

Supramolecular modification of multi-walled carbon nanotubes with β -cyclodextrin for better dispersibility

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Received: 19 July 2014 / Accepted: 8 January 2015 / Published online: 21 January 2015
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Abstract A novel hybrid material based on multi-walled carbon nanotubes was synthesized using organic synthesis, and the structures of multi-walled carbon nanotube derivatives were characterized by Fourier transform infrared spectroscopy, X-ray diffraction, thermogravimetric analysis, ^1H NMR spectroscopy, transmission electron microscopy, and scanning electron microscope. The analytical results indicated that β -cyclodextrin (β -CD) was anchored to the surface of Multi-walled carbon nanotubes (MWCNTs, OD: 10–20 nm, length: 10–30 μm) and dispersion experiments exhibited that the introduction of β -CD onto the MWCNTs would dramatically enhance the dispersion of MWCNTs in both ethanol and water media; the suspensions were found to be very stable for 2 months, and the results of this technique confirmed the experimental results. This novel technique would provide a new, simple, and facile route to prepare the modified nanomaterials based on silane-coupling agent and β -CD, and the

obtained modified nanomaterials have great potential practical significance and theoretical value to develop the novel organic–inorganic hybrid material, which was very useful for water treatment and biological medicine.

Keywords Multi-walled carbon nanotubes · β -Cyclodextrin · Organic–inorganic hybrid material · Dispersion · Nanocomposites

Introduction

The Japanese scientist Iijima first discovered carbon nanotubes (CNTs) in 1991 (Iijima 1991), and because of its unique physical and chemical properties, it soon became the focus of research scientists. Although CNTs have many superior properties, it cannot be dispersed in aqueous/organic solvents attributing to the strong intertube van der Waals force attraction. At the same time, the compatibility with other materials is not good, which is a major obstacle to restrict CNTs research and application (Mattson et al. 2000). Therefore, different chemical methods have been adopted to modify CNTs to enhance its dispersibility in solvents, which have important theoretical and practical significance. In recent years, a lot of literatures that focus on the “grafting from” method in conjunction with CNTs have been investigated to facilitate the dispersion of CNTs. For example,

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hyperbranched poly(amidoamine) (h-PAMAM)-grafted MWCNTs were successfully synthesized by grafting-from method, and the modified MWCNTs gave stable dispersion in organic solvents (Cao et al. 2004). Hye Jin Park et al. reported that the synthesis of pentafluorophenyl ester modified MWCNTs (MWCNTs-COOC₆F₅), and the results demonstrated that the dispersion of MWCNTs-COOC₆F₅ was stable in THF over 1 month (Park et al. 2008). However, there are some problems with the above methods that the stability and dispersion are limited and they are complicated.

Cyclodextrin (CD) is a cyclic oligosaccharide, which is generated by the CD glucose enzyme in starch. The most commonly used is β -CD, which is composed of seven glucose primitives by 1, 4 sugar glycoside key connection of tapered cylinder structure. CDs have a special molecular structure; they are conical with a slightly cylindrical structure. Their external surface is hydrophilic, and the interior is a hydrophobic cavity of a certain size, which render the CDs the unique “hydrophilic, hydrophobic” properties (Rekharsky and Inoue 1998). They can selectively bind small organic molecules or ions to form inclusion complexes with certain stability. CDs and inclusion complexes are host and guest, respectively (Engelinger et al. 2003). As popularly known, CDs have become an important subject of supramolecular chemistry and have been widely used in areas of analysis and chemical separation, environment protection, textile, coating, cosmetic, pharmaceutical, drug-controlled release, and oil recovery industry (He 2008; Chen et al. 2010; Shen et al. 2005; He et al. 2014). To our knowledge, only few literatures have been reported concerning the MWCNTs modified by β -CD (Wang et al. 2002; Khaled et al. 2012).

As we have previously discussed, although there are many researchers using different materials to modify CNTs to promote its dispersibility in solvents, these methods are tedious and costly; hence, it is worth developing a MWCNTs hybrid material containing a large number of hydroxyl groups through a new and simple chemical method. On the basis of the above consideration and with the combination of MWCNTs and β -CD, we report MWCNTs covalently functionalized with amphiphilic β -CD in this work. Although few studies on β -CD-modified MWCNTs were reported, amphiphilic nanotubes, peculiarly those based on silane-coupling agent, have been barely

reported. Thus, the objective of this study is to prepare the amphiphilic MWCNTs/ β -CD hybrid material with desirable dispersibility and stability in aqueous/organic solvents via a simple chemical synthesis method.

