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Nanocarbon-based Nanocomposite in Green Engineering

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ABSTRACT

Nanocarbon has emerged at the forefront of nanoscience and technology. Recently, nanocarbon-based nanocomposite has been employed in green engineering technology. Nanocarbon such as carbon nanotube, graphene, fullerene, nanodiamond, etc. is major building blocks of this technology. Polymer/nanocarbon nanocomposites possess unique electrical, mechanical, thermal, photovoltaic, and air/water pollution control features. These nanomaterial's, thus, have green engineering potential for various sectors such as automotive/aerospace, solar/fuel cell, and environment management industries. Using appropriate green nanocomposites design may offer a path to sustainable energy and environmental advancement. Development of new high performance nanocarbon designs has been a challenging topic of research in this regard.

Keywords: *Green engineering; nanocarbon; energy; environment.*

INTRODUCTION

Owing to outstanding structural, physical, and chemical properties, nanocarbon-based green nanocomposites have been used in wide variety of engineering fields [1]. Especially, the contribution of nanocarbon has been focused in terms of sustainable energy, environment, and green technology perspective. Since the discovery of carbon nanotube by Iijima [2], nanotechnology has been revolutionized. It is cylindrical macromolecule with diameter of few nanometers, while length may be up to several micrometers. It has been successfully synthesized using chemical vapor decomposition (CVD), electric arc discharge, and laser ablation techniques. For nanocompositing, carbon nanotube has been considered as an ideal carbon nanomaterial [3, 4]. Similarly, several other forms of nanocarbon such as graphene, fullerene, nanodiamond, nanofibers, carbon black, etc. have been discovered and explored. The unique and tunable properties of nanocarbon offer potential advances in energy and environmental systems towards energy efficiency, pollutant transformation, and toxicity control[5, 6].Green nanocomposite have been developed using green materials, method, and processing conditions for various technical applications (Fig. 1).

Figure1. *Nanocarbon in green engineering.*

In this review, current applications of nanocarbon in green engineering have been discussed. Green nanocomposites have been designed for automotive/aerospace sectors, solar cell and fuel cell parts, waste water treatment, and air pollution monitoring. Nanocarbon has been employed to improve the properties of green engineered nanocomposites considering the environment and safety concerns [7-10].

CARBON NANO-STRUCTURE

Carbon nanotube (CNT), graphene, nanodiamond, fullerene, etc. form important type of nanocarbon [11-15]. Few forms are mentioned inFig. 2. These forms of carbon have frequent applications in automotive/aircraft nanocomposite, solar cell, fuel cell and membrane materials [11, 13]. The zero-dimensional (0D) nanodiamond, one-dimensional (1D) nanotube, and two-dimensional(2D) graphene nano sheet may serve as prototype for the nanocomposites [16].

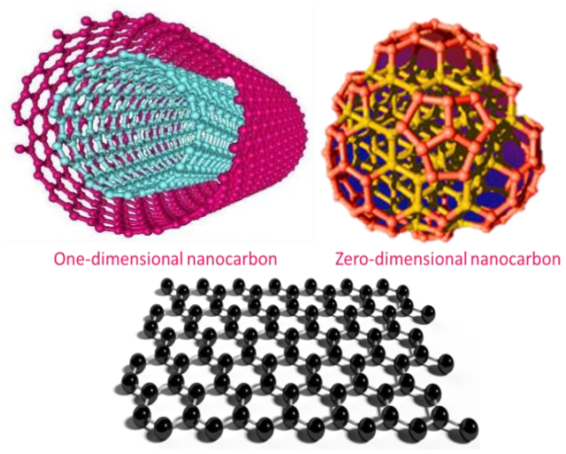

Figure2. *Nanocarbon used for nanocompositing.*

For example, CNT possess range of unique structural, physical, chemical and electronic properties (Table 1). In polymers, nanocarbons are usually introduced from 1-10%. Polymer nanocomposite with nanocarbon have light weight, processability, high electrical conductivity, strength, and other improved physical properties [17]. The conducting nanocarbon may form conducting network in matrices to achieve percolation threshold. Thus, nanocarbon incorporation may result in the remarkable enhancement in electrical conductivity, mechanical properties, and otherfeatures of the nanomaterials [18-20].

