Chemical Engineering Journal 302 (2016) 344–367

Contents lists available at ScienceDirect

Chemical Engineering Journal

journal homepage: www.elsevier.com/locate/cej

Review

Carbon nanotube–metal oxide nanocomposites: Fabrication, properties and applications

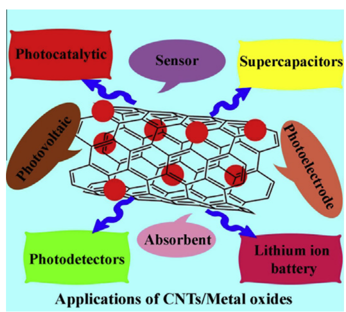
Shadpour Mallakpour [a,b,c,*], Elham Khadem [a]

[a] Organic Polymer Chemistry Research Laboratory, Department of Chemistry, Isfahan University of Technology, Isfahan 84156-83111, Islamic Republic of Iran
[b] Nanotechnology and Advanced Materials Institute, Isfahan University of Technology, Isfahan 84156-83111, Islamic Republic of Iran
[c] Center of Excellence in Sensors and Green Chemistry, Department of Chemistry, Isfahan University of Technology, Isfahan 84156-83111, Islamic Republic of Iran

HIGHLIGHTS

- The preparation and properties of MOs combined with CNTs are outlined.
- The distinctive chemistry and functionalization of CNTs have been summarized.
- The utility of CNT/MO composites for a broad range of applications have been described.
- The efficiency of several classes of CNT/MOs in sensor, absorbent, photovoltaic and etc. are presented.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 10 March 2016
Received in revised form 19 April 2016
Accepted 8 May 2016
Available online 9 May 2016

Keywords:
Carbon nanotube
Metal oxide
Combination
Photochemical stability
Absorbent

ABSTRACT

Carbon nanotubes (CNTs), a carbonaceous material, depend on morphology, size and diameter have highly unique properties in mechanical strength, thermal stability electrical conductivity, catalytic and adsorption. Over the past decades, combination of carbon nanotube with metal oxide is an effective way to build hybrid carbon architectures with fascinating new properties. The present review summarizes the recent advances on the principle and techniques of preparation, functionalization of the carbon nanotubes (CNTs). On the other hand, it discusses the effects of combination of CNT with metal oxides such as aluminum dioxide, titanium dioxide, zinc oxide, iron oxide and etc. and how they can be applied toward novel devices with remarkable properties for an extensive range of applications, over the past six years. This review provides the fundamental insights into the strategies for development of nano-hybrid with multifunctional properties for a broad range of applications such as sensor, supercapacitors, absorbent, photocatalytic, photovoltaic and etc.

Abbreviations: CNTs, carbon nanotubes; NC, nanocomposite; MOs, metal oxides; Al_2O_3, aluminum oxide; TiO_2, titanium dioxide; ZnO, zinc oxide; Fe_2O_3, iron oxide; SnO_2, tin dioxide; MnO_2, manganese dioxide; ZrO_2, zirconium dioxide; SWCNT, single-walled carbon nanotube; MWCNT, multi-walled carbon nanotube; CVD, chemical vapor deposition; TEM, transmission electron microscopy; SEM, scanning electron microscopy; FESEM, field emission scanning electron microscopy; AFM, atomic force microscopy; PVA, poly(vinyl alcohol); TCE, trichloroethylene; MB, methylene blue; LDH, lactic dehydrogenase; LIB, lithium-ion battery; DSSC, dye-sensitized solar cells; RSD, relative standard deviation.

* Corresponding author at: Organic Polymer Chemistry Research Laboratory, Department of Chemistry, Isfahan University of Technology, Isfahan 84156-83111, Islamic Republic of Iran.

E-mail addresses: mallak@cc.iut.ac.ir, mallak777@yahoo.com, mallakpour84@alumni.ufl.edu (S. Mallakpour).

http://dx.doi.org/10.1016/j.cej.2016.05.038
1385-8947/

Contents

1. Introduction

Metal oxides (MOs) have been an active field of researches due to their high modulus and strength at much higher temperature than common polymeric engineering materials, which make them appropriate for several applications. However, individual MOs cannot accomplish all requirements to develop new technologies and to solve the world's most immediate problems. For example, applications of MOs are restricted due to their inherent brittleness and low fracture toughness, so they have been a continuous driving force to encourage researchers to employ novel strategies with the aim of reinforcing and toughening MO [1–3]. In many cases, the combination of two or more materials presences a composite with features that are superior to those of the individual components.

