Synthesis and Characterization of PEGylated Graphene Oxide

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Abstract. In this work, Graphene oxide (GO) was synthesized by Hummer’s method using graphite rod. Used organic chemical materials to active (GO – COOH) for esterification reaction between the graphene oxide carboxylic acid group and the Polyethylene glycol (PEG) hydroxyl group. Graphene oxide (GO) was conjugated to PEG4000 (medical polymer). The composite (GO – PEG) characterization by XRD, FTIR, UV-Vis and AFM. In UV-Vis GO showed a sharp peak at 275 nm whiles the peak of (GO – PEG) appear at 284 nm. A strong OH bond appear in Fourier transforms infrared spectroscopy (FTIR) spectra, C –H bond of (GO – PEG) also showed. In XRD pattern GO have a sharp peak appear at 2θ = 11.83̊ that related to 001 with d-spacing of 7.76 Å while functionalization of GO – PEG 4000 conform by broad peak at 2θ= 23.38̊ with d-spacing of 3.8 Å. Atomic force microscopy (AFM) images, GO image shows Graphene oxide sheet with main grain size is 24.41 nm, In GO – PEG4000 shows aggregation of Graphene oxides with PEG4000 the main grain size increase with functionalize to 287.04 nm.

Keyword. PEGylation, Graphene oxide, Hummer’s method, PEG 4000.

1. Introduction

The Graphene oxide (GO) layer has been considered one of the most promising carbon derivatives in material science over the past few years and has demonstrated excellent physical properties, biocompatibility and chemical stability [1]. Since Graphene, a two-dimensional (2D) mono-atomically thick planar layer, was first reported in 2004 [2]. In recent years, a variety of research groups have documented biomedical and physical applications of Graphene, such as drug loading and delivery [3]. This drugs used instead chemotherapy as anti-cancer drugs [4]. GO comprises a number of hydrophilic oxygen-containing functions, such as epoxy, hydroxyl and carboxyl groups, which have improved dispersibility in solvents as well as provide reactive sites for more functionalization by specific interactions [5]. Therefore, this led to evolution of smart Nano carrier – based drug delivery system which also known as SDDSs. This system promises to apply drugs to unique and targeting cancer types [6]. The reaction between the medical polymer and Nanoparticles was controlled using a polymerization method and this was first mentioned by Speiser et al. [7]. Among this nanoparticles (GO), has many functional groups on its composition, allowing Graphene to be stable suspension in water and bound to other drugs and polymers [8]. Polyethylene glycol is the most stabilizing agents and most studies one, The immune system’s effect of phagocytosis on Graphene oxide can be prevented by using PEG which is due to decrease uptake by reticuloendothelial system (ERS) (which is the part of immune system that consist of the phagocytic cells) and because its high aqueous solubility it used widely in SDDSs [9].
this work Graphene oxides GO was synthesis by Hummer’s method and then PEG was conjugated to the GO to produce strong ester interaction between PEG and GO which is called PEGylated Graphene oxide (GO-PEG) and characterization it with different techniques.

2. Experimental section

2.1. Chemical material

99.995%, Natural graphite rod, KMnO₃ 99%, NaNO₃ 99.5%, H₂O₂, 32%, HCl 37.5%, EDC hydrochloride C₆H₁₇N₃–HCl, N–Hydroxysuccinimide (98%) from (Sigma-Aldrich), (H₂SO₄, 98%) from (LOBA Chemie), NaOH (99%) from Dae-Jung, PEG 4000 from HI Media, Diethylether (C₂H₅)₂O (98%) from Thomas Baker.

2.2. Synthesis of graphene oxide (GO)

The most economical way used to synthesis graphene oxide is Hummer’s method. In which 1g of graphite rod milling into form powder and added with sodium nitrate in sulfuric acid were mix in an ice bath for 45 min. After that 3g of KMnO₃ added gradually at temperature 35 °C. The thick blend stirred for 1 day. KMnO₃ is reduced by adding (H₂O₂, 32%). 5 ml of (HCl, 37.5%) and DI water used to wash the thick blend. The resultant was dried at 75 °C for 5h to get the graphene oxide.

