Review Article

Sustainable Development of Carbon Nanocomposites: Synthesis and Classification for Environmental Remediation

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Received 12 July 2021; Revised 7 August 2021; Accepted 27 August 2021; Published 20 September 2021

Academic Editor: Lakshmiopathy R

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Composite materials with carbon nanotube and graphene attachments have been regarded as promising prospects. Carbon nanocomposites have gained considerable interest in different fields including biomedical applications due to its exceptional structural dimensions and outstanding mechanical, electrical, thermal, optical, and chemical characteristics. The significant advances made in carbon nanocomposite over past years along with the discovery of new nanocomposite processing technologies to improvise the functional impact of nanotube and graphene composites by providing proper methods of synthesis and improving the production of diverse composite based on carbon nanomaterials are discussed. Carbon nanocomposites are applied in various fields such as aviation, batteries, chemical industry, fuel cell, optics, power generation, space, solar hydrogen, sensors, and thermoelectric devices. The recent design, fabrication, characteristics, and applications of carbon nanocomposites such as active carbon, carbon black, graphene, nanodiamonds, and carbon nanotubes are explained in detail in this research. It is found that unlike traditional fiber composites, Van der Waals force interfacial compounds have an important effect on the mechanical performance of carbon nanomaterial-based composites.

1. Introduction

The incessant demand for the commercial usage of engineered carbon-based nanomaterials are increasing in the field of modern technology, medicine, environment, and agriculture; the distinctive properties of carbon-based nanomaterials have engrossed great concentration by the researchers and industrialists which have stimulated the expansion and innovation techniques for significant industrial production [1]. Carbon is among the stimulating elements, with the capacity to produce wide range of arrangements, habitually with diverse characteristics [2]. Some of the significant allotropes of carbon encompass “hard” diamond and “soft” graphite [3]. The inno-

vative constituents that are carbon nanotubes (CNTs), fullerenes, graphene, and engrossed high contemplation from scientific industries which exhibit varieties of exceptional features as encouraging resources for abundant application fields due to their special capabilities, they were recurrently labelled as “wonder materials” [4]. The allotropical carbon transition, known as fullerenes, is generally a chemical component of carbon, or carbon particles. Here, carbon atoms naturally exist in the form of sp^2 -hybrid and are bound by covalent bonds. Fullerene (C₆₀) is a highly symmetrical spherical compound with 60 carbon atoms, at the tip of 20 hexagons and 12 pentagons [5, 6]. Carbon nanotubes (CNT) are the most notable of carbon-based nanomaterials;

CNTs are one of the carbon allotropes with excellent mechanical properties, characterized by tubular structures with a width of only a few nanometres, consisting of rolled graphene sheets and often varying in chirality, diameter, and weight [7, 8]. Graphene is a 2D allotropic carbon group consisting of “single layers of sp^2 -hybridized carbon atoms” in a 0.142 nm outcrop of 2D hexagonal crystal lattice between adjacent hexagonal carbon atoms [9]. It has various physico-chemical properties, such as unusually high structural rigidity and higher thermal stability, and the electrical properties of graphene are very different from those of 3 dimensional products [10]. Intensively developed the discovery of carbon-based nanomaterials and their study of superior characteristics, synthesis methods, culminating in the basic component called carbon vapour, which manipulates the production of carbon nanomaterials [11]. The buoyant physical and chemical characteristics of carbon-based nanomaterials influence various applications that, in effect, allow their production to intensify [12]. Figure 1 displays the variations of the carbon nanocomposites. Carbon nanostructures contain numerous low-dimensional allotropes of carbon including carbon black (CB), carbon fiber, carbon nanotubes (CNTs), fullerene, and graphene.

By achieving several thousand tons of products [14], the carbon nanotubes have resulted in industrial development being the broadest area of operation. Due to the mechanical features of CNT such as high tensile strength and improved stability, they are integrated into polymers and other resources to manufacture structural and composite materials with innovative properties as required by their application and specification [15]. Carbon nanocomposites have exhibited exceptional catalytic activity in organic chemical processes due to their shape-dependent physical and chemical properties and thickness, primarily metal nanostructures or carbon materials consisting of graphene and carbon nanotubes [16]. The catalytic yield from the use of carbon nanocomposites in various fields, including nutritional, pharmaceutical, and materials sciences for biotechnology [17], has been found to be of great value. The catalytic products produced using carbon nanocomposites are considered of great value in various fields, particularly in medicinal, biomedical, agricultural, and material sciences [18, 19]. Consequently, demand for carbon nanocomposites has increased rapidly and therefore the development of new methods of preparation deserves a high degree of interactivity [20]. Nanocomposite benefits involve module enhancement, flexural strength, thermal distortion, barrier effects, and other advantages and, unlike conventional mineral-reinforced systems, are with no typical impact and visibility trade-offs.

2. Methods of Synthesis of Carbon Nanocomposites

2.1. Covalent Functionalization. Covalent functionality uses covalent connection of functional elements to the carbon scaffold of the nanotube. It can be of two forms, covalent side-wall functionalization and defect functionalization, depending on the location of contact. The functioning of the direct covalent sidewall implies a shift in hybridisation

FIGURE 1: Classification of carbon nanocomposites [13].

from sp^2 to sp^3 and conjugation loss [21]. Functionalization of defects is based on the already existing site modifications [22]. Defect sites may include the open ends and the side-wall holes ended in hexagonal graphene framing, e.g., by functional groups and defects in stone/wales (5–7 faults). Oxidative purification also includes oxygenated sites produced as faults. SWCNTs have poor dispersibility and are shown as bundles [23]. The use of a highly reactive reagent for the covalent bond creation of the walls is guaranteed in this circumstance. It cannot be said in advance whether such additional reactions are most likely to occur at defective locations or intact hexagonal areas of the edge [24]. Several covalent methods, such as oxidative purification, amidation, esterification, thiolation, halogenation, hydrogenation, and electrochemical functionality, have been adopted for covalent functionalization [25].

