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Fabrication of multi-walled carbon nanotube–carbon fiber hybrid material via electrophoretic deposition followed by pyrolysis process

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ABSTRACT

An integrated multi-walled carbon nanotube (MWCNT)–carbon fiber (CF) hybrid material has been fabricated by electrophoretic deposition of acid-functionalized MWCNTs on CF surface followed by soaking in a 10% solution of petroleum pitch in toluene, followed by pyrolysis in a nitrogen atmosphere. It has been revealed that MWCNTs entirely covered the CF surface. Mechanical properties of composites reinforced by MWCNT–CF hybrids were considerably enhanced (up to 120% in tensile strength and 100% in elastic modulus) compared to composites reinforce by as-received CFs. According to fractography observations, robust interlocking occurred between epoxy matrix and MWCNT–CF hybrids.

1. Introduction

Due to their exceptional mechanical characteristics [1], carbon fibers (CF) have become the predominant reinforcements in fabrication of high performance composites in the last decades. Compatibility of these reinforcements with the matrix plays a pivotal role in the strength threshold of the composite [1,2]. However, non-polar, stable and smooth graphitic surface of CF is not able to provide the required compatibility with polymeric matrices [3–5].

Recently, preparation of carbon nanotube (CNT)-CF hybrid materials has attracted special attention due to outstanding mechanical properties of CNTs [6–8]. Introduction of CNTs into the interphase of CF/matrix is regarded as an ideal strategy for strengthening the adhesion between CF and matrix, and consequently providing the desired compatibility. These one-dimensional nanoparticles can increase the roughness of CF surface and therefore improve the adhesion between CF and matrix through mechanical interlocking [9,10].

Various approaches have been exploited for fabrication of CNT-CF hybrid, such as functionalization [11,12], immersion [6], in situ growth [13,14], and electrophoretic deposition (EPD) [15,16]. Among them, EPD has represented interesting features for deposition of CNTs on CF surface [17]. This method is able to uniformly deposit CNTs on CF surface and form a homogenous structure of CNTs on CF. However, adhesion between deposited CNTs and CF is restricted to physical interactions between CNT and CF surface. To provide the required adhesion, functional groups have been employed to covalently bind the CNTs to the CF surface [18,19]. These groups are first grafted on either CF or CNTs and then reacted to the other one to bind CNTs to the CF. Although these functional groups can theoretically bind CNTs to the CF surface, the overall efficiency of these reactions, especially CNT–CNT bonds, remains low due to limited chance of a successful collision between the functional groups. This can be ascribed by steric hindrance of functional groups and porosity of the formed structure of CNTs around the CF. Therefore, such functional groups could not necessarily create an integrated structure of CNTs around CF.

In this research, an integrated CNT-CF hybrid material was prepared through pyrolysis treatment. CNTs were first deposited on CF surface via EPD. Then, hybrid was impregnated in petroleum pitch and eventually pyrolyzed to strengthen the attachment of CNTs to CF through carbonized residue of the petroleum pitch. Surface characteristics of CNT-CF hybrids and compatibility of them with epoxy resin was studied. Also, single fiber tensile testing was performed to investigate possible destruction of CF structure during the procedure. Finally, mechanical properties of reinforced composites were assessed to evaluate utility of these hybrids in production of advanced composites.

2. Experimental

2.1. Materials

Commercially-available, sized CFs was purchased, which had polyacrylonitrile-based with average diameter of 7 μm. The CF

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