Table1. *Properties of carbon nanotube.*

Property	Value
Specific surface area	200-900 m^2g^{-1}
Specific gravity	0.8-2 $g^{-1}cm^{-2}$
Electrical conductivity	2×10^{-2}-0.2 Scm^{-1}
Thermal conductivity	~2000-3000W $m^{-1}K^{-1}$
Elastic Modulus	~0.1-1 TPa
Tensile strength	10-500GPa

Polymer/Carbon Nano-Structure-Based Green Nanocomposite

Green nanocomposites have been developed consisting of polymers and nanocarbon for different applications in fuel cells, solar cells, nanodevices, chemical sensors, biosensors, aerospace, automotive, etc. [6, 21]. The synergistic effect of nanocarbon and matrix material may result in excellent conducting, mechanical, thermal, and other enhanced physical properties. Various green synthesis routes have been adopted to fabricate the green nanocomposites. The polymerization has been carried out with green solvents to avoid the use of toxic organic solvents. Green solvents such as water-based solvents, supercritical carbon dioxide, ionic liquids, etc. need to be developed to overwhelm the environmental concerns. These solvents may have low volatility, good dissolving ability, high ionic conductivity, good thermal stability, wide temperature range, etc. to be employed as green medium. Moreover, it is important to develop a facile and efficient method without toxic conditions and resulting toxic materials.

Green Nano-Engineering

Transport Sector

Incorporation of nanocarbon in green polymeric nanocomposite have been employed for automobiles, aerospace, and other vehicle constituents[22-24]. In this regard, numerous polymeric nanocomposites have been prepared on commercial scale [25, 26]. Initially, macro particles were used to produce composite materials for transport sector. With the advancement in materials science, nanoparticles have been used to yield considerable changes in the physical features of final nanocomposite. Carbon nanofiber, carbon nanotube, carbon fiber, graphite, nanoclay, etc. have been incorporated in advanced light-weight transport nanocomposites. Actually, surface area per unit volume is inversely related to the particle diameter [27]. Consequently, nanostructure constituents may significantly alter the material characteristics. Carbon nanoparticle reinforced polymer matrices have been employed in automotive and aircraft industry owing to light-weight, low density, low cost, high strength, modulus, stiffness, and corrosion resistance (Fig. 3). In automobiles, nanocomposites have been used in various parts such as car interior parts, different type of sensors, tires, panels, electronics, and other technical parts. The outstanding mechanical and physical features have rendered these nanocomposites as substituent for metals such as aluminium alloys in transport applications [28]. However, for high performance applications, there are numerous property demands including improved electrical and thermal behavior [29]. Innovative green engineered constituent systems need to be developed for transport industry [30]. These nanocomposites are usually favored over metals owing to thermal stability, fatigue resistance, and corrosion overthrow. Future green nanocomposites systems pursue to further improved multifunctional nanomaterials in this field [31].

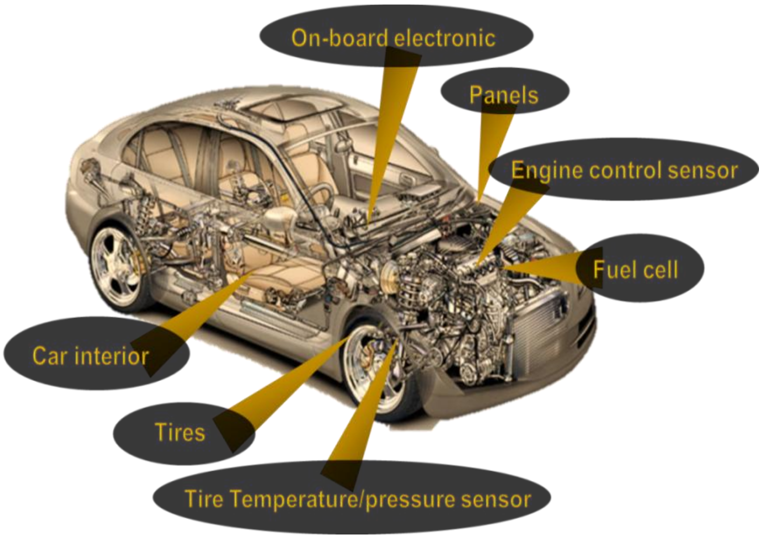

Fig3. *Nanocarbon application in automotives*.

Energy sector

In energy sector, nanocarbon structures have been successfully engineered considering the green technology. Application in photovoltaic devices shows major breakthrough of nanocarbon in solar energy sector. Photovoltaic devices simply generate electricity using sun light. Primarily developed silicon and semiconductor-based photovoltaic devices encompass drawbacks of high cost, low stability, and low conversion efficiency [32]. Henceforth, nanocarbon has been used as an alternative material in silicon-based solar cells, organic solar cells, and also in dye-sensitized solar cells (Fig. 4). Nanocarbon may provide nanoscale active surface area for massive photon absorption. Owing to nano-size and delocalized π-electrons, charge transfer mobility has been enhanced several times [33]. In hybrid solar cell of silicon and nanocarbon, cell efficiency and stability have been considerably enhanced [34]. In the case of carbon nanotube, formation of conductive percolated network may promote the charge transport through the photovoltaic system. Various conducting organic polymers used with nanocarbon include poly(3-hexylthiophene), poly(3-octylthiophene), [6,6]-phenyl-C61-butyric acid methyl ester, etc. Fuel cells designs have also been focused for green engineering using carbon nanostructures. Improvement in the fuel cell efficiencyupon incorporation of carbon nanotubein proton exchange membranes has been observed [35-39].In fuel cell membrane, nanocarbon serve to improve the thermal stability, dimensional resistance, and proton exchange performance by providing efficient charge transport at polymer/nanocarbon interface.