2.2. Noncovalent Functionalization. The noncovalent functionalization also known as supramolecular correlations is found across all types of materials which are exposed to attractive or repulsive forces, common in both organic and inorganic structures [26]. In the case of graphene, assigning defects or irregularities arising from the transition from sp^2 carbon to sp^3 carbon, though combining multiple relations, is technically useful [27]. Graphene materials and energy dissociation of less than 50 kJ mol^{-1} [28] have a prevailing relationship. A major component to be addressed in graphene and graphene oxide (GO) systems is solvation and hydrophobic effects induced by various interactions, as they affect not only their dispersibility but also the identification of associations that can be used to classify them [29]. Graphene has two forms of interactions that influence its compatibility with other nanomaterials or stimulants between electron-rich and electron-poor regions [30]. This is often seen on both face-to-face arrangement and edge-to-face arrangement [31]. Also present in biologically relevant molecules such as DNA, RNA, and porphyrins through electron interactions. In addition, these interactions are found in small molecules and are transmitted to GO and G systems

where they can be used to process and modify properties [32]. The effective dispersion of graphene was accomplished by noncovalent functionalization with amine-packed and fully packed polymers [33]. Reduced graphene in nonsolvents could be spread by noncovalent grafting with an end-functional PS-NH₂ polymer [34]. For noncovalent functionalization, numerous nonsolvents for reduced graphene, benzene, hexane, oxylene, and dichloromethane, which are immiscible with the aqueous process, were used [35]. The remaining carboxylate groups effectively provided the noncovalent functionalization locations to the protonated amine terminals of end-functional polymers after the chemical reduction of graphene oxide [36]. The noncovalent functionality promoted the transmission of graphene sheets from the water phase to the organic phase through simple sonication [37]. Figure 2 displays the noncovalent functionalization of carbon nanocomposites. Here, chitosan is packed more firmly when covalently connected to the surface of CNTs than when noncovalently functionalized CNTs. Atomic force microscopy (AFM) might be used to assess the efficacy of macromolecule coating. This figure shows Chit-f-CNT preparation (top), AFM height images (middle), and profile measurements (bottom) for pure CNT (left), Chit noncovalent functionalized CNT (centre), and Chit covalent connected CNT (right).

2.3. Wet Synthesis. Metal oxide nanoparticles are an important class of nanomaterials which find numerous scientific and technological applications. The selective surface design, step, size, and shape of nanoparticles of metal oxides can be achieved by the use of wet chemical propagation which contributes to the collection of desired properties [39]. Developments in the synthesis of metal oxide nanoparticles are noteworthy due to their use in the electronics and optics as metal oxide nanoparticles and nanocomposites are becoming more popular in applied ecology, particularly as adsorbents and photo catalysts, and also a resource for the fabrication of environmental monitoring systems [40] and catalytic and energy storage industries [41]. Metal oxides are naturally capable of isolating the metal oxide charges [42]. Nanomaterial synthesis is split into two types: top-down approach and bottom-up approach [43]. In the top-down process, a large part of the substance is broken up into nanosized bodies [44].

It takes a complicated, costly, extremely energy-intensive, and sophisticated system to sustain precise conditions such as atmosphere, heat, and temperature [46]. Top-down methodology creates nonuniform, surface-defected nanomaterials that obstruct practical application [47]. From the bottom up, the atomic or molecular agents for the formation of nanostructures are incorporated into the process. The downstream approach is largely based on humid chemicals being processed fairly scalable and flexibility [48]. The method of wet chemical synthesis has made great progress as it benefits from using a kinetic and thermodynamic provision that can alter the scale, structure, and formulation of the electronic, optical, and interface properties [49]. Wet chemical processing methods for replicating desirable shape and size of metal oxide nanoparticles have been implemented. To generate

ultrafine, extremely homogenous, and high purity powders, wet chemical techniques such as sol-gel, coprecipitation, and hydrothermal synthesis were developed [50]. The control of shape and size is accomplished by a better understanding of the fundamental events, the cycle by transforming the precursor, the surface stabilizing factor, and the reagent of the system and its interaction with the rate of proliferation and nucleation [51, 52]. A standard conventional batch technique will produce nanoparticles with a total scaling capacity of 10 mg/m [53]. The synthesis process should be versatile in terms of product quality and quantity to meet industrial specifications in order to understand the profitable functioning of colloidal metal oxide [54]. Figure 3 represents the chemical, physical, and biological approach for the synthesis of nanocomposites.

2.4. Dry Synthesis. The dry synthesis is known to be an extremely effective and adequate process for carbon nanocomposite propagation. The main benefits of this strategy are its versatility, enhanced adherence, and the advantages of the least design variables [55]. The dry synthesis has been described as the method ideally suited for the carbon decoration of metal nanoparticles [56]. The functional oxygen groups can bridge the metal nanoparticles and the carbon resources [57] through. Carbon materials with no usable surface groups may also be used consistently in carbon nanocomposite processing [58].

