

# REVIEW ON CARBON NANOTUBE BASED POLYMER COMPOSITES AND ITS APPLICATIONS

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**ABSTRACT:** The unique structural, electrical and mechanical properties of carbon nanotubes (CNTs) appoint CNTs as a promising candidate for a broad advantage on the applications of sensors, electronic devices, biomedical and many more. Due to the problems in transferring the extraordinary properties of CNTs to the application, it is critical to modify CNT surface before starting with further experimental procedure in order to improve interfacial adhesion, strength and mechanical properties of polymer/CNTs. This short review provides an overview of the state of knowledge especially in dispersion method, applications and recent research on CNTs with a particular emphasis on CNTs as reinforcement of polymer composites, for many potential applications.

**KEYWORDS:** *Carbon Nanotubes (CNTs); Polymer Composite; Dispersion; Reinforcement*

## 1.0 INTRODUCTION

Since the latter half of twentieth century, advances of carbon nanotubes (CNTs) in nano science and technology has opened a new opportunity for advanced composite material with improved performance [1]. The development of nanostructure technology in the

field of nanoscience has increase for the application of sensors, electronic devices, biomedical and many more. Thus, the CNTs have been studied extensively for a variety of potential application such as electrode for supercapacitors [2], electrode for hydrogen peroxide (H<sub>2</sub>O<sub>2</sub>) biosensor [3], CNTs in therapeutic of oncology [4] and carbon nanomaterials for fluorescence bio sensing and bio imaging in biological applications [5]. Furthermore, carbon nanotubes (CNTs) have received many attentions because of the capability to optimize the mechanical, thermal and electrical properties of polymer composites. This fact is supported by the study conducted by many researchers as tabulated in Figure 1 [6-13].

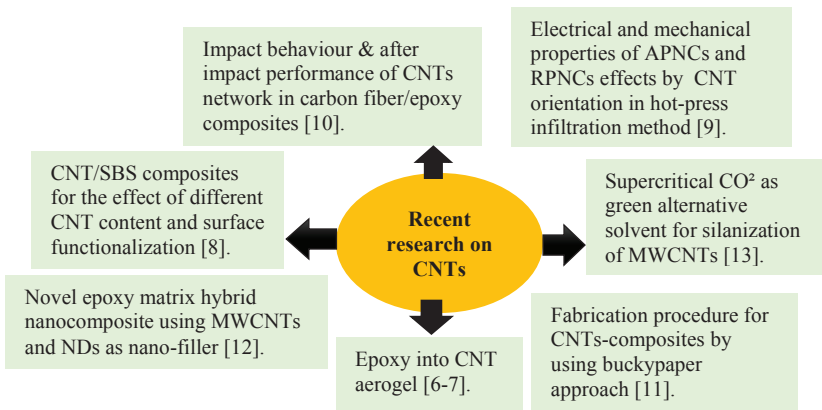


Figure 1: Recent research on carbon nanotubes (CNTs)

CNTs have been listed as future candidates for modification of polymer matrix because of outstanding strength and stiffness yet low weight, high flexibility, diameter dependent specific surface area, high aspect ratio, high thermal conductivity and electrical and moderate electrostatic discharge properties [6-8]. Based on the extraordinary electrical, mechanical, and thermal properties for polymer matrices CNTs are attributed as high potential filler material. Besides, the CNT material and surface functionalization, the properties of the polymer matrix, stabilization additives as well as the production process have a significant influence on the maximum CNT content and the resultant composite properties [6].

Despite of facing problems in transferring the extraordinary properties of CNTs to the application due to agglomeration or entanglement, there are many other research works are presented by

researchers around the globe, giving uncommon attention toward CNTs because of the significant contribution the material can offer in various applications and fields. For example, CNTs now are vigorously employed for energy storage, coatings, sports equipment, thin-film electronics and etc.

## **2.0 FABRICATION OF CNT/POLYMER NANOCOMPOSITE**

In spite of possessing high mechanical properties: Young's modulus up to 1.2 TPa [9] and tensile strength of 11-200 GPa [11], CNTs endure the difficulty from the dispersion of agglomerated CNTs during processing and produce indigent interfacial interaction between CNT and polymer matrix.

