocomposites have found applications in numerous industries, such as aerospace, automotive, electronics, construction, and packaging. For instance, lightweight polymer nanocomposites with enhanced mechanical properties have been utilized for structural applications in the automotive and aerospace sectors [4]. In the electronics industry, polymer nanocomposites have been employed for thermal management, electromagnetic interference shielding, and energy storage [5]However, challenges still exist in the fabrication and processing of polymer nanocomposites. One critical issue is the dispersion of nanoparticles within the polymer matrix, as agglomeration can lead to limited improvement or even degradation of material properties [6]. Researchers have developed various techniques to address this challenge, such as surface functionalization of nanoparticles, sonication, and the use of surfactants and compatibilizers [7]

Experimental part

Materials and method

Materials and Methods for the Preparation of Polymer/MWCNT Nanocomposites with percentage (0.1, 0.3, and 0.6wt% MWCNTs:

Materials:

Polymer matrix (epoxy resin and Curing agent or hardener from companyCNMI Epoxy Resin Bulk Turkey,2:1)

Multi-walled carbon nanotubes (MWCNTs)Solvent (acetone, ethanol, or distilled water)

Methods:

Step 1: MWCNT dispersion preparation

Accurately weigh the required amount of MWCNTs for each concentration (0.1, 0.3, and 0.6wt%).

Add the surfactant or dispersing agent to the solvent in a beaker.

Add the MWCNTs to the surfactant solution and mix using a magnetic stirrer for 30 minutes to obtain a homogenous dispersion.

Ultrasonicate the MWCNT dispersion using an ultrasonic bath or probe sonicator for 60 minutes to further disperse the MWCNTs and prevent agglomeration.

Step 2: Polymer matrix preparation

Mix the epoxy resin with the curing agent according to the manufacturer's instructions.

Step 3: Mixing the MWCNT dispersion with the polymer matrixSlowly add the MWCNT dispersion to the polymer matrix while continuously stirring to ensure even distribution of the MWCNTs.

For thermosetting polymers, continue stirring for approximately 15-20 minutes to achieve a homogenous mixture. For thermoplastic polymers, ensure that the solvent is compatible with the MWCNT dispersion solvent and mix until a uniform blend is obtained.

Step 4: Curing or drying the nanocomposite

pour the mixture into a mold and cure at the recommended temperature and time according to the manufacturer's instructions.

Step 5: Characterization of the nanocomposites

After the nanocomposites have been cured or dried, characterization tests, and thermal analysis, evaluate the effect of the MWCNT loading on the nanocomposite's properties.

Results and discussion

X-Ray Diffraction analysis

X-ray diffraction (XRD) can be used to study the structural properties of epoxy , epoxy/MWCNT ,epoxy/Graphite and nanocomposites. The XRD patterns of these materials typically show characteristic peaks that correspond to the crystal structure of the components.

In the case of epoxy, the XRD pattern show in Figure Error! No text of specified style in document. may show characteristic peaks associated with the polymer chains, which can be used to determine the degree of crystallinity and the crystal structure of the epoxy. These

peaks are typically broad and diffuse, indicating
a relatively low degree of crystallinity[8].
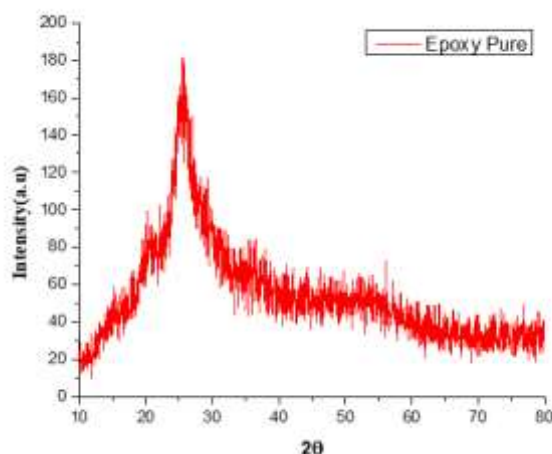
Figure Error! No text of specified style in document. **XRD pattern of pure epoxy**

epoxy is an amorphous polymer, meaning that it does not have a well-defined crystal structure. Therefore, the XRD pattern of pure epoxy typically shows broad and diffuse peaks, indicating a low degree of crystallinity. The peak positions and widths can be used to determine the amorphous content of the epoxy.When multi-walled carbon nanotubes (MWCNTs) are incorporated into the epoxy matrix, the XRD pattern may show additional peaks corresponding to the crystal structure of the nanotubes.