Nguyen-Tri et al. have established a method of quick and less dry solvent synthesis for the production of carbon nanocomposite [60]. A two-step direct process involves dry mixing of the metal precursor salt with carbon materials (CNTs or GO), followed by inert atmospheric heating [61]. No solvent, no additional reducing agents, or applied electric current are needed for the mechanochemical cycle [62]. Studies find that the mechanochemical method typically applies not only to CNTs but also to other carbon products with a high thermal conductivity, such as graphene, GO, and activated carbon [63]. The mechanochemical approach is considered rapid, adaptable, and ultimately versatile, allowing it to be used in various applications [64] for further usage. It covers possible uses in fields such as anticorrosion, antiwear, super hydrophobic area, self-cleaning, antifouling, antibacterial area, and electronics, as it is close to carbon nanocoating and it is represented in Figure 4 [65].

3. Classification of Carbon Nanocomposite

3.1. Carbon Black Nanocomposite. Polyaniline or carbon black (PANI/CB) nanocomposite structures and properties are particularly sensitive to chemical synthesis constraints [66]. It was found when the derived structures shifted from globular to a multitude of globular and nanofiber-like configurations by altering aniline and CB composition [67]. Complex nanostructures and synergistic capabilities [68] have been shown to produce the synthesis of conductive polymers and carbon-based substances. PANI/CB nanocomposites have better radiative stability and greater electrical conductivity compared to graphene-based nanotubes or nanocomposites [69]. The lightest PANI nanostructures

FIGURE 2: Noncovalent functionalisation of carbon [38].

FIGURE 3: Wet synthesis of nanocomposites [45].

would have a significant number of heterogeneous crystallization sites to strengthen, avoid assembly, and increase nanoparticle nucleation dispersion [70]. In addition to carbon black (CB), carbon fibers, melamine fibers, and mica numer-

ous reinforcement fillers have been used to enhance the mechanical properties of the finished products. Indeed, CB still retains the most significant global contribution [71]. Nanofillers, especially nanoclay (NC), have replaced

FIGURE 4: Dry synthesis of carbon nanocomposites [59].

traditional micro fillers in modern times by providing a higher surface area which correlates in much better interaction between molecular fillers [72, 73].

Based on the mechanical behaviour of nanocomposites [75], the feasible formulation of a dual filler frame in NBR matrix is researched. The impact of NC and NBR matrix interfacial communication on synergistic influence of NC and CB is explored [76]. Studies have also shown that involvement with CB, greater dispersal of NC in natural rubber, and rubber with styrene butadiene may be achieved [77]. Nanocomposites based on NBR/CB/NC and the mechanical and microstructural tests of subsequent hybrid systems have been configured to use NC and CB simultaneously [78, 79]; Figure 5 highlights methods for the synthesis of black carbon nanocomposite. The effects of heat treatment on carbon black (CB) nanocomposites are shown in Table 1.

3.2. Composites Based on Carbon Nanotubes. In the last few decades, the scope and application of nanotechnology have had an extraordinary effect on carbon nanomaterials. The university has been flush with fresh ideas, innovations, and many attempts to identify the ultimate uses for such amazing nanostructures, starting with the finding of fullerenes and going through the CO_2 era to graphene and other double-dimensional (2D) materials [81]. In this section, one such application which looked close to incorporating these materials when initially presented, but which did not meet expectations for different reasons: composite materials.

In particular, the problem of whether mechanical reinforcing structures like carbon nanotubes and graphene are the correct option remained largely unsolved and was prominently reinforced in composite matrices due to their mechanical characteristics. In addition, careful assessment and thinking are needed in the field of functionality to be obtained by inserting nanotubes against graph in a matrix [82]. Although the two are sp^2 allotropes, their structure, morphology, and dimensionality, and the nature of their interactions, with the surrounding matrix, are actually extremely different [83]. The overall mechanical composite behaviour of these two reinforcing units could therefore be distinctive [84]. It would certainly be helpful to have selection procedures in composite applications, however, in nanocomposites with CNT or graphene phases such logical techniques are not developed.

Nanostructured composite polymer materials have created new insights for multipurpose materials. Carbon nanotubes (CNTs) directly provide possible applications for the enhancement of mechanical and electrical performance in aerospace laminates [86, 87]. A new composite substance with enhanced electromagnetic properties forms the combination of epoxy resin with double-walled carbon nanotubes [88]. Documentation of nanotubes distributed in polymer matrix was intended to improve the electrical and mechanical properties of polymer composites [89, 90]. The covalent and noncovalent functionalization processes have been suggested as one of the options for improved nanotube distribution [91]. Molecular modification of the nanotube

FIGURE 5: Synthesis of carbon black nanocomposite [74].

TABLE 1: Effects of heat treatment on carbon black (CB) nanocomposites [80].

CB sample	NSA (m ² /g)	STSA (m ² /g)	O (%)	N (%)	H (%)	S (%)	C (%)	Lc (nm)	d002 (nm)
N234, untreated	126.4	120.3	2.21	0.145	0.337	0.924	93.7	1.19	0.365
N234, 900°C	134.7	124.7	1.28	0.158	0.250	0.932	95.9	1.15	0.361
N234, 1000°C	129.6	129.6	0.204	0.064	0.130	0.916	96.7	1.40	0.361
N234, 1200°C	129.0	132.8	0.128	0.041	0.021	0.790	98.7	1.44	0.355
N660, untreated	36.4	35.2	0.576	0.082	0.339	1.84	95.9	1.78	0.352
N660, 1000°C	36.4	37.3	0.110	0.056	0.141	1.78	96.8	1.59	0.355

