Chapter

Improved Nanocomposite Materials and Their Applications

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Abstract

Nanotechnologies and nanocomposite materials have gained the attention of scientific community in recent years. Nanocomposite material consists of several phases where at least one, two, or three dimensions are in the nanometer range. Nanocomposites with advanced carbon nanostructures i.e., carbon nanotube (CNTs) and graphene, attachments have been regarded as promising prospects. CNTs and graphene-based improved nanocomposites are usually categorized into various classes based on different types of discontinues phases. The nanocomposites reinforced with carbon nanomaterials i.e., CNTs and graphene have been explored extensively for use as engineering materials in several demanding applications because of their excellent properties. The present book chapter has been prepared in three main sections. In the first portion, nanocomposites and carbon nanofillers i.e., CNTS and graphene have been presented. In the second part, different types of CNTs and graphene-based improved nanocomposites have been described with reported literature. In the third section, focus is on the applications of improved nanocomposites such as energy storage, antimicrobial activity, gene delivery, catalyzed organic reactions, radar adsorbing materials, actuators, wind turbine blades, pollutant removal, aerospace industry, and conductive plastics.

Keywords: nanocomposites, carbon nanoclusters, carbon nanotubes, graphene, improved nanocomposites, applications

1. Introduction

In modern technology, composites are one of the most essential materials, which are the aggregate of two or more materials having different physical and chemical properties discriminated by their interface. Therefore, unlike the individual materials, the composite materials exhibit a distinctive property [1]. Mostly composite materials consist of at least two components including a continuous matrix phase and discontinuous reinforcement material while the other consists of one or more discontinuous phases dispersed in one continuous phase. Generally, a discontinuous phase has more advanced mechanical properties than a continuous phase. Continuous phase is known as "matrix" while discontinuous phase is called "reinforcement" or reinforcing material. Based on the size of reinforcement in the structures, composites are commonly divided into three basic classes, named macrocomposites, microcomposites, and nanocomposites. Nanocomposites offer excellent features by the application of reinforcement in the composite below 100 nm in size phase [2].

1.1 Nanocomposites

Nanocomposites are multi-phasic materials, in which at least one phase show dimensions in the nano range (10–100 nm). In nanocomposites, interaction between matrix and reinforcement is very high due to high surface-to-volume ratio. The improved properties of nanocomposites depend on properties of each material, their relative amounts, and the overall geometry of the nanocomposites. Various materials possess different properties which when combined results in the formation of new material with additional advantages relevant to different areas of science and technology. They have high thermal and mechanical stability, multifunctional capabilities, chemical functionalization, and huge interphase zone. Generally, the nanocomposites show enhanced properties, such as high specific stiffness and strength, high toughness, low density, corrosion resistance, and thermal insulation [3]. Currently, nanocomposite materials have emerged as a suitable choice to overcome restrictions of different engineering materials. The amalgamation of nanoparticles into a matrix of materials like polymer, metal, or ceramics promote their properties such as excellent mechanical stability (in terms of strength, dimension stability, toughness, flexibility, Young's modulus, etc.), good optical activities, flame retardancy, low water/gas permeability, and high electro-thermal conductivity [4]. Nanocomposites are accepted at both the academic and industrial levels due to their extraordinary properties, distinctive design capacity, eco-friendly nature, easy fabrication, and cost-effectiveness. Nanocomposites have been commonly used in numerous applications due to their advanced properties. They are reported to be the materials of the 21st century in the vision of possessing design uniqueness and property permutation that is not found in conventional composites [5].

2. Carbon nanostructures

Carbon-based materials have a huge stimulus in encouraging the improvement of society due to their abundance on the earth and environmental kindliness and other merits. Over the past few decades, carbon materials such as CNTs and graphene class of materials have seen incredible growth due to the discovery of advanced nanostructures. The innovation and study of carbon nanofillers have played a major role in the development of nanocomposites. Based on their dimensions, researchers classified materials as zero-dimensional (0-D) nanoparticles or quantum dots, one-dimensional (1-D) nanobelts, nanowires or nanotubes, two-dimensional (2-D) nanoplates or nanodisks, and three-dimensional (3-D) nanocones or nanocoils as shown in **Figure 1**. The nano-structured materials (NSMs) have drawn extreme interest due to their structure, surface area, size effects, and considerably improve the performance of the composites [7]. Carbonaceous nanofillers such as carbon nanotubes (CNTs) and graphene play a potential role as compared to others due to their improved structural and functional properties such as high aspect ratio, high mechanical and electrical properties, etc. [8]. In the last few decades, CNTs and graphene have been considered the most substantial nanofiller to formulate advanced nanocomposites for both academic and industrial fields due to their several potential applications. The combination of polymer nanocomposites with graphene-related materials (GRMs)