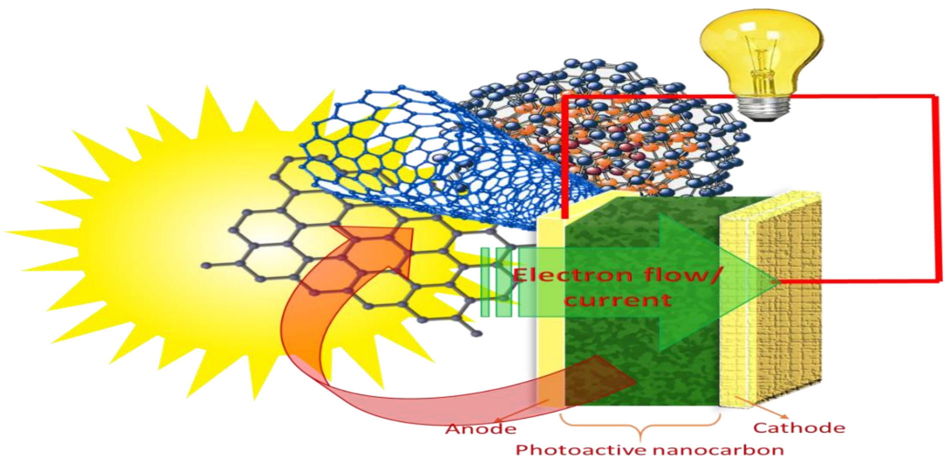

Fig4. *Simple solar cell architecture showing carbon nanomaterial in photovoltaic solar cell*

Environmental Applicability and Safety

Efficient and economical methods have been developed to manage pollutant growth owing to population and industries [40]. Nanocarbons are claimed to have high efficiency in the removal of various pollutants from air and water. Polymer/nanocarbon eco-friendly materials have been focused in this regard. Wastewater from industrial, agricultural, or domestic sources possess several toxic pollutants of heavy metal ions, dioxin, chlorobenzene compounds, aromatics, etc. The toxins may cause growing poisoning, cancer, nervous system related and other harmful threats to human health. Removal of these contaminants depends on the sorption behavior of nanomaterial's. Carbon nanotube has high adsorption capacity towards toxic substances [41]. The sorption behavior of nanocomposite primarily depends on the chemical and physical interaction of toxic compounds with nanomaterials [42-45]. Surface functionality of nanocarbon is also important in this regard. Subsequently, CNT and graphene nanomaterials may also act as sensing components to detect and monitor toxic gases released in the environment [46-48]. Nanocarbon-based gas sensors possess several compensations over conventional metal oxide gas sensors such as high sensitivity, high power consumption, and optimum operating temperature [49, 50]. Among nanomaterials, nanocarbon is possibly pervasive in the environment. It is also present as particulate matter in combustion of fuel gases [51, 52]. From environment, nanocarbon can be inhaled and deposited in human pulmonary organs [53]. Pollutants, nanoparticulates are associated with cardiopulmonary diseases, inflammation, and cytotoxicity. One of the most effective way to avail nanocarbon benefits while avoiding their toxicity is nanocompositing*via* green engineering. Use of nanocarbon in optimum amount in nanocomposites through development of physical/chemical interaction decreases the toxicity effects. Since, the release of nanocarbon from nanocomposite in environment is prevented due to the formation of matrix-nanofiller bonded structure.

Summary

Nanocarbon has been considered as the most important discovery of materials science. In terms of green engineering, energy, environment, as well as transportation sectors have been benefited from nanocarbon nanocomposites. The continued development of nanocarbon for energy, environment, and technical matrices has been a critical topic for additional research in this field. However, reinforcement and quantification of nanocarbon in matrices i.e. relevant for nanotechnology environmental health and safety measurements need to be considered to further develop this field. Green nanocomposite approach need to be investigated and highlighted as a reliable step in the engineering of automotive, aircraft, solar cell, gas sensor, and water purification membrane materials.

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