substratum by covalent functionalization decreases the aspect ratio with the formation of carbon atoms sp^3 on the nanotube layer [92]. That reduces the power conductivity of nanotubes [93]. The cylindrical CNT specification allows them to obtain a so-called electronic conjugate framework which reflects their distinctive behaviour in electronic transport [94]. Composites incorporated in a polymer host were used for microwave operations [95] as well as for electromagnetic interference shielding (EMI) or microwave absorbers such as antireflection [96]. The advent of CNTs as filler components has contributed to the production of CNT-polymer nanocomposites as the sophisticated structural material of the next century [97]. The A polyacrylonitrile (PAN)/polyvinylidene fluoride (PVDF) nanofibers achieved a high CO₂ absorption of 2.21 wt percent and demonstrated efficiency in reversible CO₂ capture under flow gas pressures [98]. Magnetic composites based on carbon nanotubes (CNTs) have huge potential for the discovery and use of magnetic solid-phase extraction (MSPE) technology [99, 100]. Figure 6 represents the classification of carbon nanotubes based on their structural arrangements.

3.3. Graphene-Based Carbon Nanocomposites. Graphene is one of the world's finest materials and has developed consid-

erable interest in physics, materials science, chemistry, and biology. Graphene has a very high conductivity in electricity and thermal efficiency, making it the best incentives for thermally conductive composites [101]. Films used as the heating element are more smart than conventional heating elements because of lower environmental pollution, easy to use on various surface areas, and have the characteristics of lightweight [102]. At the forefront of nanotechnology are carbon-based nanomaterials from earlier C60 and carbon nanotubes into graphene [103].

The monolayer graphene is dense on a single surface and can be separated from graphite using adhesive by standard graphite flake exfoliation [105]. Classification and detachment of substantial lateral dimension of pristine graphene at high solvent concentrations are difficult. Tiny layer of graphene is containing roughly 2–10 sheets of graphene atoms, like flakes [106]. This was a by-product that was created during attempts to render monolayer graphene. Ultra-thin graphite is a graphite substance greater than 3–5 nm in diameter but less than 100 nm [107]. Graphene oxide is a strongly oxidized graphene produced by intense crystal graphite oxidation followed by sonication or some other dispersion phase, typically in aqueous absorption, forming a monolayer material [108]. Reduced graphene oxide is the

FIGURE 6: Classification of carbon nanotubes based on their structures [85].

substance produced by treating GO under reduced conditions, such as thermal processing at high temperatures [109]. Decreasing GO also influences many of its properties, such as reducing its oxygen content [110], increasing its hydrophobicity, creating CO/CO₂ emission holes or defects in the carbon lattice [111], and reducing its surface load and water supply [112]. Also, the basal planes contain unchanged, hydrophobic, and capable graphene domains of $\pi - \pi$ interactions associated with dye molecules or other drugs adsorption [113]. Figure 7 displays graphene nanocomposite structure.

The van der Waals binding of the walls of carbon nanotubes to individual layers of multilayer graphic must also be considered in layered reinforcement. Compared to the strong covalent bonding of the graph layers, this link is rather weak [114]. Therefore, when multiwalled carbon nanotube (MWNT) and multilayer graphene are employed in composites, their capacity to strengthen is restricted by simple cuts between the walls or between the layers [115]. The inner stress transmission between the nanotube walls of carbon and the graph layers may be monitored by variations in the Raman-related stress band [116]. Imperfect stress transmission occurs during deformation as the Raman band is extended, and the Raman band shift is lowness compared to the single-wall or single-level material. Comparing Raman bands stress shifts in epoxy nanocomposites for single walled carbon nanotube (SWNT) and MWNT indicate that efficiency for transferring stress from interwalls for MWNTs is only approximately 70% [117]. Compared to the large number of research on CNT and graphene reinforced polymer matrix composites, the focus on ceramic or metal composites was significantly less, maybe because of limited production [118]. Furthermore, in polymer-based composites, mechanical strengthening effects are more evident. CNTs or ceramic graphic composites are driven pri-

marily by increased toughness or resistance to fracture formation because ceramics are already stiff and solid [119]. The major toughening process is the higher energy dissipation owing to graphene nanosheet pull for graphene-enhanced ceramic composites [120]. Other difficult processes discovered include crack deflection and crack bridging on the matrix reinforcement interface. In CNT-reinforced ceramic composites, similar toughening mechanisms were also reported. Improved thermal and electrical conduction is also possible [121]. Graphene plays a vital role in removal of heavy material; they are shown in Table 2.

3.4. Activated Carbon Nanocomposites. Activated carbon, also known as activated charcoal, is a type of carbon treated with small, lower volume holes that enhance the area of the surface [123]. Because of its significant degree of microporosity, one gram of activated carbon has an area of more than 3,000 m²/g, as calculated by gas adsorption [124]. ZnO or activated carbon nanocomposites are produced by physically combining the ZnO nanoparticles produced with activated carbon [125]. The proportion of nanoparticles to activated charcoal for the adsorption of Cd²⁺ from aqueous solutions was standardized (9:1) [126]. These carbon nanocomposites are produced by mechanically combining the ZnO nanomaterials excreted above with activated carbon [127]. The concentration scope of activated carbon nanocomposites of 0.15–1.5 mg/ml has been used to evaluate Cd²⁺ formulated at concentrations between 10 and 100 ppm [128]. A sonicator probe has been used to create agitation for the adsorption of cadmium ions through vibration energy [129]. The higher adsorption power and good magnetic segregation efficiency of magnetic activated carbon are Fe₃O₄ [130] and can be used as possible sorbents for the extraction of multiple toxic contaminants from wastewater [131]. The M versus H curves for Fe₂O₃ nanoparticles and Fe₃C

FIGURE 7: Structure of graphene-based nanocomposite [104].