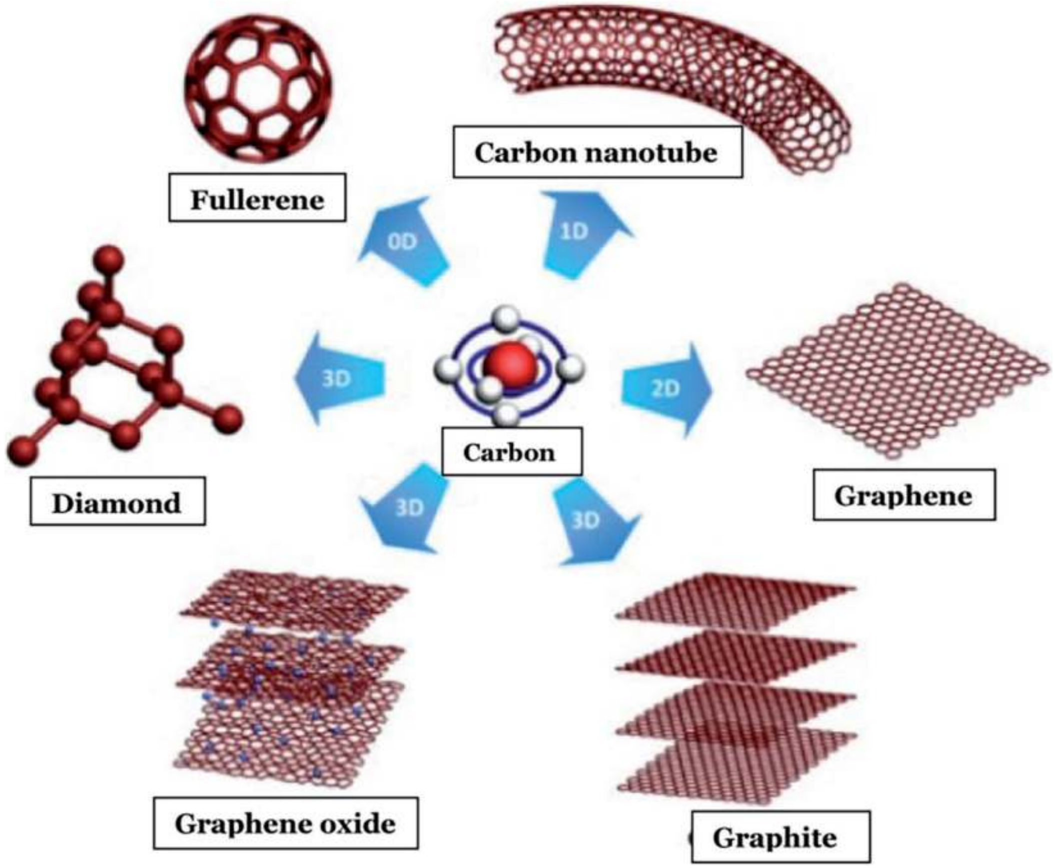

Figure 1.
Nano-carbon materials including 0D fullerene, 1D CNT, 2D graphene, 3D graphite, 3D graphene oxide, and 3D diamond are demonstrated [6].

or carbon nanotubes (CNTs) has been discovered as a result of their low mass density and excellent mechanical properties for use in engineering materials for various challenging purposes [9].

2.1 Carbon nanotubes

CNTs are one-dimensional carbon materials that are different from other carbon compounds, such as graphite, diamond, and fullerene (C_{60}, C_{70}, etc.), having an aspect ratio greater than 1000 [10]. In 1991, Iijima discovered carbon nanotubes [11], which brought innovatory changes in the field of polymer nanocomposites. Ajayan et al. [12], reported the first carbon nanotubes reinforced polymer nanocomposites. Basically, carbon nanotubes are graphene sheets having hexagonal structures which are rolled up into cylindrical form and rounded off with half shape of fullerene structure. The two types of carbon nanotubes are the single-walled nanotubes (SWNTs), which are single graphene sheets rolled into a cylinder and the other one is multi-walled nanotubes (MWNTs), in which numerous graphene layers are stacked into concentric layers in the form of cylinders with an interspacing of 0.34 nm (**Figure 2**). On the basis of atomic arrangement, the three types of structures are zigzag, armchair, and chiral (**Figure 3**) [13]. Properties of carbon nanotubes are greatly reliant on morphology, size, and diameter and maybe metallic or semiconducting depending on the atomic arrangement [14].

