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Self-assembly of cross-linked carbon nanotube films for improvement on mechanical properties and conductivity

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ABSTRACT

A facile strategy for cross-linked carbon nanotube film (CL-CNF) was carried out via self-assembly of carbon nanotubes (CNTs), which was achieved based on esterification and acylation reactions of functional CNTs respectively. Comparing with uncross-linked carbon nanotube film, this strategy could benefit for enhancing mechanical properties of CNF through altering the inter-tube interaction from weaker Van der Waals force to stronger chemical bonding, but not lost its conductivity. The tensile strength and Young's modulus of CL-CNF were remarkably enhanced, which were higher 263% and 190% than uncross-linked CNF. Meanwhile, conductivity of CNF after cross-linking increased to 210%. In this paper, the forming ester and acylation bonding in CNT network led to differences of their morphology that were observed on nanoscale. This method promoted CL-CNF as a promising material to be applied in water treatment and self-heating materials.

1. Introduction

Owing to their low density and excellent electrical property, carbon materials are obtained more attention, including carbon nanotubes (CNTs) [1] and graphene [2], etc. Since CNT was first found in 1991 [3], CNT and its composites have been widely studied. As a macro-material of CNT, carbon nanotube film (CNF) that is generally manufactured via vacuum based and pressurized filtration method, has potential applications in self-heating [4] and water treatment [5–7] materials, etc.

However, friability of CNF restricts its application seriously, because the interaction between CNTs in CNF derives from the weaker Van der Waals force. For example, Wang [1] prepared uncross-linked CNF, and stress and strain of uncross-linked CNF were only 22.1 MPa and 1.5%. Construction of CNF/polymer composite was a way to improve mechanical properties of CNF [8]. Although mechanical properties of CNF could be drastically improved via insulating and rigid resin impregnation, its density increasing, conductivity reducing and flexibility losing were inevitably acquired. Another method was preparation of cross-linked CNF (CL-CNF) by introducing some organic cross linkers, such as benzoquinone [9], epibromohydrin [10], etc. It switched inter-tube interaction from weaker Van der Waals force to stronger chemical bonding. However, introduction of organic cross linker was equivalent to adding insulator between CNTs, and this method would decrease the electrical conductivity of CNF.

To obtain the CNF with better mechanical and electrical properties, several CL-CNFs were first prepared by CNTs with carboxyl, hydroxide radical and amidogen via chemical self-assembly. This method was based on esterification and acylation reactions between functional CNTs in different solution systems, respectively. Moreover, mechanism of various reaction conditions influencing on mechanical properties of CL-CNFs was analyzed in this work.

2. Experimental

According to previous report [4], the uncross-linked CNF as control group was prepared by single-wall carbon nanotubes (SWCNTs), and its areal density was 2 mg/cm^2. Then the SWCNTs containing carboxyl (SWCNTs-COOH) and hydroxy SWCNTs (SWCNTs-OH), and SWCNTs-COOH and SWCNTs containing amidogen (SWCNTs-NH_2) with the weight ratio of 1.05: 1, followed the similar preparation process of uncross-linked CNF, to fabricate esterification and acylation CNFs in deionized water (DIW) and dimethylformamide (DMF) solution systems, respectively. Additionally, all the areal density of esterification and acylation CNFs was prepared with 2 mg/cm^2. After peeling from the filter membrane, the CNFs prepared in DIW and DMF systems were undergone UV irradiation for 6 h, for obtaining the esterification and

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acylation CL-CNFs. The esterification and acylation CL-CNFs were designated as ECL-CNFs and ACL-CNFs. The thickness of uncross-linked CNF, ECL-CNFs and ACL-CNFs prepared in DIW and DMF was 30, 27, 29, 27 and 30 um respectively, which was measured by a micrometer.