TABLE 2: Graphene nanocomposites for heavy metal removal [122].

Adsorbent	Adsorbate	Maximum adsorption capacity (mg.g ⁻¹)
Functionalised GOCA beads	Pb (II), Hg (II), and Cd (II)	602, 374, and 181
GO/PAMAMs	Pb (II), Cd (II), Cu (II), and Mn (II)	568.18, 253.81, 68.68, and 18.29
CS/GO-SH	Pb (II), Cd (II), Cu (II)	425, 447, and 177
MMSP-GO	Pb (II), Cd (II)	333 and 167
PVK-GO	Pb (II)	887.98
MnFe ₂ O ₄ /GO	Pb (II), As (II), and As (V)	673, 146, and 207
EDTA-mGO	Pb (II), Hg (II), Cu (II)	508.4, 268.4, and 301.2
Go/L-Trp	Cu (II) and Pb (II)	588 and 222
PAH-GO	Cu (II)	349.04
GO-CD-PPY NC	Cr (VI)	666.67
RGO/NiO	Cr (VI)	198
PAS-GO	U (VI) and Eu (VI)	310.63 and 243.90
Chitosan/GO	Cr(VI), Cu (II), and Pb (II)	461.3, 4238, and 310.4

MWCNT is shown in Figure 8. The adsorption process in activated carbon is distinct for organic and inorganic impurities. Activated carbon has the maximum removal effect for most organic contaminants. When activated carbon-quartz sand combination procedures were used, organic contaminants species and overall peak area may be decreased at the same time. However, the effects of phthalates, esters, and aldehydes were not substantially the same as dimethyl phthalate and di-nbutyl phthalate [132].

A basic progressive impregnation approach has been used to obtain some transition metal hexacyanoferrate [134], also known as microporous activated carbon composites [135] where in activated carbons are recognized as effective for many contaminants collected, having high surface area and formed porosity [120]. An activated carbon and

iron oxide nanocomposite was developed and defined by the methods of X-ray diffraction and scanning electron microscopy [136]. Figure 9 represents the nanocomposite based on active carbon.

In order to synthesise polysulfone- (PSF-) activated nanocomposites, a melt-mixing method was utilised. This study examined the properties of thermal, mechanical, magnetic, morphological, and carbon dioxide capturing and utilised 2-wt% activated carbon (CA, CA-Ni, and CO-Co) as a filler. The pyrolysis of the sawdust wood produced carbon compounds activated by Co and/or Ni Salt. The heat degradation and metal amount of carbon compounds were investigated. Thermogravimetric analysis is an effective method of measuring the polymer material thermal stability [137]. With the addition of metal-activated carbons, the beginning

FIGURE 8: M versus H curves for Fe_2O_3 nanoparticles and Fe_3C MWCNT [133].

FIGURE 9: Nanocomposite based on active carbon [142].

deterioration temperature has decreased to 4°C , which may improve to 3°C by the highest degradation temperature [138]. For pure PSF and its nanocomposites, T_g values measured with differential calorimetry scanners are almost comparable. The nanocomposite elasticity modulus exhibits a 17 percent increase in the clean PSF [139]. With the addition of the fillers, the water contact angle revealed a reduction in the hydrophilicity of the composite. In contrast to the nanocom-

posite, the carbon dioxide sorbent capacity shows an increase of about 10% [140]. With the injection of 20 wt percent metal-carbonized filler, the ferromagnetic behaviour of a thermoplastic nanocomposite was observed. Extraordinary magnetic characteristics make it attractive in many industrial applications for a thermoplastic polymer such as polysulfone [141]. The applications of activated carbon for are shown in Table 3.

TABLE 3: Applications of activated carbon [145].

Types of AC	Shape/particle size	Application
Powder AC (fine powder)	Pulverized carbon/less than 0.18 mm	Recovery of liquid and gas
Granular AC (coarse particles)	Irregular shaped/0.6-4.0 mm	Recovery, separation of liquid and gas
Extruded AC (cylindrical particles)	Cylindrical shaped/large than 4.0 mm	Natural gas storage, off-gases from wastewater control
Activated carbon fiber (threadlike piece)	Fabrication flexibility/narrower pore size compound distribution	Removal of volatile organic compound
Activated carbon cloths	Fabrication flexibility/uniform microporosity	Removal of volatile organic compound

A chemical binding on activated carbon powder (AC) nanoparticles was used for synthesising the magnetic Fe_3O_4 activated carbon nanocomposites with high surface area as recovered adsorbents [143]. In this nanocomposite, the component AC and Fe_3O_4 are amorphous nongraphic and cubic crystal structure each. Superparamagnetic characteristics were detected in all composite samples. $\text{Fe}_3\text{O}_4/\text{AC}$ nanocomposite magnetised saturation was considerably less than that of bare Fe_3O_4 particles, showing that the AC was really bound to Fe_3O_4 . The picture of the microstructure showed Fe_3O_4 particles were spread evenly throughout AC surfaces and hence kept a highly specific surface area. Methyl orange (MO) somewhat decreased its adsorption capacity at 30°C from 384 mg/g for AC ponding to 324 mg/g for $\text{Fe}_3\text{O}_4/\text{C}$, a reduction of 15 percent following magnet manufacturing. On $\text{Fe}_3\text{O}_4/\text{AC}$ nanocomposites, MO adsorption was shown to follow the pseudosecond-order kinetic model and Langmuir models could describe the isotherm. The simple recovery of magnetic adsorbents from water proved their use potential for eliminating harmful contaminants in the treatment of waste water [144].