The position and intensity of these peaks at position (18.83°,25.23° and 34.19°) with Millar indices(002,100,101 and 004) can provide information about the alignment and distribution of the MWCNTs within the epoxy matrix. If the nanotubes are well-aligned and uniformly dispersed, the XRD peaks may be more intense and show higher symmetry. and the average crystalline size (20.59 nm) this pattern match with

The XRD pattern of an epoxy/MWCNT nanocomposite can be analyzed to determine the crystallographic orientation and distribution of the MWCNTs, as well as any changes in the crystal structure or phase composition of the epoxy due to the presence of the nanotubes. Additionally, the XRD pattern can identify any impurities or contaminants present in the sample[8, 9].
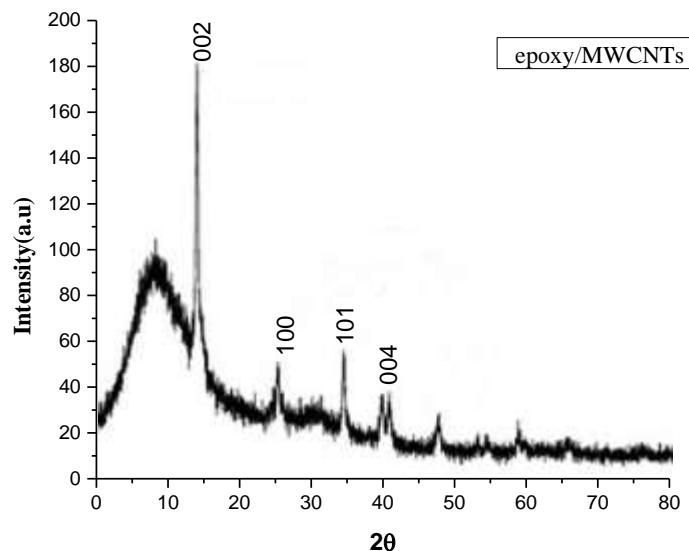
Figure 1XRD pattern of epoxy/ MWCNTs

Table 1 Structural parameters: Inter-planar spacing and crystalline size of epoxy/MWCNTs

2θ (Deg.)	WHM (Deg.)	kl Exp.(Å)	kl Std.(Å)	C.S (nm)	hkl
18.83	0.42	4.71	2.73	19.17	002
25.23	0.35	3.53	2.36	23.26	100
34.19	0.43	2.62	1.93	19.33	101
verage (nm)				20.59	

Field Emission Scanning Electron Microscopy (FESEM)