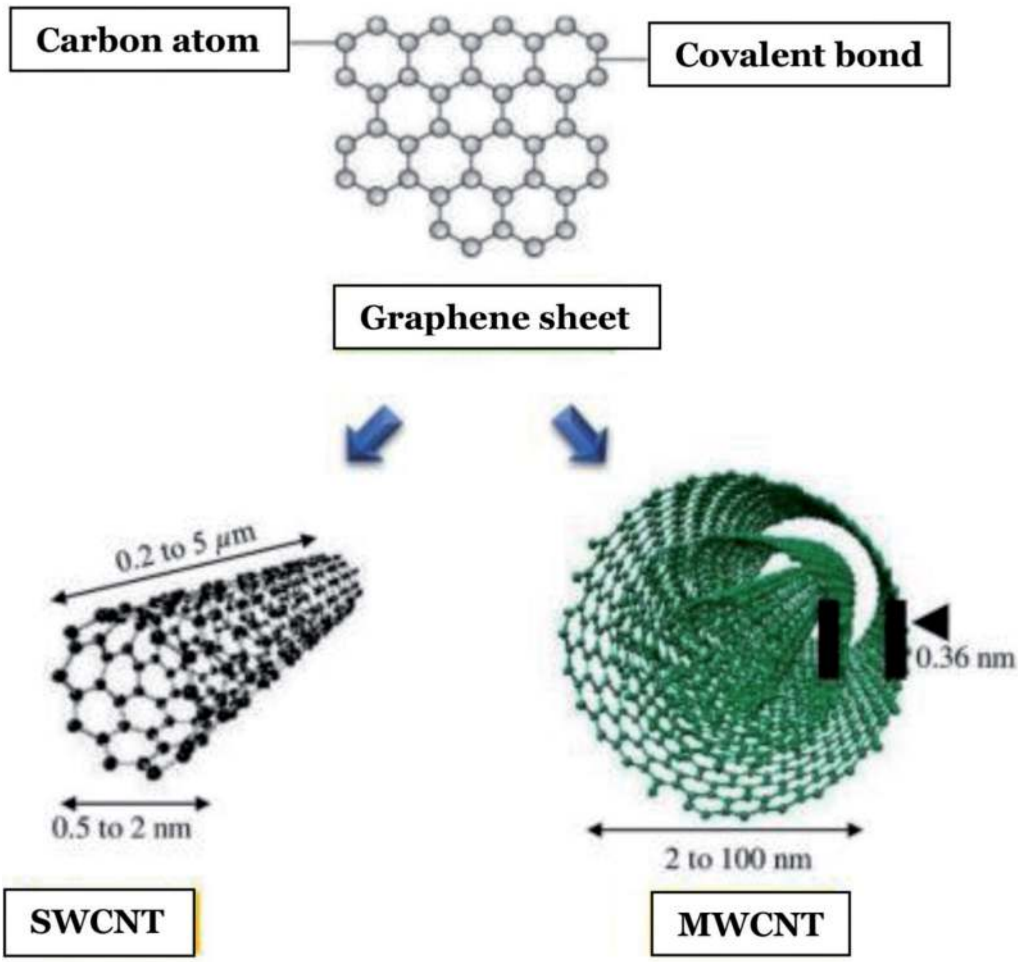

Figure 2.
The conceptual diagram showing the general dimensions of the length and width of single walled carbon nanotubes (SWCNTs) and multi-walled CNTs (MWCNTs [13].

2.2 Graphene

Graphene, a typical 2D material, has received incredible attention due to attractive features like very high specific surface area (2360 m^2g^{-1}), highest strength (≈130 GPa) and Young's modulus (≈1.0 TPa), best known thermal conductivity (TC, ≈5000 W m^{-1} K^{-1}), and electrical conductivity (10^8S m^{-1}). Therefore, graphene is the perfect nanofiller for improving the mechanical, electrical, thermal, and optical properties of polymers [15]. Through valuable interfacial stress transfer, graphene effectively improves the mechanical properties like tensile strength and Young's modulus of polymers [16, 17]. Graphene can competently strengthen brittle polymers by extending the crack propagation path in nanocomposite. The excellent electrical property of graphene can clearly improve the electrical conductivity of polymers for free electrons by building a conductive network [18]. The distinctive thermal conductance of graphene carries the excitement to formulate high-performance thermal conductive nanocomposites for application in high power density devices in thermal management [19, 20]. Due to distinct ultrahigh thermal conductivity, graphene is engaged to fabricate the thermal interface materials (TIMs) [21] and phase change energy storage composites (PCCs) [22].

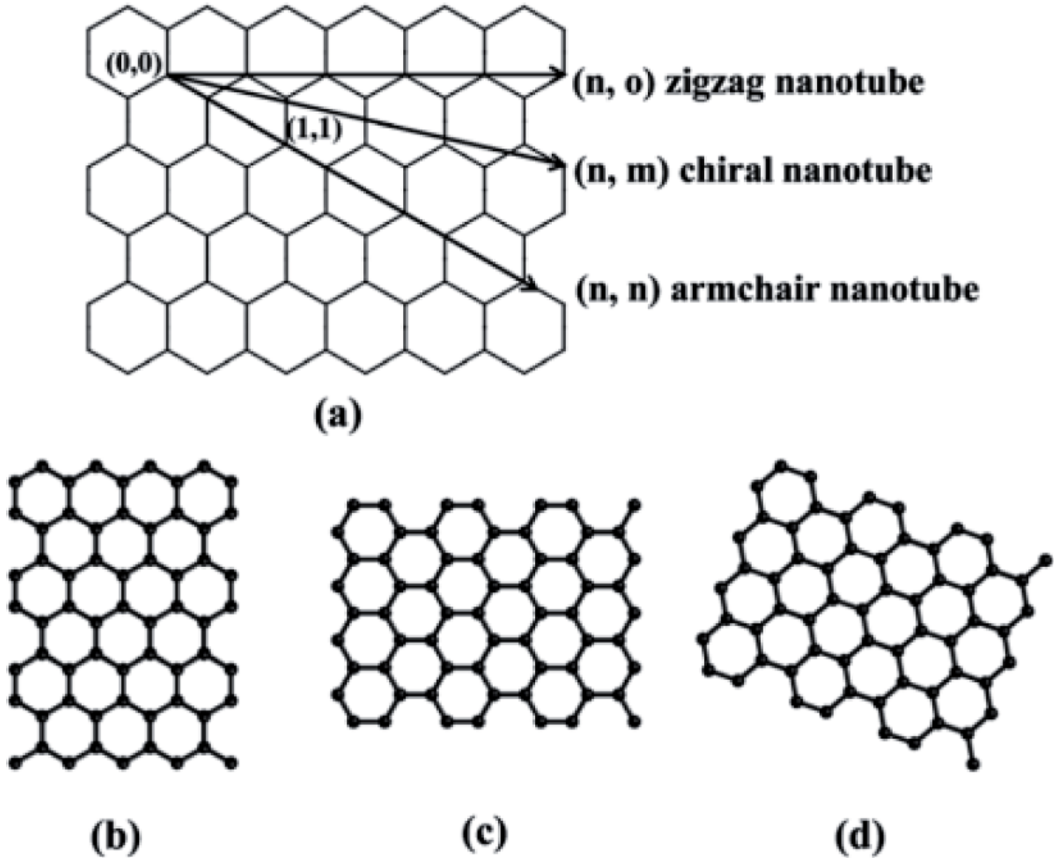

Figure 3.
Schematic representation of how a graphene sheet is rolled to form three chiralities of nanotubes: (b) zigzag, (c) armchair, and (d) chiral nanotubes [13].