Experimental

Materials and equipments

The following is the material acquired: MWCNTs (provided by Chengdu Organic Chemistry Limited Company of Chinese Academy of Sciences). All the chemicals used in the experiment were purchased from Kelong Chemical Reagent Factory (Chengdu, China): γ -(2,3-epoxypropoxy)propyltrimethoxysilane (KH560), acetone, sulfuric acid, nitric acid, N,N-dimethylformamide (DMF), sodium hydroxide, and acetic acid. The average molecular weight of β -CD was 1,134.98 (g/mol). The following were also used: JSM-7500F (SEM, JEOL, Tokyo, Japan), X'Pert Pro diffractometer (PANalytical, The Netherlands), Bruker Avance III 400 NMR (BrukerBioSpin, Switzerland), Numerically controlled ultrasonic cleaners of KQ2200D model (Kunshan ultrasonic instrument co., LTD, China), WQF-520 infrared spectroscopy (Beijing Rayleigh Analytical Instrument Company, Chaoyang, Beijing, China), STA 449 F3 (Netzsch, Germany), and JEM-100CX (TEM, JEOL, Tokyo, Japan).

Synthesis of KH560/ β -CD

In a round-bottom flask, 5 g of previously dried β -CD was dissolved in 50 mL of dried DMF at 55 °C under an inert atmosphere, to which 6.0 mL of KH560 was added (corresponding to a β -CD: KH560 molar ratio 1:6). Then, a given mass of sodium hydroxide (0.1 g) was added, and the solution was kept under an inert atmosphere, with vigorous stirring for 48 h, giving rise to γ -(2,3-epoxypropoxy)propyltrimethoxysilane-modified β -CD. Then, the modified β -CD was cooled to room temperature, separated by precipitation using a large amount of acetone, and dried in 45 °C vacuum to obtain the faint yellow powder, which was water soluble. The synthetic route and synthesis mechanism are shown in Fig. 1a, b.

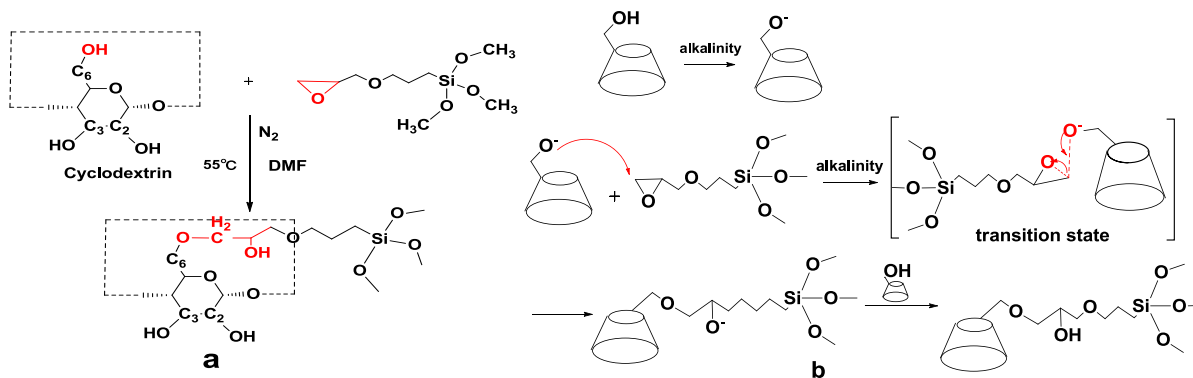


Fig. 1 a, b Synthetic route and synthesis mechanism of KH560/ β -CD

Acidification of MWCNTs

MWCNTs were added to mixed acid (concentrated sulfuric acid: concentrated nitric acid = 3:1) and dispersed by ultrasonic cleaners for 30 min. The acidified MWCNTs were poured into a three-necked flask and stirred for 12 h at 40 °C (Park et al. 2008). Then, the mixture was poured into a large amount of deionized water, washed to neutral by sodium hydroxide solution, and dried at 80 °C.

Synthesis of β -CD-grafted MWCNTs hybrid material

Approximately, 2.0 g of KH560/ β -CD was dissolved in 30 mL deionized water, and the pH value of the solution was adjusted to 4–6 with acetic acid solution, with stirring for 1 h to gain the product of hydrolysis. Afterward, 0.2 g of MWCNTs was added to the hydrolysis solution and dispersed by ultrasonic cleaners for 40 min; then, the suspension was refluxed at 85 °C for 10 h. The resulting suspension was rinsed repeatedly with a large amount of deionized water to remove the unreacted KH560/ β -CD and then filtered to give rise to the MWCNTs/ β -CD supramolecular hybrid material. The schematic reaction of KH560/ β -CD and MWCNTs-COOH is illustrated in Fig. 2.

Characterization

The chemical structure of KH560/ β -CD was determined using the NMR spectroscopy. ^1H NMR spectra were recorded with Bruker Avance III 400 NMR

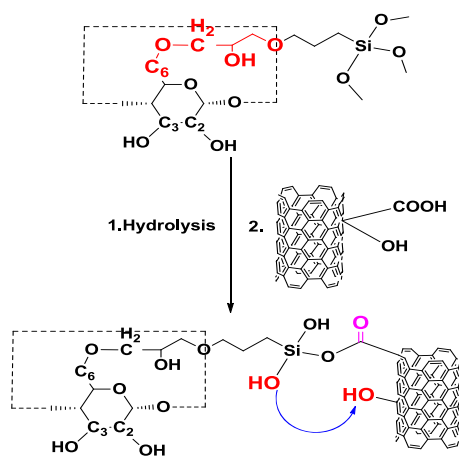


Fig. 2 Schematic reaction of KH560/ β -CD with MWCNTs-COOH

(BrukerBioSpin, Switzerland) in D_2O at room temperature.