The polymer chain of CNTs restrains the production of homogeneous dispersion of CNTs in polymer matrices. The problem majorly emerged from the stable and strong van der Waals' interaction amongst the CNTs that make the polymer chain difficult to intercalate [13]. In this context, synthesis induced "entangled" and "aggregated structure" of CNTs magnifying the problem of homogeneous dispersion. Poor interfacial adhesion between CNTs and polymer is another critical parameter in the issue of homogeneous dispersion of CNTs in polymer matrices. This factor dictates the efficiency of load transfer in the CNTs based polymer composites [14]. The poorly dispersed CNT possibly diminished the significant properties of CNT [15].

The factors that causing the problem in distribution of CNT filler in a polymer matrix including size and geometry effect of CNT nano diameter, high aspect ratio and exceptionally large surface area of CNT, particle agglomeration reaction of electrostatic interaction and van der Waals forces, disentanglement method of CNT [16]. Thereto, [16] have compared the dimension and number of particles between CNT toward alumina particle ( $Al_2O_3$ ), carbon fibers, graphite nanoplatelets (GNPs) and concluded that CNTs is more difficult to disperse in a polymer matrix than other reinforcements.

Therefore, it is critical to modify CNT surface before starting with further experimental procedure in order to improve interfacial

adhesion, strength and mechanical properties of polymer/CNTs [13]. There is a sizeable volume of literature on modification of CNT surface. A group of researchers included these six mechanical dispersion techniques in their studies: ultrasonication [16], high shear stress [17], calendaring process [18], ball-milling [19], stirring [20] and extrusion [3] as specifically depicts in Figure 2.

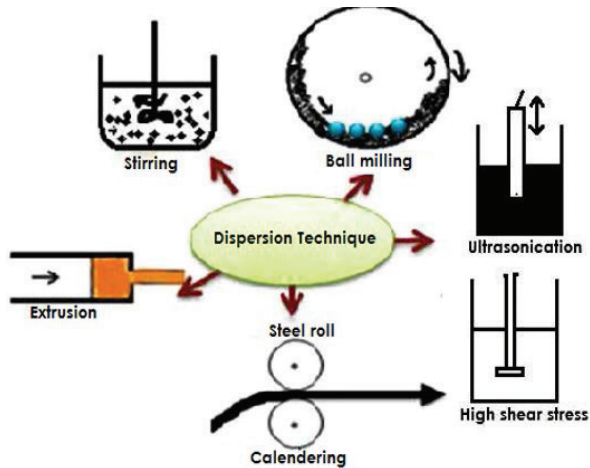


Figure 2: The dispersion techniques of CNTs [16]

### 3.0 MWCNT VERSUS SWCNT

According to [21] carbon nanotubes seem to be a wonder material which became most mentioned building blocks in nanotechnology scope after been discovered. The tensile strength is one hundred times of steel, thermal conductivity similar to copper and possesses the ability to carry much higher currents than other material. This wonder material captured much attention of the researchers.

Microtubules of graphitic carbon were discovered in 1991 by Sumio Iijima of NEC Laboratory in Tsukuba, Japan, using arc-discharge method and characterized by High-Resolution Transmission Electron Microscope (HRTEM) with outer diameter of 4-30 nm and a length of up to 1  $\mu\text{m}$  [22]. The tubules are effectively long, thin cylinders of graphite. The types of carbon based nano materials are made up of single-walled nanotubes (SWNTs) and multi-walled nanotubes (MWNTs) [23]. These two nanotubes are dissimilar in the arrangement aspect of graphite cylinders.

Nevertheless, the geometry of the nanotubes including this three arrangements: armchair, zig-zag and chiral arrangement [24]. Kumar et al. [24] have categorized CNTs according to the types as arm-chair; zig-zag and chiral nanotube based on the allotropes of carbon with fullerene-related cylindrical nano structure. The structures consist of graphene cylinders closed at either end with caps containing pentagonal rings. The nanotube strength increased with the increasing nanotube helicity. Thus, the Arm-Chair nanotubes had the highest strength due to the widest helicity [25] and the exact magnitude of stiffness properties depends on the diameter and chirality of the nanotubes and whether they are single-walled, double-walled or multi-walled form [12]. Figure 3 below shows clearly the types of CNTs as explained above.