2.3 Diamond

Diamond is a three-dimensional carbon material with a crystal structure called diamond cubic. Diamond is an outstanding carbon material because of its inert nature, high-thermal conductivity, stiffness, biocompatibility, and optical transparency. Nanodiamonds (NDs) are advanced carbon nanostructures with sp^3 hybridized carbon atoms bonded to form diamond-like cubic geometry. Their dimensions are in the range of 5 to 10^2 nm. Numerous properties of NDs are far better than bulk diamond and they present these properties on nanoscale [23]. The superior mechanical and thermal characteristics of ND make it a suitable nano-filler for carbon-based nanocomposites. The surface of common synthetic NDs has no functional groups. Nevertheless, an ND can be modified with a functional polymer or be functionalized with hydrogen/deuterium-terminated, halogenated, aminated, hydroxylated, and carboxylated by strong reagents and under severe conditions according to targeted applications and desired physicochemical properties [24].

2.4 Fullerenes

Fullerenes are a new class of carbon nanomaterials discovered in 1985 by Kroto et al. and get the Nobel prize award in chemistry for the year 1996 [25]. According to

Mukherjee et al. the diameter of fullerenes nanomaterials is ≤1 nm [26]. The fullerene family includes several atomic C_n clusters (n > 20), composed of carbon atoms on a spherical surface. They are closed-cage carbon molecules containing pentagonal and hexagonal rings with sp^2 hybridized carbon atoms bonded by covalent bonds. The carbon atoms are regularly arranged at the vertices of pentagons and hexagons surfaces. They have the formula C_{20+m}, with m being an integer number, and comprise a wide range of isomers and homologous series, from the most common and investigated C60 and C70 to the so-called higher fullerenes like C240, C540, and C720. The incorporation of fullerene nanofiller into numerous polymers has been achieved by physical and chemical methods [27]. In this way, the combination of distinctive features of fullerenes with physical properties of polymers may yield advanced polymeric materials with novel physicochemical characteristics. The attractive physiochemical properties of fullerene-based nanomaterials make them suitable materials to use in medicinal chemistry [28].

3. Improved carbon nanocomposites

In various fields of technology such as medical, sensors, computing etc. materials play important role for our comfort. The use of new materials with enhanced properties is a critical need due to demand for betterment. High-performance nanocomposites are recommended for industrial use like energy storage, damage sensing, aerospace and automobiles but have some limitations. The discovery of carbon-based nanofillers plays a vital role to overcome these limitations [29]. Combination of CNTs and Graphene extensively improves the properties of nanocomposites. CNTs and graphene are considered significant nanofillers to formulate advanced nanocomposites due to their several possible applications. At nanoscale, carbon nanotubes and graphene nanoplatelets (GnP) materials suggest an exclusive combination of elastic modulus (0.8–3 Tpa), thermal conductivity (3000–6000 W/m-K), and electrical resistivity (3–20 μΩ-cm) [30–33]. Some researchers have processed nanocomposites in the range of 0.2–5 weight % of CNTs into various polymer matrix materials [34]. These nanocomposites revealed 10–35% enhancement in properties such as modulus, strength, impact resistance, thermal conductivity, and electrical conductivity, compared to the matrix polymer.

3.1 Carbon nanotubes-based nanocomposites

Carbon nanotubes have been deemed as versatile building blocks to create a novel generation of nanocomposites desired for a variety of commercial applications.

3.1.1 Polymer/CNT nanocomposites

The nanoscale CNTs amalgamation into a polymer system highly modifies the properties of composites even at a particularly low content of filler. As explained earlier, CNTs are the strongest and hardest fibers ever known. The excellent mechanical and other physical properties of CNTs demonstrate huge potential applications of Polymer/CNT nanocomposites which are one of the most studied systems. Polymer matrix can be easily fabricated without disturbing CNTs by conventional manufacturing techniques resulting in cost reduction for mass production of nanocomposites in the future [35]. Paul et al. [36] synthesized polypyrrole (PPy) and MWCNTs nanocomposites with different compositions by chemical oxidative polymerization method. Polypyrrole (PPy)/MWCNT have been effectively used as supercapacitor devices. Béguin and his research group studied conducting polymer and CNTs based nano-electrodes with improved mechanical, thermal, and electrical properties [37]. PANI/ MWCNT nanocomposite with a specific capacity of 440 Fg^{-1} at 5 mVs^{-1} and capacitance retention of 93% after 1000 cycles was reported [38]. Lezak et al. [39] prepared polyaniline (PANI) as an intrinsically conducting polymer and poly (vinylidene fluoride) (PVDF) and MWCNTs.

3.1.2 Activated carbon/CNT nanocomposites

Activated carbon, also known as activated charcoal, is a carbon type that is treated with tiny volume holes to improve the surface area. One gram of activated carbon, due to its increased microporosity, has a surface area of more than 3000 m^2/g calculated by gas adsorption [40]. Activated carbon (AC)/CNTs nanocomposites are superior materials having AC as matrix material and CNTs as fillers. Numerous researchers have used activated carbon for production of CNT nanocomposites. Huq et al. [41] studied the preparation of AC and CNTs based supercapacitors by a superficial electrophoretic deposition (EPD) method. In this study, the as-prepared AC/CNT electrode had capacitance maintenance of 85% after 11,000 cycles. In EDLC electrode, activated carbon has been used for an extensive period due to its high capacitance, low cost, and long cycle life [42]. Qiu et al. [43] prepared activated carbon fibers (ACHFs) combined with carbon nanotubes and nickel nanoparticles (CNTs-Ni-ACHFs) by thermal reduction and chemical vapor deposition method. Usually activated carbon, due to its very high surface area, is used as an absorbent [44].