To confirm the structure of KH560/ β -CD and MWCNTs/ β -CD, WQF-520 infrared spectroscopy was utilized to characterize their structures. A small amount of powder was mixed with some potassium bromide powder. After adequate grinding, the infrared absorption peaks through the infrared spectrum were observed.

The KH560/ β -CD and MWCNTs/ β -CD were tested by employing the X'Pert Pro diffractometer. Copper $\text{K}\alpha$ radiation source with a voltage of 40 kV and a generator current of 40 mA was used. The scanning rate was 2°min^{-1} , and scanning range was about 5–90°.

Transmission electron microscope (TEM) observations analysis was carried out by employing a JEM-

100CX transmission electron microscope at 80 kV. The specimens were initially sonicated with ethanol for a few minutes to form suspensions, and then one drop of the dilute suspensions of CNT-nanoparticles was placed on a carbon-coated grid and evaporated the solvent before TEM observation.

The thermogravimetric technique was used to study the thermal stability of the hybrid material. Take the proper weight of the samples on the crucible. The TG was carried out on STA 449 F3 (Netzsch, Germany) at a heating rate of 10 °C/min from 25 to 800 °C under nitrogen atmosphere.

The information about the surface appearance of the MWCNTs/ β -CD supramolecular hybrid material was observed using the JSM-7500F model SEM.

Dispersion experiment

To test the dispersion of hybrid material in different solvents, the dispersion experiment was conducted at room temperature. Ten small bottles with stoppers of the same size were employed in the dispersion experiment. The same amounts of MWCNTs-COOH and MWCNTs/ β -CD powder were added into bottles, and then various solvents (water, ethanol, acetone, xylene, DMF) with the same volume (20 mL) were poured into bottles, and the concentration of all samples was fixed at 2 mg/mL. Subsequently, the mixtures were sonicated for 20 min by numerically controlled ultrasonic cleaners KQ2200D model until visually homogeneous, and stable suspensions were formed.

Results and discussion

^1H NMR spectra analysis

In this work, KH560/ β -CD was prepared via the reaction of hydroxyl groups on the outside surface of β -CD with γ -glycidoxypropyltrimethoxysilane (GPTMS) under alkaline condition. To confirm the chemical structure of KH560/ β -CD, the ^1H NMR spectra of β -CD in D_2O were investigated using the Bruker Avance III 400NMR (BrukerBioSpin, Switzerland) spectrometer. It could be seen from Fig. 3 that chemical shift in the peak of $\delta = 4.67$ was the deuterium in D_2O (Kolokolov et al. 2010). As illustrated in Fig. 3, the peak located at chemical shift

of $\delta = 4.94$ was associated with glucose unit protons of β -CD (H_{e} , $\text{O}-\text{CH}-\text{O}$), and the glucose units are shown in Fig. 3. The signals located at broad chemical shifts in the region of 3.92–3.78 ppm were attributable to the inner methylidyne and methylene protons between the hydroxyl groups and carbon moieties (H_{c} , $\text{C}-\text{CH}-\text{OH}$, and $\text{C}-\text{CH}_2-\text{OH}$), and peaks located at broad chemical shifts in the region of 3.75–3.72 ppm were assigned to the inner methylidyne protons between the oxygen and carbon moieties (H_{e} , $\text{C}-\text{CH}-\text{O}$). The signal located at $\delta = 3.50$ – 3.42 ppm was attributable to the methylidyne, methylene, hydroxyl groups, and oxygen and carbon moieties (H_{f} , H_{g} , $\text{O}-\text{C}(\text{H}_{\text{g}})_2-\text{CH}_{\text{f}}(\text{OH})(\text{CH}_2)$). The peak was observed at $\delta = 3.39$ – 3.22 because of the protons of H_{c} , H_{d} . The peaks at $\delta = 2.89$ corresponded to the hydroxyl protons adjacent to the methylene and methylidyne moieties (H_{h} , $\text{CH}-\text{OH}$, and CH_2-OH), and the peaks at $\delta = 3.52$ were due to the proton of $\text{Si}-\text{CH}_3(\text{H}_{\text{i}})$. The chemical shift values at $\delta = 1.54$ and $\delta = 0.5$ were assigned to the protons of H_{b} and H_{a} . Thus, it could be concluded that β -CD modified with KH560 had been successfully synthesized.

