

Editorial

Multi-Walled Carbon Nanotubes

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1. Introduction

Since their discovery, multi-walled carbon nanotubes (MWCNTs) have received tremendous attention because of their unique electrical, optical, physical, chemical, and mechanical properties [1]. Their particular characteristics make them well-matched for a plethora of application areas, namely, nanoelectronics, energy management, (electro)catalysis, materials science, the construction of (bio)sensors, multifunctional nanoprobes for biomedical imaging, sorbents for sample preparation, the removal of contaminants from wastewater, as anti-bacterial agents, drug delivery nanocarriers, and so on—the current relevant application areas are countless. This Special Issue is a collection of 13 original research articles that address remarkable advances in the synthesis, purification, characterization, functionalization, and application of MWCNTs in established and emerging areas. A brief discussion of the main outcomes of each study is presented in the next sections.

2. Synthesis and Structural Characterization of Multi-Walled Carbon Nanotubes-Based (Nano)Composites

The trends and advances regarding the synthetic routes and structural properties of MWCNTs-based (nano)composites have been discussed in several reports [2–6], proving the importance of this topic for pushing MWCNT exploitation and industrial use forward. Ma et al. [2] proposed a new route for the synthesis of MWCNT nanohybrids using azide-terminated poly(methyl methacrylate), through the utilization of a combination of reversible addition fragmentation chain transfer and the alkyne-azide click reaction. The as-prepared nanohybrids could be steadily dispersed in aqueous solutions, including water, because of the azide-terminated poly(methyl methacrylate) chain on the MWCNT surface. Chandra et al. [3] inserted nanopalladium on carboxylated and octadecylamine functionalized MWCNTs that were further extensively characterized. The synthesized hybrids exhibited a good catalytic activity towards a carbon–carbon coupling reaction. Liu et al. [4] and Savi et al. [5] synthesized and characterized new composites using silicone rubber/polyolefin elastomer blends containing ionic liquids modified with carbon blacks and MWCNTs, and MWCNTs dispersed in an epoxy resin matrix, respectively. The prepared composites have an interesting potential for electromagnetic interference shielding applications [4] and microwave absorbing uses (although only low weight percentage should be used) [5]. In addition, Min et al. [6] developed a novel nanocomposite based on acidified MWCNTs, graphene oxide, and cerium oxide nanoparticles, which displayed a promising tribological performance.

3. Modelling of Multi-Walled Carbon Nanotubes-Based Nanofluid Flow

Nanofluids are obtained by the incorporation of nanomaterials into a base fluid, with the main goal of enhancing specific properties, such as the density, viscosity, thermal conductivity, and specific heat. Thus, they have been increasingly developed and characterized, using several mathematical models, for further applications, mainly in the field of engineering (heat exchangers, freezing,

cooling, heating systems, etc.). Muhammad et al. [7] described the three-dimensional rotational flow of three different MWCNT-based nanofluids (prepared with water, engine oil, and kerosene oil as the base liquid) considering thermal radiation and heat generation/absorption. The main parameters of the non-Newtonian behavior of the several nanofluids were determined and discussed. Saba et al. [8] also studied the flow of nanofluids composed of water and MWCNTs. The authors of [8] thoroughly investigated the several variables that affect the MWCNT-based nanofluid flow over a curved stretching surface and for heat transfer distribution.

4. Applications

4.1. Adsorption

MWCNTs are also being successfully explored in environmental applications, such as for water quality control and treatment. Two interesting reports [9,10] are included in this Special Issue, both of which are related to the use of MWCNTs as adsorbents of contaminants, namely nonylphenol [9] and organochlorine pesticides [10] from source waters and agricultural irrigation water samples, respectively. The contributing authors [9,10] characterized the main operational parameters and the type of adsorption demonstrating the applicability of MWCNTs for the removal and extraction of contaminants from water samples.

Alguacil [11] also characterized the possibility of applying MWCNTs as sorbents, but in this case, for gold(I) and gold(III) cations' adsorption from cyanide and chloride solutions. The reached data suggested that the recovery of the selected metal may be accomplished by subsequent elution with acidic thiourea solutions (for cyanide medium) or with aqua regia (for chloride solutions), with a further possibility of obtaining zero-valent gold nanoparticles.

4.2. Sensors Design

MWCNTs have been extensively incorporated into electrochemical (bio)sensors' design, regardless of the detection scheme and the target analyte, because of their inherent properties. Their high conductivity, catalytic properties, high surface area, chemical stability, and biocompatibility promote a significant increase in the sensitivity, lifetime, and overall performance of the devices, as concluded in the contribution of Oliveira et al. [12]. Nevertheless, the authors of [12] also concluded, after analyzing the published data from the 2013–2018 period concerning the new generation of sensors, that further technical developments are still needed in order to lower the cost of production of high quality MWCNTs. Moreover, the lack of comprehensive characterization of the toxicity of MWCNTs was also identified as an issue for the increase of the in vivo MWCNTs based sensors usage.

4.3. Drug Delivery

MWCNTs (functionalized or not) have been exploited in the drug delivery, biochemistry, and medicine fields. Chen et al. [13] described the effect of different levels of the carboxylation of MWCNTs on the dissolution rate of sulfamethoxazole and griseofulvin, two therapeutic hydrophobic drugs used as antibiotic and antifungal agents, respectively. The anti-solvent synthesis of micron-scale drug particles was the applied technique [13]. The reached data suggested that the degree of functionalization may help to control the release of the drugs, as decreasing the C:COOH ratio in the functionalized MWCNTs promoted a significant increase in the dissolution rates [13].

4.4. Cementitious Materials

The incorporation of nanomaterials including MWCNTs in building materials is increasingly being characterized in order to enhance the mechanical, physical, and electrical properties of the structures, while reducing their failure. Dalla et al. [14] studied the influence of introducing MWCNTs as nano-reinforcements in cement mortars. The obtained results showed that the permeability, electrical

resistivity, and the flexural and compressive properties of the mortars were significantly affected by the inclusion of MWCNTs at levels ranging from 0.2–0.8 wt % of cement [14].

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