3.1.3 Metal oxide/CNT nanocomposites

Carbonaceous materials have high power and low energy density which cause restrictions in their general application. However, metal oxides, due to their high-energy density, are used as pseudo capacitor electrodes for supercapacitors [45]. Yuan et al. [46] developed a new method for CNTs coated magnesium oxide (MgO) nanoparticles to increase the interfacial bonding strength. Yuan et al. [47] examined a sandwich structured MoO_2 @TiO_2 @CNT nanocomposite by an easy two steps synthesis method under Ar/H_2 flow, controlled hydrolysis, and a subsequent heat treatment. Alam et al. [48] prepared BaMg0.5Co0.5TiFe10O19/MWCNT nanocomposites by varying the amount of MWCNTs (0, 4, 8, and 12 vol%). Nanocomposite with 8% vol. of MWCNTs performed best.

3.1.4 Carbon fibers/CNTs

A novel method was studied to graft carbon nanotubes over carbon fiber to form a CNT/CF [49]. Islam reported direct covalent bonded CNTs and CF without any catalyst or coupling agents through ester linkage. CNTs can be used to reinforce CFs to improve interfacial shear and impact strength [50]. Two methods are reported to attach CNTs with CF by physical adsorption (Van der waals interaction), which are weaker than chemical covalent bonding [51].

3.2 Graphene-based nanocomposites

Graphene-based nanostructured materials have distinctive 2D structures with high electronic mobility, exceptional electronic and thermal conductivities, excellent optical performance, good mechanical strength, and ultrahigh surface area as compared to other materials.

3.2.1 Polymer/graphene nanocomposite

Graphene nanofiller addition within the polymer has a promising application in biosensors, energy storage devices, photocatalysts, drug delivery. Recently, a wide range of processing methods has been studied for scattering both GNP and GO-derived fillers into polymer matrices. Controlled amount of nanomaterial by weight % and size is carefully taken into deliberation [52]. Salimikia et al. [53] synthesized a solid-phase microextraction fiber over polyaniline/graphene oxide nanomaterial using the electrospinning method and used it as sorbent for determination of nicotine. Farajvand et al. [54] prepared Graphene oxide/polyaniline nanocomposite and used it as an adsorbent to determine cadmium (II) ions in an aqueous solution.

3.2.2 Activated carbon/graphene nanocomposite

Activated carbon is considered as the center of research for commercial utilization. Adsorption properties of metal ions by AC/GR have been examined and a number of methods have been developed for synthesis of graphene/activated carbon nanosheet composite to make high-performance electrode material for supercapacitors. Many research groups have used activated carbon for preparation of graphene nanocomposites. Xin et al. [55] reported a new carbon nanocomposite material having graphene and activated carbon and used it for oxygen electrode (cathode) in Li-ion batteries. In the AC/GR, the graphene showed a three-dimensional (3D) arrangement having good electrical conductivity and exceptional mechanical strength and elasticity, while the AC coating on the graphene surface supplied several meso/micropores with diameters less than nanometers. Lu et al. [56] investigated an easy method to prepare a new catalyst by electrodepositing of Ag nanocrystals on the different polymer dyes, Poly (methylene blue) or Poly (4-(2-Pyridylazo)-Resorcinol) modified graphene carbon spheres (GS) hybrids which had advantages of both carbon spheres and graphene composite and were employed for detection of H_2O_2 as non-enzymatic electrochemical sensor. Hossain and Park [57] studied the hydrothermal method for the synthesis of glucose-treated reduced graphene oxide-activated carbon composites. Platinum nanoparticles were electrochemically deposited on a modified composite surface. Chitosan-glucose oxidase composites and Nafion were incorporated into modified surface of working electrode for the preparation of an extremely sensitive glucose sensor.

3.2.3 Metal oxide/graphene nanocomposite

In this type of nanocomposites, metal oxide particles are incorporated in graphene nanosheets. Metal oxide-based Graphene nanocomposite has attained the attention of scientific community as anode materials due to high kWh/cost and effective high-performance electrode material in an electrochemical supercapacitor. Beura et al. [58] prepared ZnO-based graphene nanocomposites by hydrothermal method and used it as a catalyst for the degradation of dyes. The band of the nanocomposites was 2.84 eV, while the photoluminescence lifetime increased from 15.05 to 21.60 ns. Photocatalytic activity of the composite material was investigated by both anionic and cationic dyes. Borah et al. [59] used an in-situ method to synthesize TiO_2/rGO. The prepared nanocomposites were used to catalyze the transesterification of waste cooking oil into biodiesel. Excellent catalytic activity was shown by the catalyst and 98% conversion of oil into biodiesel was seen at optimum reaction conditions. Wang et al. [60] presented a detailed summary of the research progress on the low-cost metal oxides/graphene nanocomposites (MOs/G) as anode materials for SIBs.

3.2.4 Metal/graphene nanocomposites

Various heavy metals such as Au, Fe, Cu, Ce, etc., have been introduced into graphene nanosheets to form different nanocomposites. Nanocomposite with ultra-low resistivity than conventional copper metal at room temperature is the next generation conductor. Several research groups have fabricated metals/ graphene nanosheets. Arukula and co-workers [61] prepared rGO/polyaniline (PANI)/Pt–Pd nanocomposite by wet reflux strategy. The prepared nanocomposites materials were used as potential anode catalysts with improved methanol oxidation tendency for direct methanol fuel cells (DMFCs). Xuan et al. [62] reported a 3D patterned porous laser-induced silver-based graphene nanocomposite. The prepared nanocomposites were used as an electrode, which showed high, uniform electrical conductivity even under mechanical deformations. Incorporation of platinum and gold nanoparticles on the 3D porous LIG importantly enhanced the electrochemical capacity for wearable glucose sensor applications. Zheng et al. [63] reported the quick and effective preparation and characterization of a novel nitrogen-doped graphene copper nanocomposite. The prepared nanocomposite showed superior electrical conductance of 538 W/m·K at room temperature, which is 138% greater than that of copper. The measured electrical resistance was 0.16 μΩ cm at 25°C which is much lower than that of copper. Gupta et al. [64] reported copper-based reduced graphene oxide nanocomposite for use as a catalyst. The copper-based reduced graphene oxide catalyst was easily recovered and used for seven consecutive cycles.