Fourier transform infrared spectroscopy (FT-IR) study

The FT-IR spectra of KH560/ β -CD and MWCNTs/ β -CD are shown in Figs. 4 and 5, respectively. The FT-IR spectrum of KH560/ β -CD (Fig. 4) shows the bending vibration peak and stretching vibration of the $-\text{OH}$ group at 3,425 and 1,663 cm^{-1} , respectively. Other peaks at 2,939 and 2,871 cm^{-1} were due to the stretching vibrations of the $-\text{CH}_3$ and $-\text{CH}_2$ groups, respectively, which belong to the functional groups of the silane-coupling agent (KH560). The peak around 756 cm^{-1} was attributable to $\text{Si}-\text{O}-\text{Si}$ weak absorption band, and the peak at 1,035 cm^{-1} was due to the stretching vibrations of the $\text{Si}-\text{O}-\text{Si}$ group. The peak at 1,007 cm^{-1} was attributed to the stretching vibrations of the $\text{C}-\text{O}$ group, and the peak at 1,161 cm^{-1} was associated with the $\text{C}-\text{O}-\text{C}$ group of glucose units. All the peaks indicated that KH560/ β -CD had been successfully synthesized, which was consistent with the experimental results of nuclear magnetic.

Figure 5 displays the FT-IR spectrum of MWCNTs/ β -CD; it could be seen that the peak observed at 3,426 cm^{-1} was attributed to the presence

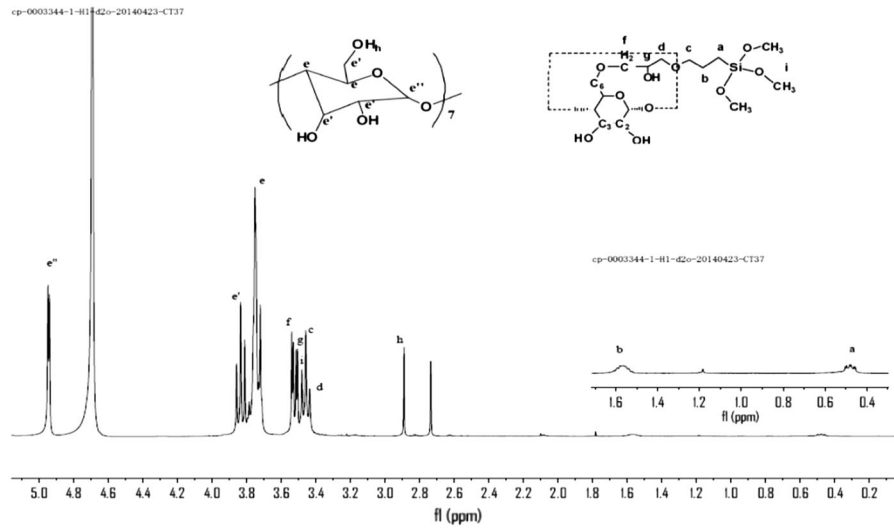


Fig. 3 ¹H NMR spectra of the modified β-CD (KH560/β-CD)

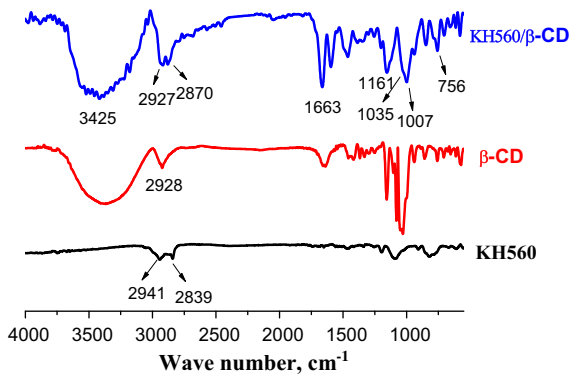


Fig. 4 FT-IR spectra of KH560/β-CD

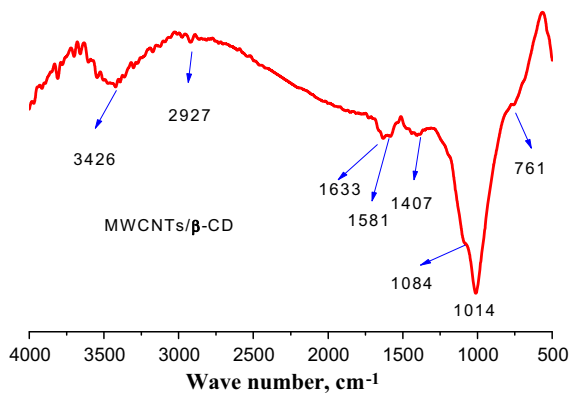


Fig. 5 FT-IR spectra of MWCNTs/β-CD

of the –OH group on the MWCNTs/β-CD. The peak observed at 2,927 and 1,014 cm⁻¹ corresponded to the stretching vibrations of –CH₂– and –C–O–C– groups of β-CD, respectively. The peak around 756 cm⁻¹ was attributable to Si–O–Si weak absorption band, and the peak at 1,084 cm⁻¹ was due to the stretching vibrations of the Si–O–Si group. The peaks at 1,633 and 1,581 cm⁻¹ were assigned to the –C=O group of MWCNTs–COOH, thus functionalizing the modified β-CD onto the MWCNTs.