Field Emission Scanning Electron Microscopy (FESEM) is an advanced imaging technique that provides high-resolution images of the surface morphology and microstructure of materials, including polymer nanocomposites like epoxy/MWCNT. By interpreting FESEM images of epoxy/MWCNT nanocomposites, researchers can evaluate the dispersion of MWCNTs within the epoxy matrix, investigate the interfacial interaction between the MWCNTs and the matrix, and observe the overall quality of the nanocomposite[10].Figure (3) show the MWCNT dispersion quality within the epoxy matrix. Uniformly dispersed MWCNTs appear as individual tubes or small bundles uniformly distributed throughout the matrix.
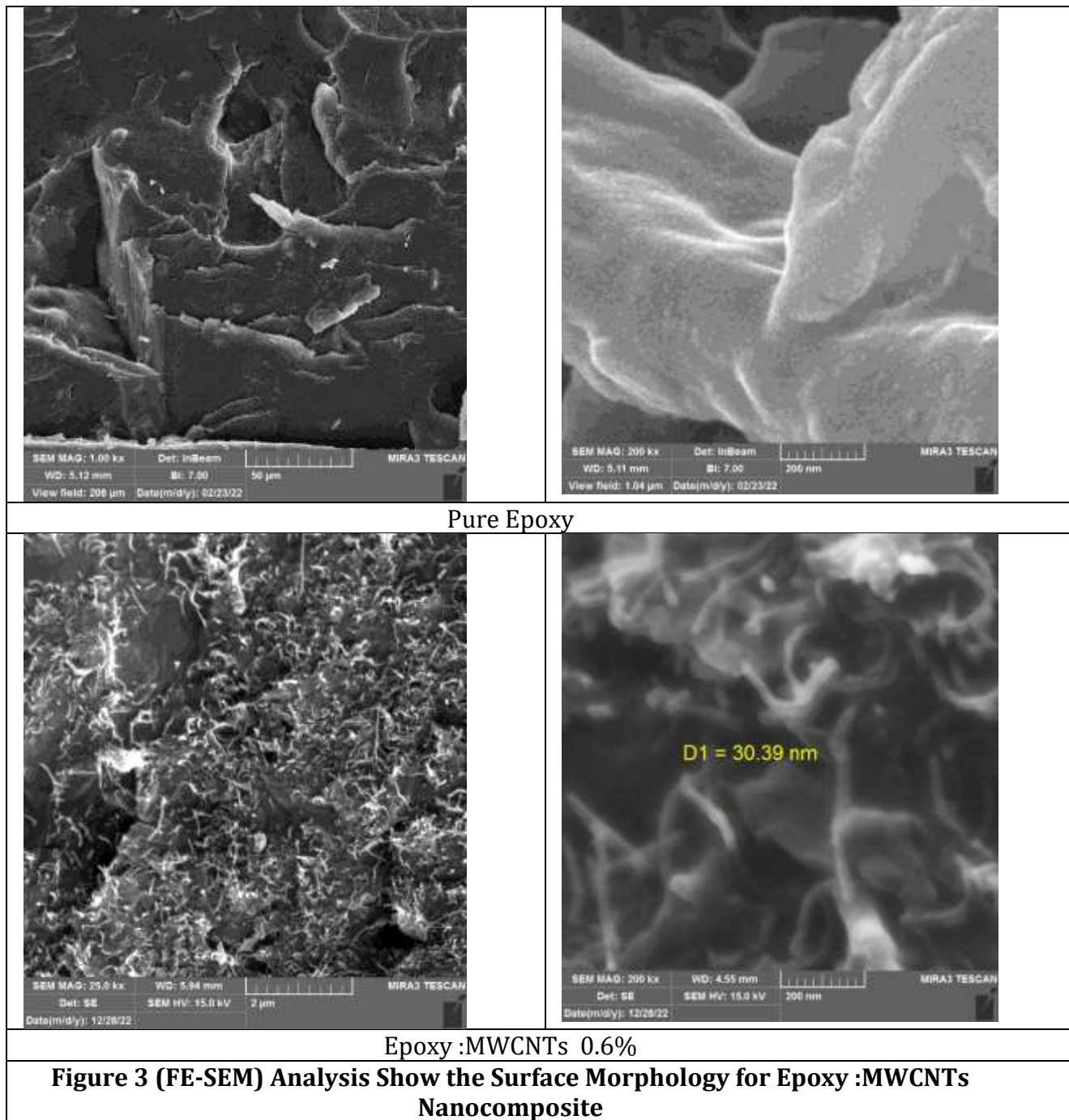
The Interfacial interaction between MWCNTs and the epoxy matrix at their interface. A strong interfacial interaction is crucial for effective stress transfer and enhanced mechanical properties. If the FESEM images show good adhesion between the MWCNTs and the epoxy matrix without visible gaps or voids, it suggests a strong interfacial interaction.from the figure appeared the Nanocomposite quality of the epoxy/MWCNT nanocomposite. do not exist the defects such as voids, cracks, or delamination's, which can compromise the mechanical properties and overall performance of the nanocomposite. A high-quality nanocomposite should have a uniform and dense microstructure without visible defects.

the MWCNT alignment Depending on the application, the orientation of MWCNTs within the matrix can be relevant. FESEM images can provide information on the alignment of MWCNTs, which can affect the anisotropic properties of the nanocomposite.

MWCNTs can be randomly oriented, aligned parallel to each other, or aligned in specific

directions depending on the processing technique used.

Pure Epoxy

Epoxy :MWCNTs 0.6%

Figure 3 (FE-SEM) Analysis Show the Surface Morphology for Epoxy :MWCNTs Nanocomposite

Thermal analysis results

Figure (4)depicts the relationship between heat flow and temperature, enabling the calculation of the first-degree glass transition. The figure demonstrates that the composite material undergoes a glass transition—an endothermic process—within a specific temperature range. Following this transition, the material's behavior stabilizes for a range of temperatures, approximately up to 380°C, after which the material experiences thermal degradation depending on the bond type and required energy for bond breaking.

