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Enhanced durability of silanized multi-walled carbon nanotube/epoxy nanocomposites under simulated low earth orbit space environment

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ABSTRACT

Silane treated carbon nanotube filled polymer nanocomposites are suggested as a new alternative to reduce the degradation of polymer matrix composites (PMCs) exposed to the low earth orbit (LEO) environment. The silanization of multiwalled carbon nanotubes (MWCNTs) is conducted using 3-aminopropyltriethoxysilane (APTES). Nanocomposites filled with MWCNTs with and without silanization were prepared by the solution mixing method using mechanical/physical approaches to homogeneously disperse the MWCNTs into the polymer matrix. The samples were exposed to an accelerated low earth orbit simulated space environment for 20 h. The synergistic environmental factors used in the ground simulation systems were high vacuum, atomic oxygen (AO), ultraviolet (UV) radiation and thermal cycling. The material properties for nanocomposites reinforced with MWCNTs with and without silanization before and after exposure to the low earth orbit space environment were evaluated by total mass loss (TML), tensile test, thermo-gravimetric analysis (TGA), thermo-mechanical analysis (TMA), and thermo-optical analysis. Surface morphologies of the exposed samples were characterized through scanning electron microscopy (SEM). The results indicated that improvement of the interfacial bonding between the nanotubes and the matrix by the silanization of MWCNTs can considerably reduce the degradation rate and enhance the thermal stability, without sacrificing the thermo-mechanical properties of nanocomposites with very low MWCNT content under LEO space environmental conditions.

1. Introduction

The emerging shift to using carbon nanotube reinforced polymer as a material in aerospace programs has been anticipated ever since carbon nanotubes (CNTs) were discovered in 1991 [1]. The intense interest in CNTs as a very attractive reinforcement material for high-strength structural and high-performance functional polymer composites is due to CNT's unique properties such as high aspect ratio, low density, excellent mechanical strength, and good electrical and thermal conductivity [2]. Especially, in aerospace applications, CNTs possess great potential as fillers for structural and functional materials. Recently, to reduce the weight of aircraft, carbon nanotube reinforced polymer materials are being considered as suitable replacements for structural materials for non-load bearing components made with other composites or metals; these CNT-based materials are also being applied as functional materials to spacecraft to protect critical parts against electrostatic discharge. The low earth orbit space environment in which spacecraft operate includes many harsh constituents, such as atomic oxygen (AO), ultraviolet (UV) radiation, thermal cycling, ultra-high vacuum, micrometeoroids and man-made debris [3]. These environmental factors cause polymer film and polymer–matrix composites (PMCs) material to suffer accelerated degradation, resulting in a loss of mass and deterioration of performance. Therefore, space environment survivability in the development of polymer materials compatible with space applications is of significant importance for the desired mission life of spacecraft at LEO altitudes. As a method to protect polymers and PMCs, a widely used concept is the application of a protective coating that is stable under the space environment. However, once damage occurs to the protective coating, it can subsequently lead to erosion of the underlying polymer. An alternative to coatings has been explored using materials inherently resistant against the LEO environment incorporating silicon into the backbone of polymers [4].

Unlike a number of studies of space environment effects on polymer and PMC materials in LEO, limited work has been done on the effect of space environmental exposure on the properties of CNT-reinforced polymer materials [5]. Much of the research focused on using CNTs has been on using them as electrically conductive additives for polymers to mitigate electrostatic charge build-up [6,7]. Other areas for CNT reinforced polymer materials