2.3. Preparations of PEG 4000 - functionalized GO

The activation of (GO – COOH) was began by esterification reaction between the Graphene oxide carboxylic acid group and the PEG hydroxyl group which is necessary for PEGylation of GO thus; 120 mg/ml of NaOH was solved in 20 ml in DI and added to 20 ml of GO suspension 2mg/ml, the suspension sonication for 1h and stirred for 3h. The pH of suspension was reduced by added 3ml of HCl then it was centrifuged twice 4000 rpm for 30 min to produced (GO – COOH) (GO carboxylic acid). The residue was wash with water twice.

The (GO – COOH) was diluted by 10 ml water to active (GO – COOH) 400 mg of EDC and 240 mg of NHS was added to (GO – COOH) then For (GO – PEG) 1500 mg of PEG4000 was added to the resultant and stirred for 24h.

Final step, the resultant was centrifuged and washed by DI water. UV-Vis and FTIR used to Characterization the resultant to identify whatever the carboxylation and PEGylation were conjugated.

3. Result and dissection

PEGylation (GO – PEG) was Characterization by UV – Vis spectroscopy, Fourier transforms infrared spectroscopy (FTIR), X-Ray diffraction (XRD), and atomic force microscopy (AFM). Figure1. Illustrates a simple schematic of synthesis of graphene oxide from graphite and the GO- PEG bonding and structure.

Figure1. Structure of GO- PEG.
3.1. UV – Vis analysis

Figure 2. Showed the spectra of GO and (GO – PEG), the blue line indicate the GO spectra at 275 nm which represent the absorptions bands that related to electronic transition $\pi \rightarrow \pi^*$ for C-C (aromatic rings) and transition $n \rightarrow \pi^*$ for C=O in the Graphene oxide. The red line represent the (GO – PEG) that shifted to 284 nm which confirms the synthesis of (GO – PEG) [10, 11].

![Figure 2. UV-Vis spectrum for GO and GO-PEG.](image)

3.2. FTIR analysis

Figure 3 displays FTIR spectra of GO and (GO – PEG). In the figure, blue line represent the GO sample, and the peaks at 3338 is stretching related to OH, while 1618, 1382 and 1026 cm$^{-1}$ are C=O groups in carbonyl and carboxyl [12]. Peak at 1724 cm$^{-1}$ is related to C=C and peaks at 1066 and 1382 related to C-O [13]. While in case of (GO – PEG) the peak at 3338 cm$^{-1}$ shifted to 3427 cm$^{-1}$ also appearance of C-H at 3920 cm$^{-1}$ which proved that GO conjugation to PEG, also the appearance of C=C, C-O and C=O at 1641, 1390, 1107 cm$^{-1}$ was also identified [14].

![Figure 3. FTIR spectra for GO and GO-PEG.](image)
3.3. XRD DIFFERACTION

Blue line in Figure 4 represents the XRD pattern of GO which a sharp peak appear at $2\theta = 11.83^\circ$ that related to 001 with d – spacing (7.76 Å) and conform the hexagonal structure of graphene oxide while the red line indicted to functionalization of GO – PEG 4000 with broad peak at $2\theta= 23.38^\circ$ with d – spacing (3.8 Å) which is results from functionalized while the peak of GO disappear because GO has an effect on the structure of the PEG molecular chain in the crystal lattice , disturbing the order of its crystallization. This decreases the crystallinity of PEG and result in an effective conjugation of PEG to GO Nano-sheets by ester bonding. [14].The orientation (001) determine by high score plus program.

3.4. AFM analysis

Images in Figure 5 Show the AFM analysis of GO and GO – PEG4000 in GO image shows graphene sheet with main grain size is 24.41 nm which conform the Nano size of synthesis. In GO – PEG4000 shows aggregation of graphene oxide with PEG4000 the main grain size increase with functionalize to 287.04 nm [15].

4. Conclusion

Graphene oxide Nano - particles successfully synthesized with mean grain size 24.41 as sheet form which analyzed by AFM. GO shows high absorbance in UV region with stretching related to OH at FTIR spectrum. PEG4000 conjugated with GO which is seen in C-H at 3920 cm$^{-1}$ at FTIR spectrum
with broad peak in XRD diffraction. The last form of conjugated GO – PEG4000 shown in AFM image as aggregation viscous.

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