Table 2 illustrates the impact of increasing the percentages of MWCNT, on the glass transition temperature (Tg) of the polymeric composite, which generally increases. MWCNTs are often used as reinforcing agents in polymer

composites to enhance their mechanical, thermal, and electrical properties. The incorporation of MWCNTs into epoxy can also influence its Tg. Research has shown that adding MWCNTs to epoxy can raise its Tg because MWCNTs' high aspect ratio offers a large surface area for interaction with the epoxy matrix, potentially leading to a rigid network formation. The interaction between MWCNTs and the epoxy matrix can further limit the molecular mobility of the polymer chains, thus increasing the Tg.

The degree of Tg increase depends on factors such as MWCNT concentration and aspect ratio, as well as processing conditions. At low concentrations, the Tg increase is relatively minor, but as MWCNT concentration rises, the effect on Tg becomes more pronounced. It is essential to note that MWCNT dispersion in the epoxy matrix is crucial for achieving the desired Tg enhancement. MWCNT agglomeration can result in areas of high stiffness, leading to stress concentration and premature composite failure. Consequently, suitable processing methods like sonication or surfactant treatment may be necessary to ensure the even dispersion of MWCNTs in the epoxy matrix.

In summary, adding MWCNTs to epoxy can elevate its Tg by forming a rigid network and restricting polymer chain molecular mobility. However, attaining a uniform MWCNT dispersion in the epoxy matrix is critical for ensuring the desired Tg enhancement and avoiding premature composite failure.[7, 11]

Table (1) shows the effect of increasing the percentage of adding MWCNT on the degree of glass transition of the polymeric composite