3.2.5 Fibers/graphene nanocomposites

In this type of nanocomposites, graphene is used as a filler while fibers are used as a matrix. Davoodi and co-workers [65] reported the preparation of polylactic acid and GO-based nanocomposite using the electrospinning method. The mechanical properties, surface chemical structure, and topology study of the nanofibers were performed. Jin et al. [66] used a facile method for the hybridization of polyaniline nanofibers (PANI NFs) on functionalized reduced graphene oxide (FrGO) films. The GO was first reduced and functionalized by sulfur to form FrGO. Hydrothermal method was used to hybridize FrGO and PANI NFs to form PANI NFs/FrGO composite films. The as-prepared nanocomposite films were uniform, flexible, and stable with a high specific capacitance of 692.0 F/g at 1 A g^{-1} and excellent capacitance retention of 53.5% at 40 A g^{-1}. Wan et al. [67] used a facile two-step method to prepare a ternary flexible nanocomposite material of bacterial cellulose/graphene/polyaniline (BC/GE/PANI). The prepared nanocomposite showed enhanced electrical conductivity of 1.7 ± 0.1 S/cm, which is greater than most of the polyaniline-based composites.

Matrix	Filler type	Filler fraction (wt %)	Young's modulus (GPa); polymers	Tensile strength (MPa); polymers	Young's modulus (GPa) and increment %; composites	Tensile strength (MPa) and increment %; composites
Epoxy	Pristine GNPs	3.0	1.48	46.46	1.64 (10.8%)	49.78 (7.1%)
Epoxy	Pristine MWCNTs	3.0	1.48	46.46	1.69 (14.2%)	54.48 (17.3%)
PVA	Modified MWCNTs	0.5	0.0166	19.11	0.0329 (98.2%)	34.60 (81.1%)
PVA	Graphene oxide	0.3	2.32	25.3	5.82 (150.9%)	63.0 (149.0%)
PES	Pristine MWCNTs	1.0	0.045	1.70	0.067 (48.9%)	2.38 (40.0%)
PES	Graphene oxide	1.0	1.16	30.79	1.95 (68.1%)	55.73 (81.0%)
HDPE	Modified MWCNTs	2.5	0.75	26.5	1.15 (53.3%)	34.5 (30.2%)
HDPE	Pristine GNPs	10	0.96	27.2	1.49 (55.2%)	33.4 (22.8%)

Table 1.
Comparison of mechanical properties of different polymers and their nanocomposites [68].

Table 1 shows the comparison of mechanical properties of some polymers and their nanocomposites.

4. Applications of improved nanocomposites

Applications of improved carbon nanocomposites are shown schematically in **Figure 4**.

4.1 Energy storage

Currently, Graphene materials find a number of applications in the field of renewable energy, particularly photoenergy field, including solar thermal conversion, solar electricity conversion, photocatalysis, etc. New technologies related to solar cells have been developed in which either the active medium or transparent/distributed electrode consists of Graphene materials. A newly developed 3D cross-linked graphene material working as an ideal solar thermal converter can obtain the efficiency of 80% and more than 80% under one sun intensity and the ambient sunlight respectively [69]. The structural design possessed by the material plays a significant role in improving the efficiency of energy conversion. The unique structure of graphene foam due to an array on its 3D skeleton, created by nanoplates of the graphene, provides a greater area for heat exchange. This enhances the efficiency of solar-thermal conversion up to 93.4%. Dye-sensitized solar cells (DSSC) consisting of a redox couple and a counter electrode are used extensively for solar-electrical energy conversion [70]. Dye-sensitized solar cells (DSSCs) composed of coloring molecules, natural liquid electrolytes, and nanocrystalline metal oxides

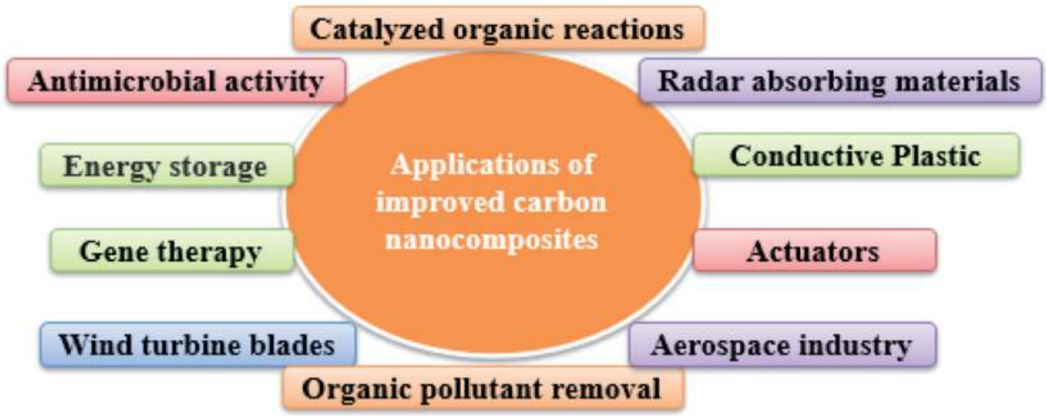

Figure 4.
Applications of improved carbon nanocomposites.

have shown greater performance in energy conversion and manufacturing costs and low energy. Nowadays, graphene-based electrodes exhibiting chemical stability and good conductivity, very large surface area, considerable high porosity, and electrocatalytic activity are used in DSSC. The application of this electrode led to the improvement in the performance and the reduction of the cast to a large extent. A super-capacitor designed by Stroller et al. [71] from the chemical modification of graphene material exhibited specific capacitance 135 F/g, 99 F/g, and 99 F/g in aqueous electrolytes, ionic electrolytes, and organic electrolytes respectively. High life cycle and high power have been shown by these types of storage devices. Zhang et al. [72] synthesized a useful stretchable electrode by the mechanical exfoliation of graphene prior to chemical treatment. These electrodes show high flexibility and compatibility in usage in various electrolytes. Moreover, graphene conducting polymer composites or graphene transition metal composites can be used to devise Super-capacitors.