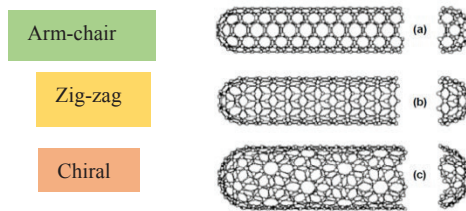


Figure 3: The types of carbon nanotube (CNT): (a) arm-chair nanotube (b) zig-zag nanotube and (c) chiral nanotube [24]

The MWCNTs are similar to concentric cylindrical graphite tubes made up of SWCNTs. Although it is easier to produce significant quantities of MWCNTs than SWCNTs, their structures are less well understood than SWCNTs. This is because of their greater complexity and variety. The MWCNTs so far have more defects than SWCNTs which diminish the desirable properties. Furthermore, many of the nanotube applications now being considered or put into practice involving MWCNTs, because they are easier to produce in large quantities at a reasonable price and have been available in decent amount for much longer time than SWCNTs [23].

#### 4.0 APPLICATION OF CARBON NANOTUBES-BASED POLYMER

It is expected that the utilization of carbonaceous nanomaterials especially MWCNTs in the composites will increase the industrial applications due to the reasonable cost [26]. Based on the literature

available so far, a few studies have been agreed that despite of facing considerable list of challenges in employing CNT-based polymer composite, these materials have already been explored for a range of applications in different fields such as sensors, electronic devices, energy storage and biomedical applications as summarized accordingly in Table 1.

Table 1: The list of application for CNTs-based polymer composites

| Sensors                                                                                                                                                   | Electronic Devices                                                     | Energy Storage                                                                            | Biomedical Application                                                                                                                                                                                       |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------|-------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| -EC DNA sensor [28]<br>-EC warfarin sensor [29]<br>-EC rutin sensor [30]<br>-Vapor of chemical gas sensor [16]<br>-Strain sensor [31]<br>-Gas sensor [32] | -Dye sensitized solar cells [33]<br>-Dry EC actuators [34]<br>-SC [35] | -Battery electrode [36]<br>-PCM thermal energy storage [37]<br>-rGO/SWCNTs electrode [38] | -Scaffold in tissue engineering [39]<br>-Orthopedic implantable device [40]<br>-Blood purification [41]<br>-Nano-surgical needles [42]<br>-Fuel empowered artificial muscles [43]<br>-Joint replacement [44] |

#### 4.1 Sensors

A sensor is a device in application to detect any changes in a physical stimulus and turns it into a signal which can be measured or recorded. The physical stimuli can be from temperature, blood pressure, humidity, speed and etc. The stimuli are categorized to acoustic, electric, magnetic, optical, thermal and mechanical form. Figure 4 shows the working schematic diagram of chemiresistive gas sensor. As explained previously gas sensor is among the sensors that employed CNTs in regard to the superior properties and cost reduction offered. A few researcher explained that the sensor change the output resistance when a particular gas is adsorbed on the sensing element from the surrounding [44]. The adsorbed gas molecules desorb from the sensor surface when the gas disappears and the sensor regains its original resistance [45].

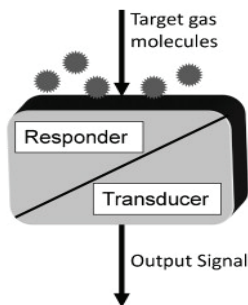


Figure 4: Schematic diagram of gas sensor [45]

Besides, in the fabrication of sensors, MWCNTs are often used to promote the electron transfer reactions of various molecules and increase the available electroactive surface area of various electroactive substances [46]. In sequence, a novel imprinted electrochemical sensor based on chitosan-silver nanoparticles (CS-SNP)/graphene-multiwalled carbon nanotubes (GR-MWCNTs) modified gold electrode for detection of neomycin was developed [47].

## 4.2 Electronic Devices

To date, CNTs can be used as electrodes in many devices [48]. The continuous carbon nanotube (CNT) fibers offer the unique potential for applications in electronic devices. This is an honor to the high mechanical performance, excellent electrical conductivity and large specific area that the material exhibited [49]. Several contributions report excellent electronic properties of carbon nanotubes for applications as dye sensitized solar cells [32], dry electrochemical actuators [33], and supercapacitor [34]. Figure 6 shows the typical structure design flexible CNT film based supercapacitor. The CNTs in the flexible CNT films tend to interweave with each other to form robust networks with tunable optical and mechanical performance, such as transparent and stretchable network. Therefore, the fabrication of flexible thin-film supercapacitors with stretchable or transparent properties for portable and wearable electronic devices are favorable [34] as shown in Figure 5.