XRD analysis

Research indicated that if the host and guest was a physical mixture, both characteristic peaks would appear on the diffraction figure, namely KH560 and β-CD diffraction peak superposition, whereas the KH560 as a liquid could not produce diffraction peaks (Bratu et al. 1998). As displayed in Fig. 6a, β-CD was a highly crystalline material with main diffractions at 9.1°, 12.5°, 16.9°, and 22.7° (2θ). On the other hand, as shown in Fig. 6a, KH560/β-CD presented a larger amorphous phase but with some intense traces of crystallinity. The amorphous phase could be identified by the fact that there are no single, sharp, intense, and well-recognizable but only broad, low-intense, and not clearly recognizable peaks. As discussed previously, if it is just a simple physical mixture, then the XRD diffraction patterns would only render the diffraction peaks of β-CD, whereas some different situations

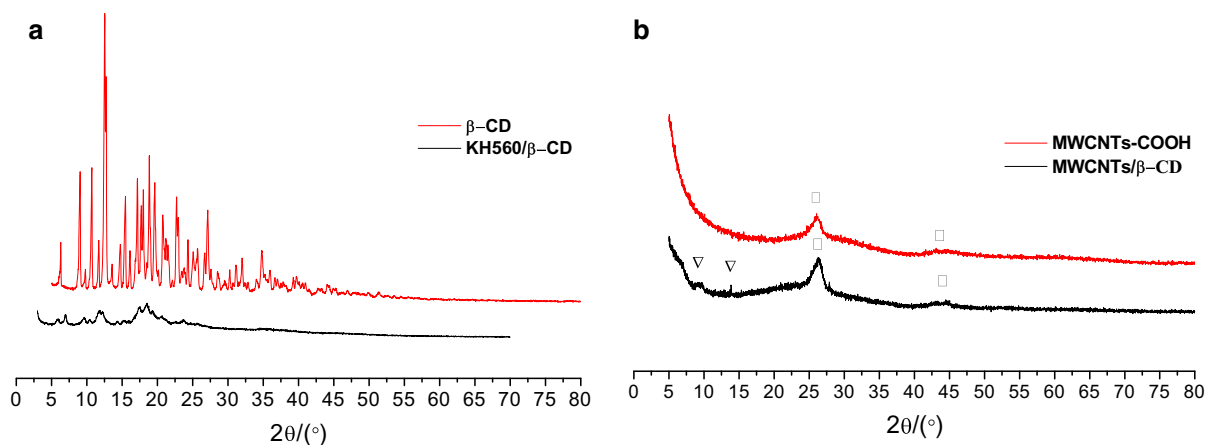


Fig. 6 **a** XRD curves of KH560/β-CD and β-CD; **b** XRD curves of MWCNTs/β-CD. *Rectangle* are the characteristic diffraction peaks of MWCNTs-COOH and *Inverted Triangle* are the characteristic diffraction peaks of β-CD

perceived that part of the β-CD diffraction peak ($2\theta = 22.7^\circ, 26.5^\circ, 35.1^\circ$) disappeared. The X-ray data revealed that the KH560 had reacted with β-CD and a new compound had been formed, which was supported by the results of FT-IR and ^1H NMR spectra.

Figure 6b illustrates the XRD patterns of MWCNTs/β-CD samples prepared by modifying the MWCNTs-COOH with KH560/β-CD. The characteristic diffraction peaks of β-CD were observed at $2\theta = 9.2^\circ$ and 13.9° from Fig. 6b, whereas other diffraction peaks of β-CD disappeared because the quantity of the modified β-CD grafted on the surface of MWCNTs was too small. There was a very strong diffraction peak at $2\theta = 25.8^\circ$ and a small peak at $2\theta = 43.9^\circ$ for the crystal plane diffraction peak of walled carbon nanotubes [002] and [101], respectively. However, when compared with the XRD patterns of the acidified MWCNTs, some differences could be seen that the strength of the two peaks has changed. Diffraction peaks of the modified carbon nanotubes by KH560/β-CD were stronger than those of the unmodified carbon nanotubes, indicating that the crystalline order of the modified CNTs and the graphitization degree increased, thus leading to the expansion of the intensity of the diffraction peak. The emergence of β-CD characteristic peak and the change of the peak intensity fully demonstrated the success of β-CD-modified carbon nanotubes.