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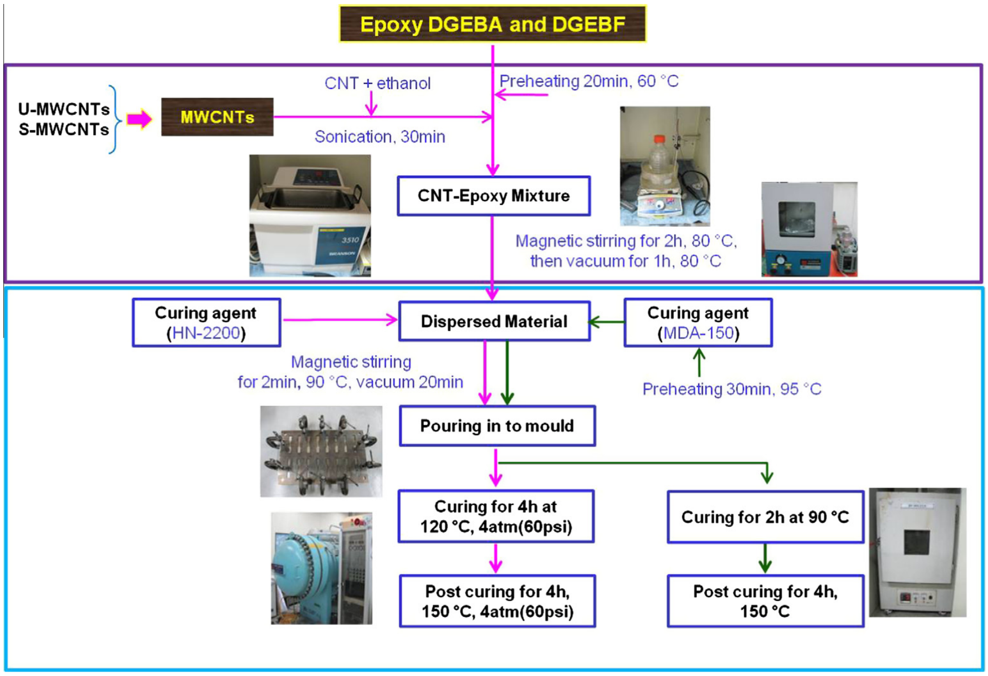

Fig. 1. Procedures and equipments of MWCNTs/epoxy nanocomposites manufacturing.

Table 1
Tested resin systems.

Abbreviation	Resin system		Materials	
An_Ep_128	Epoxy	Anhydride hardener	YD-128	HN-2200
AA_Ep_115		Aromatic amine hardener	YD-115	MDA-150
AA_Ep_170			YDF-170	MDA-150

are as lightweight, high thermal conductivity and structural matrix systems. Thus, it is of practical importance to study the space environment characteristics of CNT reinforced polymer materials that are aimed at space applications.

In this paper, silane-grafted CNT reinforced polymer materials are suggested as a new means to overcome the disadvantage of polymer matrix composites against such the destructive LEO space environment.

The main purpose of this study is to establish a siloxane network into the polymer bulk by incorporating silane grafted MWCNTs into the epoxy matrix to improve the resistance of the polymer nanocomposites against LEO space environmental factors. Therefore, the silanization of MWCNTs by 3-APTES is conducted. Nanocomposites filled with unmodified MWCNTs and silane treated MWCNTs having three different resin systems are prepared and then tested under simulated LEO space environment conditions. Also, the effects of silane treated MWCNTs on the properties of polymer nanocomposites exposed to the LEO environment were investigated and described.

2. Experimentation

2.1. Materials

MWCNTs supplied by Iljin Nanotech Co., Ltd., Korea were used as reinforcement in this work. The MWCNTs synthesized by catalytic chemical vapor deposition process, had a diameter range of 10–15 nm; the purity was above 95%. 3-APTES with a purity of 99% (Sigma Aldrich) was used for silanization of the MWCNTs. A diglycidyl ether of bisphenol A (DGEBA) resin, designated “YD-128” (Kukdo Chemical, Korea), “YD-115” (Kukdo Chemical, Korea, resin diluted with butyl glycidyl ether) and a diglycidyl ether of bisphenol F (DGEBF) resin, designated “YDF-170” (Kukdo Chemical, Korea), were used. The curing agent was anhydride hardener (HN2200) and aromatic amine hardener (4,4-diamino diphenyl methane, DDM, Kukdo Chemical, Korea). The following reagents and solvents were used without further purification: nitric acid (70%, Dae Jung

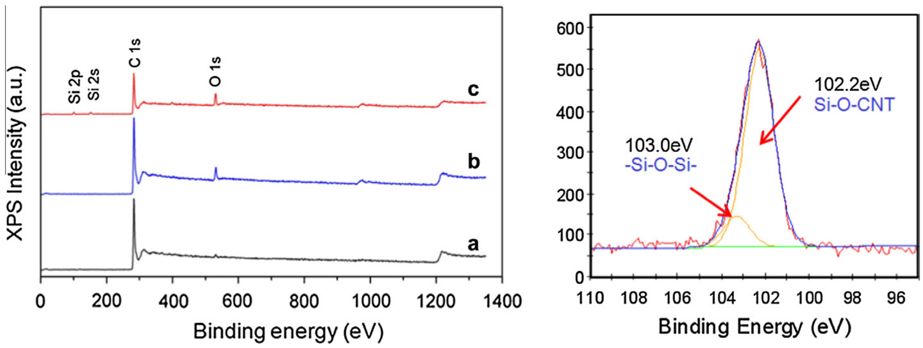

Fig. 2. XPS survey spectra of silane treated MWCNTs and peak separation of Si 2p XPS spectrum.