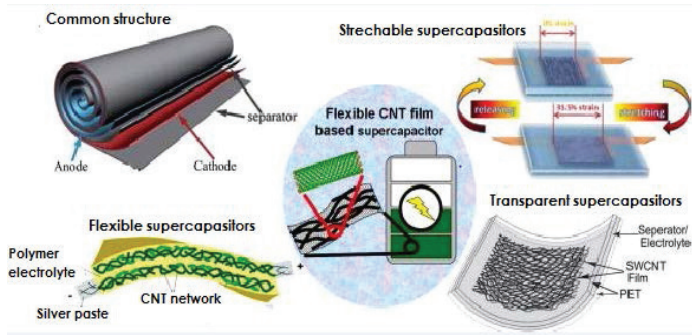


Figure 5: Common structures design of CNT film based flexible electrodes and supercapacitors devices [35]

### 4.3 Energy Storage

Energy storage devices is an important entity to achieve an effective level in the process cycle of renewable energy sources [50]. This device also acting as a key role in various fields, such as transportation [51] and consumer electronics [52]. According to Azam et al. [53], various alternatives have been studied to support electricity usage and one of it is renewable energy sources such as solar [54], wind power [55], and fuel cell [56]. There are a lot of scientific studies being conducted to develop more advanced energy storage devices. The latest finding shows that energy storage devices such as batteries and electrochemical capacitors (ECs) exhibit great properties. Both of them exhibit great performance, high energy and power density, and environmental friendly [53].

According to [53], among many other materials, CNT is one of the materials that gain more attention used in fabrication of battery and EC electrodes [57]. Carbon nanotubes are a promising candidate to use as one of the material for anode electrode in batteries particularly in lithium ion type. This powerful performance relies on their unique structural, mechanical, and electrical properties. In addition, the highly conductive carbon nanotubes offer enhanced electronic transport in these nanostructured anode materials [35]. Thus, CNT material is expanding by time to serve as a multi-skilled material that can improve many applications in many ways. Since batteries are a dominant energy storage device due to large energy density compared to capacitors, they are commonly used for long-term energy storage. Figure 6 represents the development of flexible



secondary alkaline battery with recharge ability similar to that of conventional secondary alkaline batteries by [58].

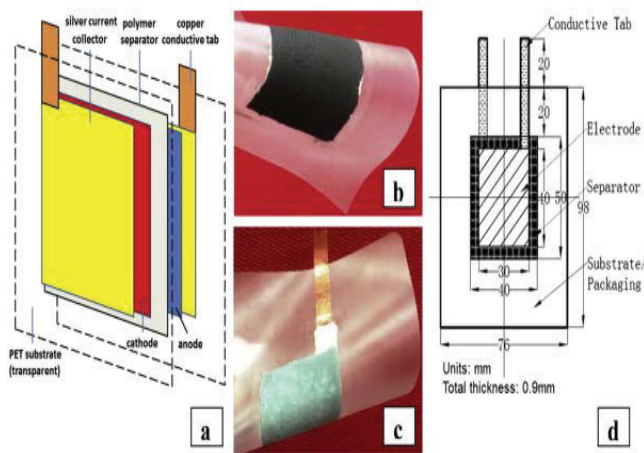


Figure 6: (a) Structure of flexible secondary alkaline battery, (b) photograph of flexible cathode, (c) flexible anode and (d) typical size of flexible cell [58]

Particularly, the fabrication of diverse CNT-based polymer composites in the last decade has opened their use in a wide collection of biomedical applications. More recently, CNTs have also shown utility in the emerging field of nano-biotechnology [38]. In this context, CNTs have been already exploited for the preparation of scaffold in tissue engineering [38], orthopedic implantable electronic device [39], blood purification [40], nano-surgical needles [41], fuel-powered artificial muscles [42], CNT-based nanocomposites for joint replacement surgery and dentistry [43].

## 5.0 CONCLUSION

In summary, the excellent mechanical properties of CNTs combined with many other significant properties successfully introduced CNTs as an excellent candidate for structural and functional applications of CNT/polymer nanocomposites. Although many research works have devoted to the development of CNT/polymer nanocomposites for various purposes, the applications as real products are still in progress. According to the findings from the scientific studies by researchers in the polymer nanocomposites area, there are two major interrelated issues that must be addressed regarding this wonder

group of material: namely (i) lack of solubility and dispersion when came into interaction with polymer resins and (ii) poor interfacial adhesion between CNTs and various polymers. In this review, overview of the research in CNT/polymer nanocomposites with focusing on the principle of CNT dispersion and functionalization as well as the effect of CNT dispersion and functionalization on the properties of CNT/polymer nanocomposites and the application of the material are discovered and illustrated.

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