4.2 Antimicrobial activity

Graphene nanomaterials possess intrinsic antimicrobial properties and also act as a platform to design antimicrobial nanocomposites having higher antimicrobial activity. Graphene is an ideal scaffold material owing to its huge surface area to anchor various sorts of macromolecules and nanoparticles. The attachment of diverse compounds such as quaternary phosphonium salts to graphene has greatly improved the antimicrobial properties. Researchers have shown great interest in Silver owing to its higher antimicrobial activity and studied it extensively to design graphene-based antimicrobial nanocomposites. In this section, the research carried out on the development of graphene–silver antimicrobial nanocomposites will be discussed. As the nanocomposites possess greater antimicrobial activity, graphene–silver nanocomposite is preferred over silver nanoparticles alone. Graphene–silver nanocomposites facilitate the leached silver ions from the nanoparticles to penetrate the cell owing to graphene which possesses the property to rupture a cell membrane. The purpose of this proposed mechanism was to explain the synergetic effect caused by silver and graphene existing together in the form of nanocomposite, and proteomic analysis of this effect of graphene–silver nanocomposites compared to silver nanoparticles alone [73] supported the mechanism as well.

4.3 Gene therapy

Gene therapy is a big breakthrough in medical science. Gene therapy is a new technique to treat various genetic diseases such as cystic fibrosis, Parkinson's, and various cancers. Efficient gene therapy includes a gene vector that protects the desired gene from nuclease degradation and allows cellular uptake of DNA with high transfection efficiency. The selection of an appropriate gene vector is the main obstacle in the development of gene therapy. The non-toxic nanocarrier in efficient gene therapy is Graphene and graphene-coated substrates. Graphene-based nanosheets have sp^2 hybridized orbitals, which are capable to interact with drugs and other molecules like nucleic acids such as DNA and RNA. Thus, they can be used for gene delivery or as carriers and protectors of probes involved in identifying miRNAs [74]. Hyunwoo et al. synthesized GO-based polyethyleneimine (PEI) composite and used it as an efficient gene delivery carrier in gene therapy [75]. Among different carriers, polyethyleneimine (PEI) has been typically recognized as the "golden standard" cationic polymer in gene transfection, because of its strong binding to DNA and RNA and effective uptake by cells. However, due to high cytotoxicity and poor biocompatibility, applications of PEI polymers in gene therapy is limited [76].

4.4 Catalyzed organic reactions

Carbon-based nanocomposite materials have been extensively used as heterogeneous catalysts in many organic chemical reactions. In chemical industries, less than 10% of the chemical reactions are still conducted without the addition of specific catalysts [77]. The catalytic products such as organic building blocks, pharmaceuticals, natural products, and agricultural derivatives are very valuable in chemical industries [78]. In many industrial chemical reactions, different types of supported and unsupported metal catalysts have been investigated. In the last few decades, the researchers gave more importance to using carbon nanostructure-based composites as heterogeneous catalysts in organic transformations. The highlighted advantages of carbon-based nanocomposites catalysts are high surface area, stability, fine dispersion, reusability, and easy recovery after completion of reactions. Furthermore, the introduction of metal nanoparticles onto the carbon support has shown more usefulness in carrying out the highly selective catalytic organic reactions [79]. In comparison with CNTs, graphene or GO has been preferred due to its low cost, large-scale preparation, and less health risk.

4.5 Radar absorbing materials

Electromagnetic wave absorbing materials are widely used in radar-absorbing technology. The absorbing of electromagnetic waves has many widespread applications, including minimizing the radar signature of a target, protection of human eyes, protective shielding of computers, consumer electronics, and optical sensors from intense laser pulses. Composites, in which polymer matrix having embedded multiwalled carbon nanotubes (MWCNTs), have been studied in multi-frequency detection mode instruments. Their applications in the microwave frequency range are anti-reflection, microwave absorbers, and electromagnetic interference shielding. The use of CNTs in radar-absorbing nanocomposite materials is more prominent due to their attractive properties i.e., electrical capacity, stiffness along large electromagnetic wave absorption tendency in the microwave range [80]. Zakharychev et al. [81]

have investigated the radar absorbing properties of epoxy binder and CNT nanocomposites in the frequency of 52–73 GHz.

4.6 Actuators

Shape memory alloys or liquid crystal elastomers have latent ability for activation under the right conditions. However, blending of two or more materials is required by other systems to report a new physical response leading to activation process. Recently, it has been proven that the polymer nanocomposite seems to be the best candidate for mechanical activation processes. The reported literature showed that most of the studies were concerned with the activation of the already described polymer matrix by introducing nanotubes. A new activator response was reported by Courty and their team by an electrical field due to the presence of CNTs in an elastomer polysiloxane [82]. Koerner et al. fabricated new polydimethylsiloxane (PDMS)/MWCNT nanocomposite material which showed a mechanical response to infrared radiation [83]. The mechanical response of (PDMS)/MWCNT was due to absorption of photons from irradiation and not due to slight heating of material. Moreover, the nature of activator mechanism is not known. Mylvaganam and Zhang [84] developed a method for the preparation of activating nanocomposite material i.e., polyimide and CNT nanocomposite.