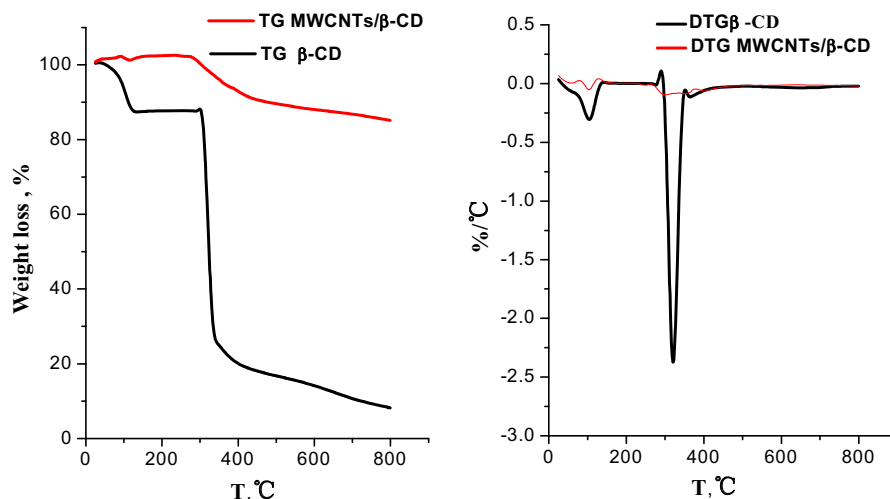
Thermal behavior

From the curves of TG-β-CD and DTG-β-CD in Fig. 7, the weight loss process of β-CD could be generally

divided into the following three parts: (1) when the ambient temperature was up to 100°C , an obvious weightlessness could be seen from the curves of DTG-β-CD, and the weight loss was caused by the water in the β-CD cavities. (2) As illustrated in the DTG curve of β-CD, there was an apparent weight loss peak at 275°C , whereas the corresponding TG curve did not change at 275°C . The peak at 275°C was associated with the fact that samples of β-CD might exist in different crystal forms, and some of them may more or less readily transform into each other. This behavior had been ascribed to both reversible and irreversible phenomena by different authors (Giordano et al. 2001; Morin et al. 2000). (3) The phenomenon of rapid weight loss appearing at 321°C was attributed to the decomposition of β-CD (Szejtli 1982).

As illustrated in the curves of MWCNTs/β-CD, weightlessness temperature was basically similar to the β-CD, whereas some differences still existed. The water loss at $100\text{--}120^\circ\text{C}$ was due to the water in the β-CD cavities and that adsorbed by the modified carbon nanotubes (not fully dry). When comparing the weight loss of the modified carbon nanotubes at 303°C and 403°C with β-CD at 323 and 365°C , it was easy to find that the weight loss temperature of β-CD had shifted, suggesting that the modified β-CD was not merely coated on the surface of carbon nanotubes but reacted with groups on the surface of carbon nanotubes to form chemical bonds that changed the weightlessness temperature, which was in total agreement with the conclusion withdrawn from FT-IR, XRD, and SEM analysis. When the temperature

Fig. 7 TG curves of MWCNTs/ β -CD and β -CD



continued to rise above 410 °C, the weight loss of MWCNTs/ β -CD altered not significantly with the increase of temperature, which revealed that β -CD grafted on the surface of carbon nanotubes had completely decomposed as well as the success of β -CD-modified carbon nanotubes.

SEM and TEM images for hybrid material

Figure 8a presents the SEM image of MWCNTs-COOH, and Fig. 8b, c illustrates the different magnifications of SEM images for MWCNTs/ β -CD hybrid material. As shown in Fig. 8, some differences could be clearly observed: the remarkable enlargement of carbon nanotubes after being modified by β -CD indicates that the surface of MWCNTs had been coated evenly with the modified β -CD, which supported the experiment results of XRD and TG.

For the above-mentioned phenomenon, it could be interpreted as follows: KH560/ β -CD had reacted with the groups (hydroxyl and carboxyl) on the surface of MWCNTs. Due to the unique “hydrophilic and hydrophobic” properties of β -CD (the larger opening of the cone was hydrophilic, whereas the side with a smaller diameter was hydrophobic) and hydrophobic properties of MWCNTs, when the modified β -CD was anchored to the surface of MWCNTs, the small-diameter side interacted with the wall of MWCNTs and intertwined with each other. However, the larger opening of the cone interacted with the large-diameter side of other β -CD through hydrophobic interactions, van der Waals force, and hydrogen-bonding

interactions, leading to the tubes of MWCNTs intertwined with each other.

The MWCNTs/ β -CD dispersion was also visualized by TEM image (Fig. 8d,e). As seen in the image of MWCNTs (Fig. 8d), it showed a smooth surface. In contrast, the image of MWCNTs/ β -CD (Fig. 8e) suggested that it was a bunch of individual MWCNTs with heterogeneous layers onto the surface, and this observation provided a direct evidence for the functionalization of β -CD onto the MWCNTs, which was apparently the reason for the dispersibility and stability of hybrid material. The schematic diagram of the proposed mechanisms for β -CD grafted onto MWCNTs surface is shown in Fig. 9.