3.5. Nanodiamonds. Nanodiamonds offer outstanding mechanical and optical characteristics and are adjustable to the surface. They are also nontoxic, making them suitable for biomedical uses. Nanodiamonds are made from explosive molecules that offer carbon source and conversion energy [146]. The approach for the disposal of obsolete weapons such as composition B, while other explosives may also be employed, is ecologically and economically feasible. The detonation occurs in a confined chamber with a “dry” or “wet” synthesis, or inert gas or water (ice) as shown in Figure 10 [147]. The resulting product soot exposure is a 4-5 nm diamond combination with various carbohydrates and contaminants. Depending on cooling medium, the carbon output is 4-10% of the weight of the explosive, during that explosion Danilenko found the formation of nanodiamonds [148]. Bouget’s pressures and heat are not sufficiently enough to make liquid carbon in bulk, but are high enough to generate nanoscale liquid carbon. The liquid carbon area is moved to lower nanocarbon temperatures, while the nanodiamond region is moved slightly into higher pressures. It is therefore hypothesised that nanodiamonds develop via the condensation and crystallization of the liquid carbon in volume of the super saturated carbon vapour [149]. Other approaches (such the use of shock waves to generate graphite nanodiamonds) yield crystallite-sized nanodiamonds of

more than 10 nm. The soot detonation, apart from the diamonds phase, includes both graphics (25%-80% wt) and incombustible impurities (1%-8% metals and oxides). The distinctive property of nanodiamonds is that many different functional groups are bonded to their surface compared to carbon nanotubes and other graphic nanoparticles, thereby permitting advanced surface functionality without sacrificing the beneficial characteristics of the diamond core [150].

However, it is equally important to understand how these groups interact with their environment and minimize harmful consequences (such as aggregation). While commercial nanodiamond powders may be utilised for the covalent functionality of different functional groups, the usage of air purification or ozone-generated carboxylated nanodiamonds and then the rich chemistry of COOH groups are more easy to start with. Nanodiamond is a good filler for composites due to its superior mechanical and thermal characteristics and the rich surface chemical properties of diamond nanoscale particles. The diamond core’s biocompatibility and chemical stability make them extremely suitable for biomedical use. The addition of tiny quantities of nanodiamond generated transparent polyvinyl alcohol nanocomposites with enhanced mechanical characteristics [152]. Surface chemistry can influence the interactions between the nanoparticles of the diamonds and the matrix, as well as the dispersion of the nanoparticles in the matrix. Table 4 shows the biomedical applications of nanodiamond composites.

4. Industrial Applications of Carbon Nanocomposites

4.1. Super Capacitors. As an electricity collection system, super condenser finds desirable applications in consumer product and alternative energy sources due to its increased energy density, rapid discharge and charge time, lower heating, protection, long-term operating reliability, and no removable components [154]. In particular, CNTs are desirable electrode resources for the production of high-performance super condensers due to its innovative characteristics of high conductivity, high specific volume, high charging power, high mesoporosity, and high electrolyte functionality [155]. These are an appealing choice for applications for energy storage in compact or remote devices [156] where electrodes and traditional condensers must be overdimensioned due to unfavourable power-to-energy ratio [157]. Carbon aerogel (CA) or any other types of carbon

FIGURE 10: Synthesis of nanodiamond [151].

products such as black carbon or carbon cloth are commonly used in these super condensers [158]. Two essential parts for a CNT super capacitor are the electrodes and the electrolyte [159]. Capacity of traditional carbon electrodes will slowly decrease as current discharge density increases [160]. Specific capacitance of nanocomposite electrode with-grown single-walled CNTs, pure PPY, and single-walled CNT-polypyrrole (PPY) is a result of discharged current densities [161].

The performance of today's super capacitors in terms of power density must be significantly increased, yet maintaining a long life cycle to satisfy the demanding demands of electric hybrid and large-scale industry applications [162]. In order to increase the efficiency of supercapacitors, nano-carbon materials from first generation are employed as electrode materials. MWCNTs as electrodes are in regular, box-like form, with a capacitance up to 120 FG1 and a pure electrostatic attraction characteristic (the value depends on the scanning rate). A gravimetric capacitance of 20 to 300 F/g is displayed for EDLCs with a SWCNT electrode. Graphene-processed supercapacitors do not improve performance considerably. The biggest drawback for super capacitors is the limited specific surface area of such nanocarbons [163].

4.2. Biosensors. The integration of observable traits into analytical instruments, particularly in medical research, is becoming a prerequisite for early detection of various diseases [164]. Carbon nanotubes (CNTs) are pseudoone-dimensional carbon allotropes, especially identified as a system of carbon atoms arranged into one or more levels of smooth cylinders with either open or closed edges [165]. CNTs have quite wide specific surface area which enables for the immobilization of a substantial number of operational units such as biosensing receptor moieties [166]. CNTs possess special optical intrinsic properties such as near-infrared photoluminescence (NIR) [167]. The biocompatibility and biodegradability were increased by turning the layer of pristine CNTs into hydrophilic f-CNTs [168]. Such biosensors analyse a broad variety of genetic markers of cancer by conjugating DNA or proteins, peptides, enzymes [169], and electrochemical biosensors for the early diagnosis

of genetic markers of cancer [170]. Microspecificity of the enzymatic reaction is used by CNT-based enzymatic electrochemical nanomaterials to guide electrical transfer among biomolecules [171]. CNT paste was produced of brumofom, and the electrode was designed with superior enactment over all other carbon electrodes [172]. Bioaffinity electrochemical biosensors are very robust complexes [173] in CNT-DNA electrochemical biosensors have been designed to acquire a simple, cheap, fast sensor [174]. Figure 11 shows the applications of biosensors from nanocomposite. For example, the synthesis of 3-methoxy phenol sensor used for biotech applications made from Fe_3O_4 .CNT NCs/GCE, and its calculation is shown in Table 5.