Over the last two decades, carbonaceous nano-fillers such as graphite, diamond and fullerene, and carbon nanotubes (CNTs) have established part of widespread research and challenging due to their superior behaviors and interesting applications over other materials. Among them, CNT due to better structural and fascinating properties was attracted in science fiction novels and opened up a broad range of possible researches and functional applications [4–8]. In this scenario, one field of research that has been developing very quickly is the design, development and characterization of inorganic hybrid carbon-based nanostructures, generally consisting of MO and CNTs. Attaching CNTs with MOs cause to new functionalities in terms of electronic, optical and mechanical properties [9–11].

Various factors such as CNT shape, size, interaction, dispersion, alignment play an important role for fabrication of nanocomposite (NC) [12,13]. In a composite factors controlling such as the orientation of the CNTs, homogeneity of the composite, nanotube matrix adhesion, nanotube aspect ratio, and the volume fraction of nanotubes can have remarkable influences on the performance of the composites [14]. In recent years, preparation of CNT/MO composites have been extensively studied. Addition of CNTs to a ceramic matrix not only can change physicochemical properties, but also can provide multidisciplinary applications to adsorb hazardous pollution, photocatalytic, medical and etc. Depending on which materials is greater in composite, CNT/MO composite materials can be categorized into two groups; MO-decorated CNT and CNT-doped MO that herein both two groups will be discussed [5]. Fig. 1 shows CNT–TiO_2 interaction as an example (Fig. 1). In first group, oxidize CNT (CNT-COOH) is functionalized by attaching MO NPs i.e. nano-particulate MO (5 nm) deposited on CNT, either by covalent or noncovalent interaction. In second group, CNTs are embedded within the MO matrix i.e. CNTs deposited on larger MO (100 nm) [2,15,16].

An extensive number of literatures over the past decade sought to develop CNT/MO composites with potential applications [16,17]. In this contribution, we survey the literature and highlight recent progress in the development of MO attached on the CNT material. This review aims to provide a broad and updated vision of effect of combination of CNTs with designated MOs such as aluminum oxide (Al_2O_3) titanium dioxide (TiO_2), zinc oxide (ZnO), iron oxide (Fe_2O_3), tin dioxide (SnO_2) and etc. in the field analytical chemistry by covering the period 2010–2015.

2. Synthesis of carbon nanotubes

From a historical point of view, the discovery of CNT in 1991 [18] provided the revolutionary changes in the scientific community from both technological and a fundamental point of view. Carbon nanotubes according to the number of rolled up graphene

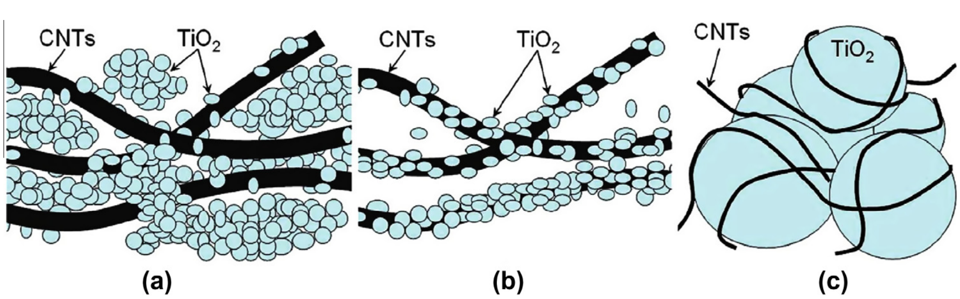


Fig. 1. CNT–TiO_2 morphologies for promotion of reactive surface area and inter-phase contact. (a) Shows schematically a random mixture of TiO_2 NPs and CNTs, (b) TiO_2 coated CNTs, and (c) CNTs wrapped around large TiO_2 NPs.[15]