Dispersibility of hybrid material

MWCNTs readily aggregated in aqueous/organic solution because of high surface energy; thus, it is difficult to suspend them in solvents, especially in the aqueous phase (Sinani et al. 2005). The MWCNTs dispersed in the aqueous phase have observable applications in the field of medical chemistry, especially as a sensor (Xu et al. 2006; Wang et al. 2007). Many researchers attempted to employ various methods to prepare water-soluble carbon nanotubes, including surfactant modification, hydrophilic, and amphiphilic polymer modification. Although the experimental results revealed that the chemical modification of carbon nanotubes was able to improve its dispersibility in the aqueous solution, experiment methods were complex and sustaining the stability of

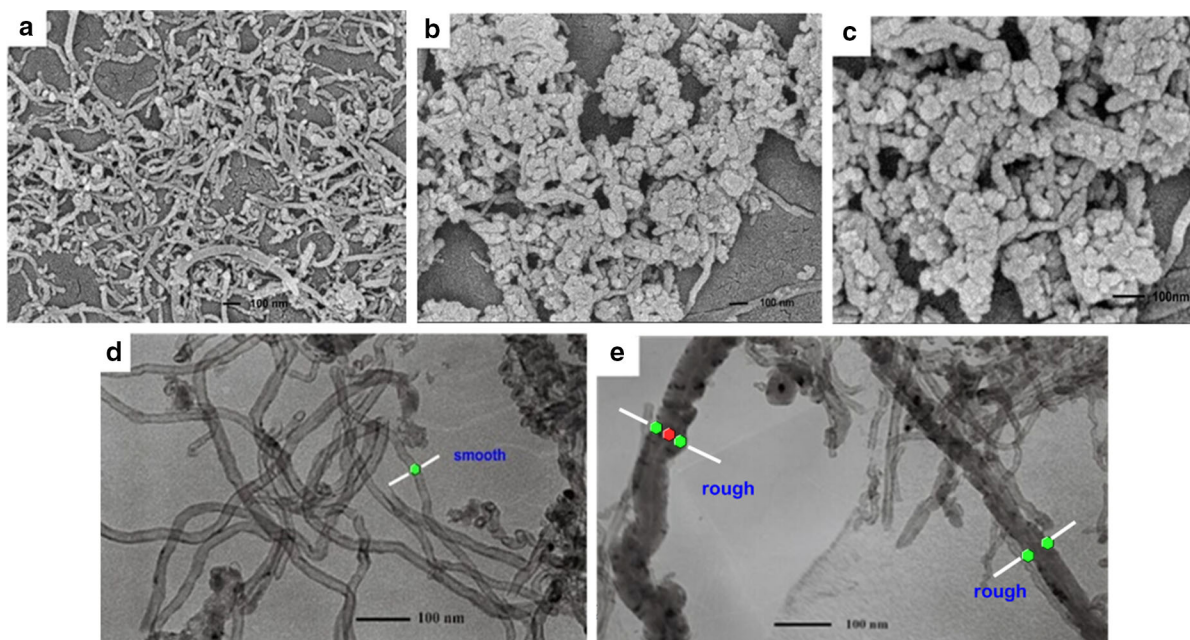


Fig. 8 a–c SEM images of a MWCNTs-COOH, b, c MWCNTs/β-CD; d, e TEM images of d MWCNTs-COOH and e MWCNTs/β-CD

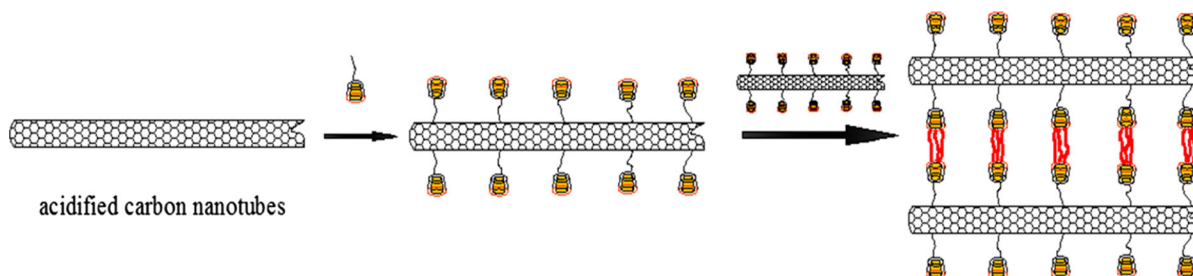


Fig. 9 Schematic diagram of the proposed mechanisms for β-CD grafted onto MWCNTs surface

dispersed MWCNTs without aggregation in the aqueous solution was still a challenge. To preclude this problem, β-CD was modified with silane-coupling agent to attain water-soluble powder (KH560/β-CD), and then the hybrid material was prepared by modifying MWCNTs-COOH with KH560/β-CD. Subsequently, the same amount of modified carbon nanotubes was dispersed in different solvents to investigate the degree of dispersibility and stability under identical experimental conditions at ambient temperature. To ascertain the degree of dispersibility and stability, the different solutions were monitored under undisturbed conditions up to two months. The dispersibilities of hybrid material (MWCNTs/β-CD)

were studied not only in the aqueous phase, but also in various organic solvents, such as ethanol, acetone, xylene, and DMF, and the relevant photographs at different times are illustrated in Fig. 10.