Although the study of carbon nanotubes in biological applications is still in its early stages, it has enormous potential. Carbon is a particularly biocompatible substance since it makes up a large portion of the human body [176]. Cell growth on CNTs has been proven; hence, they do not appear to be harmful. The cells also do not attach to the CNTs, which opens the door to uses such as antifouling coatings for ships and prosthetic coatings [177]. The ability to functionalize (chemically alter) the sidewalls of carbon nanotubes (CNTs) opens the door to biological applications such as neuron development and regeneration and vascular stents. It has also been shown that a single strand of DNA may be linked to a nanotube and then efficiently implanted into a cell [178].

4.3. Solar Cells. A new type of solar cell, dye-sensitized solar cells (DSSCs), based on nanocrystalline TiO_2 electrodes, has captured the attention of industry and academia [179]. DSSCs offer lower manufacturing costs relative to commercial silicon-based solar cells and provide similar advantages for amorphous silicon solar cells [180]. CNTs will have a possible high-field direction that interpenetrates DSSC electrodes along. The hypothesis was that carbon nanotubes would effectively increase the electrode's electrical conductivity and thus improve the solar system's light conversion performance [181]. Due to extreme CNT aggregation [182], the expansion of the CNT charge will impair the efficiency of DSSC cells. Dye-sensitized solar cells (DSCs) consisting of colouring molecules, nanocrystalline metal oxides, and natural liquid electrolytes have valuable high-performance characteristics in energy conversion and low energy and manufacturing costs [183]. The carbon cloth (CC) altered MWCNT- MnO_2 /PPy nanocomposite electrode has a good biocompatibility resulting in a well-recognized moderator for the production of bioelectricity in wastewater with less MFCs [184]. Microbial fuel cells (MFCs) generate electricity for the oxidation of organic materials such as acetate, lactate, and glucose from exo electrogenic substances [185]. MFCs have applications in the fields of renewable energy recovery, remotely controlled power supplies, nanomaterials and biofilm testing, hydrogen production, and chemical fermentation systems due to their flexibility in processing various bacterial sources [186].

4.4. Radar Absorbing Materials. The curiosity in radar-absorbing materials (RAM) has extended to the business

TABLE 4: Biomedical applications of nanodiamonds [153].

Nanodiamond kind	System	Cells	Toxicity
Fluorescent nanodiamonds prepared by detonation method	Fluorescence nanodiamond PCL fibers	Human lens epithelial cell line	Nontoxic and the scaffold can support in vitro cell growth
Nanodiamonds	Particle	Hepatocyte cells	Nontoxic less than 10 $\mu\text{g/ml}$
Nanodiamonds	Particle	Lymphocytes and cervical cancer cells in vitro	Toxic
Nanodiamonds	Particle	Three kinds of mammalian cells	It is possible an effect in noncovalent adsorption between NDs and serum proteins in culture medium
Nanodiamonds	Natural polymers-BG composite coating by electrophoretic deposition	Human osteosarcoma cell line	Improving cellular behaviour

FIGURE 11: Applications of biosensors from nanocomposite.

sector as they can be used to minimize electromagnetic interference due to recent developments in electromagnetic devices entering the RF frequency range [187]. Short carbon fiber reinforced composites (CFRC) are ideally suited for the development of thin multipurpose RAM [188]. Owing to their high execution of electrical and thermal qualities at comparatively low concentration, composites dependent on polymers and carbon nanofillers have received significant interest in both academic and industrial societies [189]. Extraordinary interest has been given to carbon nanostructure-filled polymer nanocomposites as electromagnetic absorbers in both military and civil applications [190] in terms of their ability to modify electromagnetic and molecular properties at comparatively low quantities of nanofiller extraordinary interest has been given to carbon nanostructure-filled polymer nanocomposites as electromagnetic absorbers in both military and civil applications [191] in terms of their ability to modify electromagnetic and molecular properties at comparatively low quantities of nanofillers and their light weight, outstanding thermal tolerance and high mechanical characteristics and their light weight, and outstanding thermal tolerance and high mechanical characteristics [192].

4.5. Energy Storage. The intrinsic characteristics of CNT make them two fast-growing technologies the ideal material to be used as electrodes in condensers and batteries. The electrical conductivity of CNTs is high, and their area of exceptionally high surface ($\sim 1000 \text{ m}^2/\text{g}$) is particularly accessible to the electrolyte because of their linear geometries. Research has shown that CNTs have the largest reversible capacity for usage in lithium-ion batteries with any carbon material [193]. In addition, the CNTs are ideal materials for electrodes with supercapacitors and are readily available for sale. Moreover, CNTs are used in several components of the fuel cell. They have various features, such as high thermal conductivity and surface area, and are important in PEM fuel cells as electrode catalyst support [194]. They also may be utilised in gas diffusion layers, in addition to current collectors, due to their high electrical capacity [195]. CNTs are also able to demonstrate great strength and toughness to weight as part of composites in fuel cells that are utilised in transportation applications where durability is essential [196].