3. Results and discussion

Interaction types between CNTs would impact on the morphology of CNFs. Topological differences could be found in partial enlargement images of surface of uncross-linked CNF, ECL-CNFs

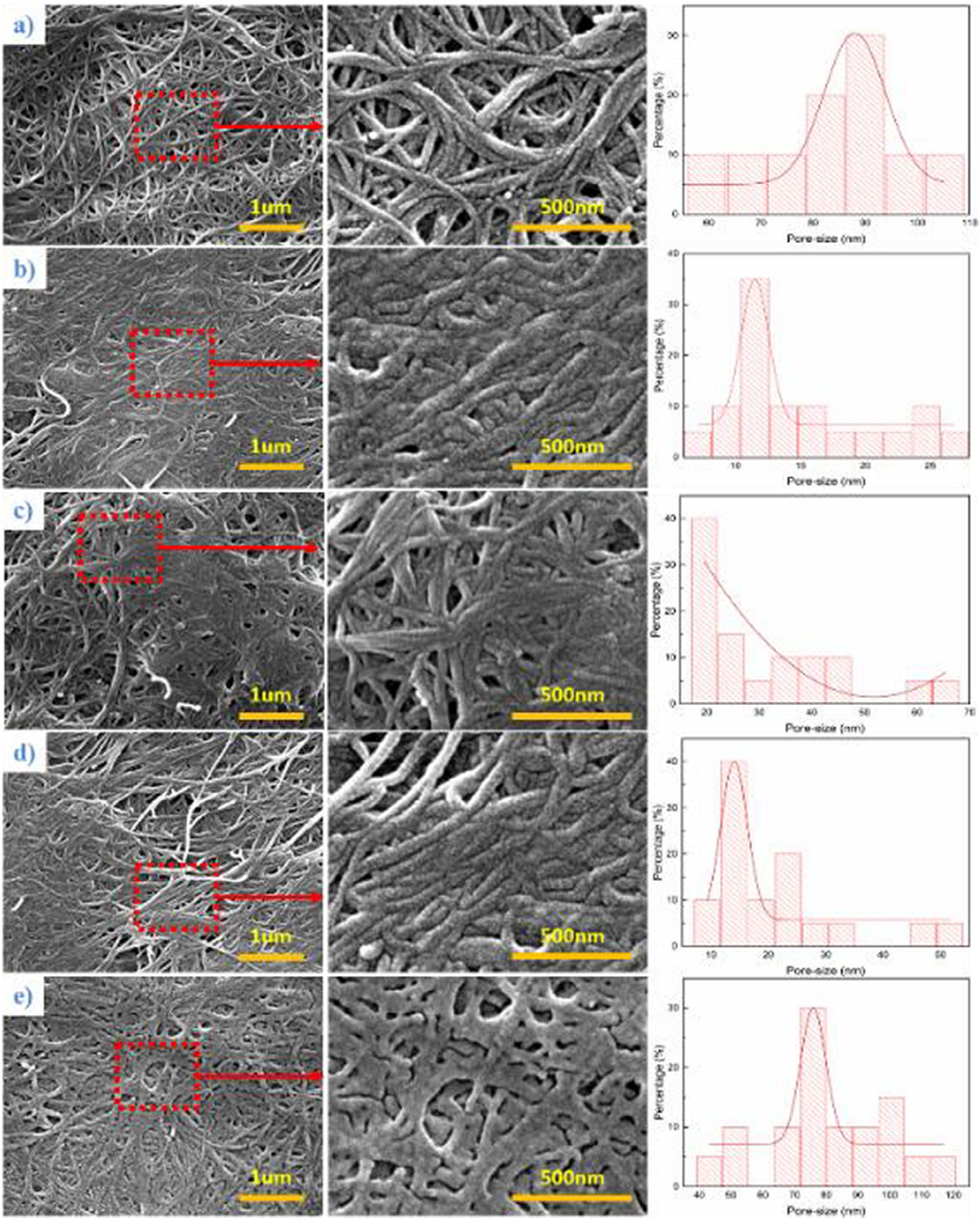

Fig. 1. SEM micrographs of surface, pore size distribution and Gaussian distribution curves of a) uncross-linked CNF, b) ECL-CNF prepared in DIW, c) ECL-CNF prepared in DMF, d) ACL-CNF prepared in DIW and e) ACL-CNF prepared in DMF.