As revealed in the photo of MWCNTs-COOH (A1) dispersed in water, the MWCNTs-COOH settled down completely in water after 2 months because of its van der Waals force, high surface, and high aspect ratio (Dai et al. 2003; Gao et al. 2003). However, the photo of MWCNTs/β-CD indicated that only a small proportion of powder settled down, whereas most of the powder could be dispersed in water and maintained stability in a long time, indicating that the introduction of β-CD onto the surface of MWCNTs-COOH was

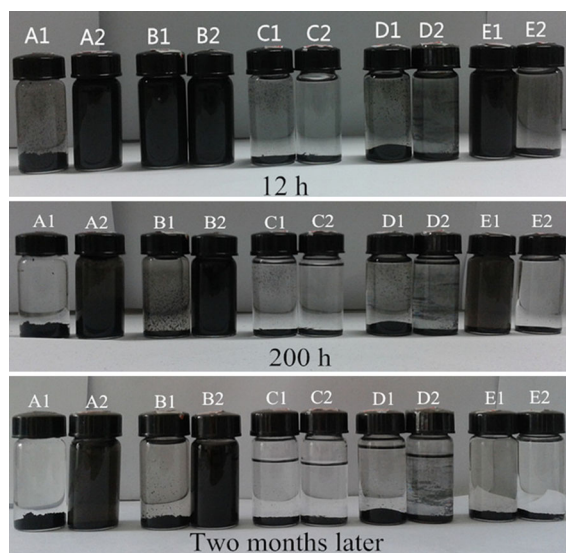


Fig. 10 Photograph of dispersibility measurements of MWCNTs/ β -CD. A: water (A1: MWCNTs-COOH, A2: MWCNTs/ β -CD), B: ethanol (B1: MWCNTs-COOH, B2: MWCNTs/ β -CD), C: acetone (C1: MWCNTs-COOH, C2: MWCNTs/ β -CD), D: xylene (D1: MWCNTs-COOH, D2: MWCNTs/ β -CD), E: DMF (E1: MWCNTs-COOH, E2: MWCNTs/ β -CD). The concentration of all samples was fixed at 2 mg/mL

able to improve the dispersibility and stability in water, which was obviously supported by the finding of SEM. This was because the unique “hydrophilic and hydrophobic” properties of β -CD and a large number of hydroxyl groups increased the hydrophilic character and hence facilitated dispersibility. Thus, the hybrid material was stable for 2 months in the aqueous phase. To inspect the dispersibility and stability in various organic solvents, several samples were prepared to disperse in various solvents. The results presented in Fig. 10c–e illustrated that after being placed 2 months since the dispersions were made, all carbon nanotube powders (modified and unmodified) settled down under identical experimental conditions at ambient temperature, which were attributed to the polarity of the solvent, and the hydrophobic and hydrophilic character of the modified powder. However, when compared with the MWCNTs-COOH, the homogeneous dispersibility was noticed in ethanol (Fig. 10 B2), whereas the solubility of β -CD and MWCNTs-COOH in ethanol was very low. Ethanol promoted the dispersibility of MWCNTs-COOH because of the abundant hydroxyl

and carboxyl groups presented on the surface of MWCNTs. More specifically, the homogeneous dispersibility observed in ethanol was associated with increased polarity, hydrophilic interaction, and hydrogen bonding between hydroxyl and hydroxyl groups.

As reported in literatures, Myunghun Kim et al. reported that the synthesis of polystyrene brush on MWNTs treated with KMnO_4 in the presence of a phase-transfer catalyst and the PS-encapsulated MWCNTs were well dispersed in hydrophobic solvent, toluene (Kim et al. 2007). Jinuk Ha et al. reported that polystyrene was functionalized with MWCNTs and found the dispersibility only in toluene (Ha et al. 2006). Murugan et al. found that the MWCNTs functionalized with amphiphilic poly(propyleneimine) dendrimer showed an effective dispersibility in aqueous and organic solvents (Murugan and Vimala 2011). In this study, MWCNTs/ β -CD containing both hydrophobic and hydrophilic properties enabled dispersion of hybrid material efficaciously in aqueous/organic solvents.

Conclusions

In conclusion, we have successfully developed MWCNTs/ β -CD hybrid material by functionalization of MWCNTs-COOH with modified β -CD. The hybrid material was confirmed by employing FT-IR, X-ray diffraction, thermogravimetric analysis, $^1\text{H-NMR}$ spectroscopy, and SEM. To inspect the dispersibility and stability of hybrid material, the same amount of powders was added to various solvents, such as water, ethanol, acetone, xylene, and DMF. The results indicated that β -CD-grafted MWCNTs (MWCNTs/ β -CD) have fairly good dispersibility in water and ethanol because grafted β -CD interacted with media and promoted the compatibility. This method was thought to provide a new, simple, and facile route to prepare modified MWCNTs to enhance the dispersion of MWCNTs for potential application in the field of biological medicine and water treatment.

Acknowledgments The authors gratefully acknowledge the financial support from Sichuan Province Basic Research Plan Project 2013JY0099, Sichuan Science and Technology Innovation Seedling Project Funded Projects 2014-073, and the foundation of State Key Lab of Oil and Gas Reservoir Geology and Exploitation PLN0806.

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