4.6. Field Emission Applications. CNTs are the best-known source of any substance in the area. It is comprehensible because of its great electrical performance and the incredible sharpness of its tip (when the curvature radius of the tip is reduced, the electric area will be concentrated, resulting in enhanced emissions from the field, this is because of the sharp lightning rods) [197]. Moreover, the sharpness of the tip also suggests that they emit at a very low voltage, which is a critical attribute for creating low-power electrical devices [198]. CNTs may be quite current, perhaps up to 1013 A/cm^2 . CNT's are very high. The current is also quite steady. This characteristic is implemented immediately and attracts great interest in field-emission flat panel displays. CNT-based displaying uses a distinct electron gun (or perhaps several of them) for every pixel in the view, as opposed to traditional cathode ray tube display with a single electron gun [199]. CNTs have low turn-off and operating voltages, a large current density, and constant, long-lived behaviour, which make this application highly desirable. Other applications using CNT's field emission properties are general low-

TABLE 5: Calculation of 3-methoxy phenol sensor with $\text{Fe}_3\text{O}_4\text{-CNT NCs/GCE}$ [175].

Samples	Observed current (μA)				Conc. (μM)	SD ($n = 3$)
	R1	R2	R3	Average		
Industrial effluent	7.09	5.27	4.91	5.75	23.76	1.17
PC baby bottle	7.73	5.25	4.42	5.80	23.96	1.72
PC bottle	1.66	4.14	3.85	3.22	13.30	1.36
PVC food packaging bag	4.18	3.08	2.77	3.34	13.80	0.74
Red sea water	4.33	3.31	2.58	3.41	14.09	0.88
Tape water	3.54	2.66	2.31	2.83	11.71	0.63

voltage cold cathode light sources, electron microscope sources, and lightning arresters [200].

4.7. Conductive Plastic. Plastics have been used in many cases as a metal replacement. Polymers have improved enormously for structural applications but not where electrical conductivity is essential, as plastics are particularly strong electrical insulators [201]. The filling of polymers with lever fillers like as carbon black and bigger graphite fibers can prevent this deficit (the ones used to make golf clubs and tennis rackets) [202]. However, the loading needed is generally considerable, resulting in hefty parts and plastic parts which have a high degraded construction characteristic, in order to give the requisite conductivity via traditional fillers [203]. As the load needed for a certain conductivity is reduced as the filling particle aspect ratio is higher. For this reason, CNT is excellent since it has the greatest carbon fiber aspect ratio. In addition, their intrinsic inclination to shape cords provides naturally very lengthy leading routes even at extremely low loads [204]. This characteristic of CNT is used in applications such as electrostatic dissipation (ESD), composite EMI (electromagnetic interference), shielding, gasket, enclosure, and other usage coatings, low-observance radar absorption materials, and conductive (even transparent) antistatic and material coatings [205].

4.8. Future Scope. Significant improvements in the preparation of carbon nanotube-polymer composites with remarkable mechanical and physical characteristics have been achieved. In this area, a great deal of study is still required until these remarkable characteristics are completely realised in a macroscopic nanometric medium. In addition, experiments have to be done in order to identify disintegration or recycling mechanisms for carbon nanocomposites in order to create something new at the end of their life cycle (recycle). Furthermore, research has not progressed much while attempting to produce naturally enhanced compounds using biologically degradable polymer matrix, as the creation of such “green composites” poses a number of obstacles. They are regarded as the most ecologically sound material but issues such as poor adherence to the fiber matrix, difficulty in fiber orientation, and the attainment of nanoscale dimensions halt those materials in search of appropriate applications. In this regard, some limitations include insulating individual nanofiber composites to evaluate the nanofibers tensile characteristics and adhere them to a load tester

which is yet difficult. Electro spun nanofiber, atomistic modelling, and continuum mechanism methods remain a major challenge to theoretical approaches in prediction of the mechanical behaviour of CNTs implanted in electro spun fibers.

5. Conclusion

Carbon nanocomposites assisted by metal nanoparticles have been observed to perform a substantial role in a broad array of potential applications in science and technologies. In this research work, the prominent enhancements have been made in formulating carbon nanotube polymer composite materials with excellent mechanical and thermodynamic properties are studied. The carbon nanotube functionalization improves the diffusion status of carbon nanotubes and to change the properties of the device and boost the attributes of polymer nanocomposite products, particularly material properties. The incessant demand for the commercial usage of engineered carbon-based nanomaterials is increasing in the field of modern technology, medicine, environment, and agriculture; the distinctive properties of carbon-based nanomaterials have engrossed great concentration by the researchers and industrialists which has stimulated the expansion and innovation techniques for significant industrial production.

- (i) The advanced production techniques for carbon nanocomposites (primarily graphene or graphene oxide and CNTs) and their usage in organic processes have been discussed
- (ii) Layered nanocomposites are the most widely used materials for increasing the barrier character of polymer nanocomposites in packaging applications
- (iii) Nanocomposites also serve as organic photovoltaic sheets in solar panels. These films may be utilised as flexible semitransparent modules and are exceptionally light in weight. The other advantages of these films are continuous production for different light and climatic conditions
- (iv) Nanocomposites based on graphene oxide (GO) can make a substantial contribution to the treatment of waste water by removing heavy metals

- (v) Due to characteristics such as long-term durability, better sensitivity, stronger order conductivity, and easy production, carbon nanocomposites are used in construction of sensors

Conflicts of Interest

The author(s) declare(s) that they have no conflicts of interest.

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