Chapter 5

Carbon Nanocomposites:
Emerging Engineering Technologies and Industrial Applications

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ABSTRACT

Successful deployment of carbon nanocomposites in many applications, such as sensing, energy storage, and catalysis, relies on the selection, synthesis, and tailoring of the surface properties. Carbon nanotubes, due to their large surface areas, unique surface properties, and needle-like shape, can deliver a lot of therapeutic agents, including DNA, siRNAs and proteins to the target disease sites. Carbon nanotubes can be readily excreted through the renal route by means of degradation through myeloperoxidase enzyme. Nanotubes are categorized as single-walled carbon nanotubes and multiple walled carbon nanotubes. Theirs advances have been made in the delivery of anticancer, anti-inflammatory drugs, bioactive molecules, and proteins. Drugs and biomolecules can be loaded in carbon nanotubes, which can then be utilized as targeted molecules. Recently, carbon nanocomposites have attracted a lot of attention in the field of cancer diagnosis and therapy, with their ability to deliver therapeutic molecules and allow visualization of cells and tissues, which are necessary for the cure and treatment of diseased and damaged tissues.

1. ADVANCEMENT, AND APPLICATIONS OF CARBON IN COMPOSITES

Carbon nanotubes (CNTs) are a novel class of materials with a diverse range of applications (Madkour, 2019,2020,2022;2023) due to their unique physical properties.The physical, optical, and electronic properties of the CNTs further provide means for the precise control over their transport to specific target organs or tissues, and their controlled release according to the desired dosing regimen. Recently, several research groups have attempted to measure the electrical properties of carbon nanotubes experimentally.

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The development of scanning tunneling microscopy (STM) and spectroscopy-based techniques has been particularly helpful in these experimental developments.

Carbon nanotubes is a fullerene molecule, it was first discovered in 1991 by Japanese scientist Iijima (Iijima, 1991) as tube-shaped of graphitic carbon, can be obtained either single or multi-walled nanotube, having a diameter measuring on the nanometer scale, and generally known as buckytubes. Carbon nanotubes (CNTs) can be defined as allotropes of carbons in tubular shape, which looks like graphene sheet rolls. The diameter of CNTs varies from 1 to 100 nm, while the length of CNTs may be up to millimeter scale. CNTs can be classified based on the number of layers: single-walled carbon nanotubes (SWCNTs) and multiple-walled carbon nanotubes (MWCNTs). In addition to this classification, SWCNTs can be categorized as armchair carbon nanotubes, zigzag carbon nanotubes, and chiral carbon nanotubes by their crystallographic configurations. Each type of CNTs has advantages, disadvantages, and unique properties due to their distinctive characteristics.

CNTs have large specific surface areas on which a wide range of molecular moieties can be attached. Also CNTs can be functionalized to enhance their physicochemical properties and permeation abilities through cell membranes.

CNTs are a very promising technique in sensing technology (Marquez et al.2023,Qureshi et al.2023) since they offer structural competence and measurable response under applied stresses and strains. They have functional capabilities such as actuation, sensing, and power harvesting even when operating at very low voltage. Integrating CNTs into polymers results in a whole new range of smart structure applications, advanced sensors, and actuators . For example, CNTs-based laminate composites had been used as strain sensors with wireless transmission systems and also as a sensing skin for damage detection. It had been also used to develop hybrid composites with self-sensing properties . Conductive thread created by twisting the CNT forests into a wire had also been used as a sensor to monitor deformation including delamination in composites . There is a wide range of in situ strain sensors based on multi-walled CNTs which are insensitive to temperature variation . Studies have shown that the delivery of drugs and genes to brain can be achieved with functionalized CNTs. Thus, CNTs provide a new drug delivery approach to CNS diseases. However, problems with the alignment of CNTs with fibers in an epoxy matrix and their dispersion is often difficult so alternative approaches such as radial in-situ growth of CNTs on fiber surface are considered. In addition, the electrical response of the CNTs-based sensing film depends on their concentration in the matrix because more concentration leads to more nanotube-to-nanotube junctions thus increasing the conductance but, it is not favorable to increase the concentration beyond the percolation threshold. So, it is vital to evaluate the concentration of CNTs in the sensing film to optimize their sensing performance. Some research studies had also been conducted to develop CNTs-based wireless embedded sensors for composite civil structures . CNTs dispersed in cement matrix not only improve their mechanical properties and develop a smart material for real-time damage detection but also result in an efficient way of crack bridging during initial crack propagation . Recently, the University of Cincinnati developed an artificial neural system consisting of a long film of CNTs as a grid/sensor network attached to the surface of the structure. Furthermore, some researchers had also studied the strain sensing behavior of CNTs-based nanoscale sensors using Raman spectroscopy by indirect measurement of the resistance of a nanocomposite but it was very huge to be used in a sensor mechanism. In addition, MEMS of these nanoparticles were also developed using lithography and aligned SWNTs which can detect small cracks and measure small strains. But, this system required large signal processing because of sensors array to cover large areas for real-time SHM. Recently, a new real-time SHM technique termed nano-engineered thermal (NET) sensing had been developed using

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