4.7 Wind turbine blades

In the last few decades, it has been proved that the fastest-growing installed energy generation technology is wind energy. The energy department of US has set a goal for their researchers to produce at least 20% of its electrical energy up to 2030. To achieve the goal, the focus of the wind industry is to manufacture large blades. This is because the square of rotor radius increases the wind turbine energy output. This is a big challenge for the researchers to make such a large-sized blade with excellent mechanical properties i.e., excellent stiffness and strength, long fatigue life, and low weight. To enhance the strength of polymer matrices used for wind turbines, CNTs are the best candidate because of their excellent properties. Most of the previous work showed that CNTs used in polymer matrices have enhanced the strength and stiffness of composites materials. Recently this is also been reported that the use of CNT increased the fatigue and tensile properties of thermoset resins used in wind industry. To improve such type mechanical properties CNTs are the best candidates among the discovered fillers. It was reported that incorporating a small quantity of CNTs (0.2 wt%) improved the fatigue resistance of an epoxy system which is extensively used in the wind-energy industry. Tensile and dynamical mechanical analyses were performed on neat epoxy and on epoxy/CNT nanocomposite. The CNT composites had long fatigue life as compared to neat epoxies under the same conditions [85].

4.8 Organic pollutant removal

With rapid industrialization and untreated wastewater disposal, water pollution has become a serious threat to both flora and fauna. The contaminants which affect the water quality badly are synthetic organic dyes, petroleum, antibiotics, drugs, pesticides, polyaromatic hydrocarbons, heavy metal ions, etc., which have brought a lot of adverse effects on human health and social development. The most used method for decontamination of polluted water is the biological method. There are some limitations of the biological method i.e., some refractory organic and inorganic pollutants in wastewater are not effectively removed [86]. Therefore, some other methods have been developed to remove refractory organic and inorganic pollutants from wastewater such as adsorption and advanced oxidation processes (APS). In the last few decades, CNTs and graphene-based materials have been widely used by many researchers in wastewater treatment. Carbon nanomaterials-based nanocomposites can be used as an adsorbent in adsorption studies while in AOPS they are used as effective catalysts due to their unique physical and chemical properties. In a word, the CNTs-based materials may have potential application prospects in water treatment [87].

4.9 Aerospace industry

In recent years, the dependence of humans on speedy transportation has boosted many folds. The high demands make the research of this area very fast and more fascinating. In aerospace industry, keen interest is shown in the mechanical, thermal, chemical along with electrical and biodegradable properties. In chemical properties, the focus is to stop the corrosion of the system. The lightweight of the aerospace structure is vital, but the role of mechanical properties cannot be ignored. The role of mechanical properties is crucial for design like impact and scratch tolerance, toughness, strength, etc. The high thermal emissivity decreased solar absorption, electric conductivity, and resistance for radiations are also the key parameters, which are kept in focus while designing the aircrafts [88]. In the last few decades, the use of various epoxy resins in the aerospace industry had enhanced enormously. Almost in all these applications, carbon nanostructures are considered as advanced materials, which may be used incorporation with other nanomaterials or simply as the replacement of them [89]. In certain nanocomposites, carbon fibers were replaced by CNTs, the reason was to reduce the weight of composite materials. The use of epoxy nanocomposites is valued in aircraft/aerospace industry due to its high strength-to-weight ratio and enhanced temperature resistance. The best example is the wingtip fairings of Lockheed's F-35 which is made of CNT/epoxy nanocomposite. In the present situation, the application of CNT-based epoxy nanocomposites in the aeronautical and aerospace industry is obvious from their use in the space shuttle and advanced commercial aircraft (such as Boeing 787 and Airbus A380). In 2010, NASA published a report which showed the road maps for the future applications of nanomaterials and utilization of CNTs in aerospace industries. This report reveals that CNTs have tremendous potential to be used in aerospace applications which includes reduced vehicle mass, superior functionality, improved self-healing characteristics, improved control and damage tolerance, durability, and greater thermal protection. The use of CNT in the aerospace industry represents a very bright picture [90].

4.10 Conductive plastic

Plastic is one of the important materials used in the modern world as a metal replacement. The mechanical properties of plastics have been improved up to a maximum extent, but their limitations are arising when electrical conductivity is needed, as plastics are mostly nonelectrical conductors. To remove this deficiency different filling agents like carbon black and bigger graphite fibers have been incorporated in plastic polymers [91]. The loading of polymers with traditional filler to enhance the electrical conductivity results in weighty parts with high degraded construction properties

[92]. For this reason, carbon nanostructures i.e., CNT is exceptional with 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 [93]. This property of CNTs makes it the best choice to use in applications, such as gasket, enclosure, composite EMI (electromagnetic interference), electrostatic dissipation (ESD), shielding, and other usage coatings, low-observance radar absorption materials, and conductive (even transparent) antistatic and material coatings [94].

5. Conclusion

In recent years, the CNTs and graphene-based improved nanocomposites have been found to play a significant role in a wide range of potential applications. The incorporation of CNTs and graphene nanofillers into a matrix of particular materials either polymer activated carbon, metal, metal oxide, and fibers, upgrades their novel properties, such as excellent mechanical stability (in terms of strength, toughness, flexibility, Young's modulus, dimension stability, etc.), good optical features, flame retardancy, low water/gas permeability, and high electro-thermal conductivity. The improved nanocomposites material is known as the material of the 21st century because of their widespread applications in different fields such as energy storage, medical, wastewater treatment, aerospace, etc.

Acknowledgements

The authors would like to convey their gratefulness to National Centre of Excellence in Physical Chemistry, University of Peshawar for providing us necessary support and facilities to carry out this study.

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