Wt %	Glass Transition Temperature	Crystallization Temperature
pure	217.39	287.58
0.1% Ep:MWCNTs	225.64	287.41
0.3 % Ep:MWCNTs	230.01	288.04
0.6 % Ep:MWCNTs	238.63	287.07
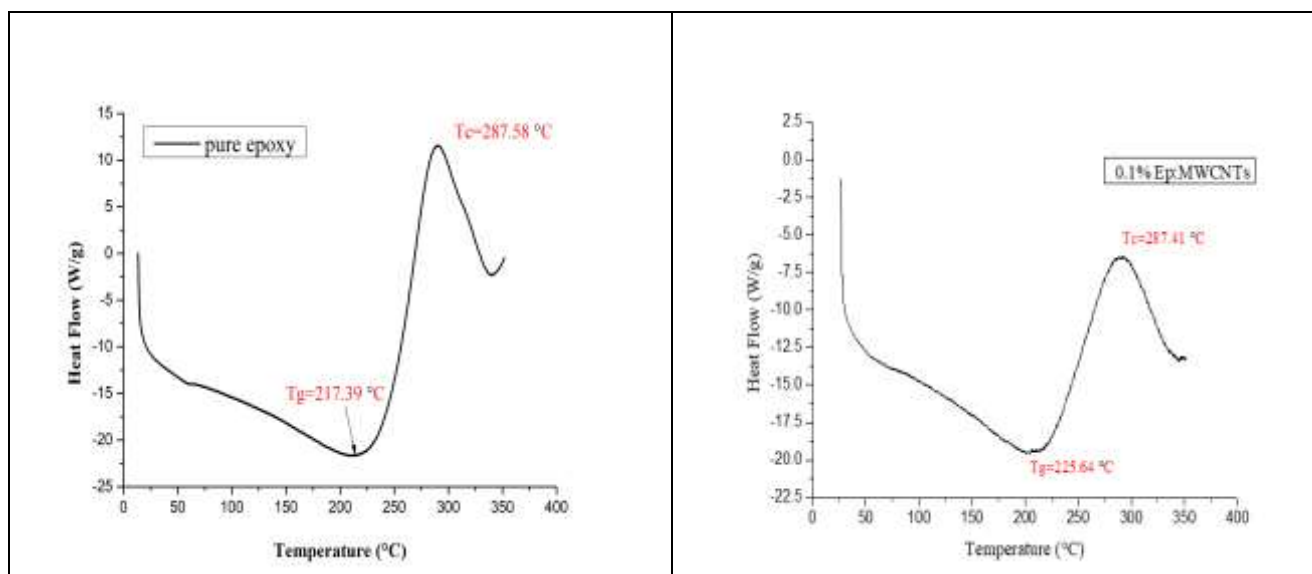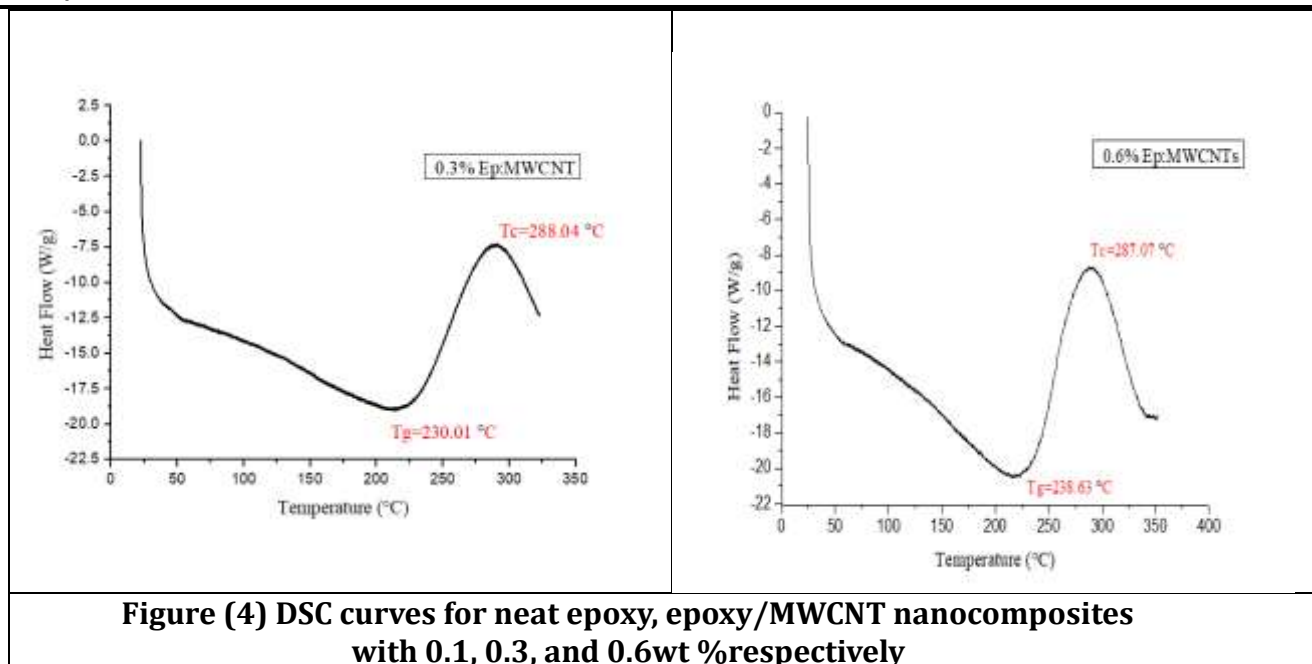
Figure (4) DSC curves for neat epoxy, epoxy/MWCNT nanocomposites with 0.1, 0.3, and 0.6wt %respectively

Conclusions

In conclusion, the preparation of epoxy/MWCNT nanocomposites with varying concentrations (0.1, 0.3, and 0.6 wt%) involved a series of steps, including MWCNT dispersion, polymer matrix preparation, mixing the MWCNT dispersion with the polymer matrix, curing or drying the nanocomposite, and finally characterizing the nanocomposites. XRD analysis was employed to study the structural properties of the nanocomposites, revealing information about the alignment, distribution, and crystal structure of the MWCNTs within the epoxy matrix.

FESEM analysis provided high-resolution images of the nanocomposite's surface morphology and microstructure, allowing for the evaluation of MWCNT dispersion, interfacial interaction, nanocomposite quality, and MWCNT alignment. These factors are crucial for optimizing the nanocomposite's mechanical, thermal, and electrical properties.

Thermal analysis illustrated the impact of MWCNT concentration on the glass transition temperature (Tg) of the polymeric composite, with higher concentrations generally leading to increased Tg. The results highlight the importance of achieving uniform MWCNT dispersion in the epoxy matrix for the desired Tg enhancement and prevention of premature composite failure.

Overall, the study demonstrated the potential of MWCNTs as reinforcing agents in epoxy nanocomposites, enhancing mechanical, thermal, and electrical properties by forming a rigid network and restricting polymer chain molecular mobility. However, careful control of MWCNT dispersion and concentration is essential to maximize these benefits and ensure the optimal performance of the resulting nanocomposites.

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