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Material Properties

# Enhanced mechanical properties of carbon fiber composites by grafting different structural poly(amido amine) onto fiber surface

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ABSTRACT

The mechanical properties of carbon fiber composites depend on the interfacial strength between fiber and epoxy matrix. Different poly (amido amine) (PAMAM) dendrimers were grafted onto carbon fiber to improve the interfacial strength of the resulting composites. Functional groups on the carbon fiber surface were examined by X-ray photoelectron spectroscopy. The surface morphology of the resulting materials was characterized by scanning electron microscopy and atomic force microscope. The characterization results revealed that PAMAM dendrimers were chemically grafted onto the surface of carbon fiber. More importantly, the mechanical properties of the resulting composites were enhanced owing to the presence of sufficient functional groups on the carbon fiber surface. In addition, after PAMAM containing chair conformations were grafted, the interlaminar shear strength had the highest increase of 53.13%, higher than that of the fiber grafted with PAMAM containing terminated linear amine. This work provides an alternative approach to enhance the mechanical properties of fiber composites by controlling the interface between fiber and epoxy matrix.



## 1. Introduction

Advanced structural fibers such as natural fiber, glass fiber and carbon fiber (CF) have been widely applied in advanced fiber reinforced composites [1–3]. Among them, CF have been widely used in aerospace and military applications due to their excellent electrical properties, high modulus, strong tensile strength and large aspect ratio [4,5]. However, the surface of CF is usually smooth and chemically inert, causing poor matrix compatibility and weak properties of the fiber/matrix interface. The performance of polymer composites depends highly on the interface between CF and matrix resin [6]. Therefore, many reports have been devoted to modify carbon fiber surface in an attempt to enhance the interfacial strength of the resulting composites, such as polymer sizing [7,8], physical coating treatment [9,10] high energy irradiation [11,12] and chemical grafting [13,14]. Recently, chemical grafting of molecules with many active amine groups, such as poly (amido amine) (PAMAM) dendrimer, hyperbranched polyglycerol (HPG) and polyethyleneimine (PEI) onto carbon fiber surface has attracted considerable interest [15–17]. Grafting these molecules significantly improved the interfacial properties of carbon fiber reinforced composites.

Because of the low melting viscosity, three dimensional architectures and reactive peripheral amine groups [18,19], PAMAM can easily generate a uniform film on carbon fiber surface and show great potential in improving the properties of fiber-matrix interface [20]. However, the effects of differently structured PAMAM on the interfacial properties between carbon fiber and epoxy matrix would be different.

In this study, we investigated the microstructure and mechanical properties of carbon fiber composites by fiber surface treatments with differently structured PAMAM dendrimers. Scheme. 1a illustrates the functionalization progress of carbon fiber and schematic representation of PAMAM functionalized carbon fiber. One kind of PAMAM containing linear amine terminated was prepared by repeated reaction between Ethanediamine and Methyl Acrylate (designated as L-PAMAM, the molecular structure being shown in Scheme. 1b. The other kind of PAMAM containing chair conformations was synthesized by one step synthesis between *N*-Aminoethylpiperazine and Methylene-Bis-Acrylamide (designated as C-PAMAM, the molecular structure being shown in Scheme. 1c). X-

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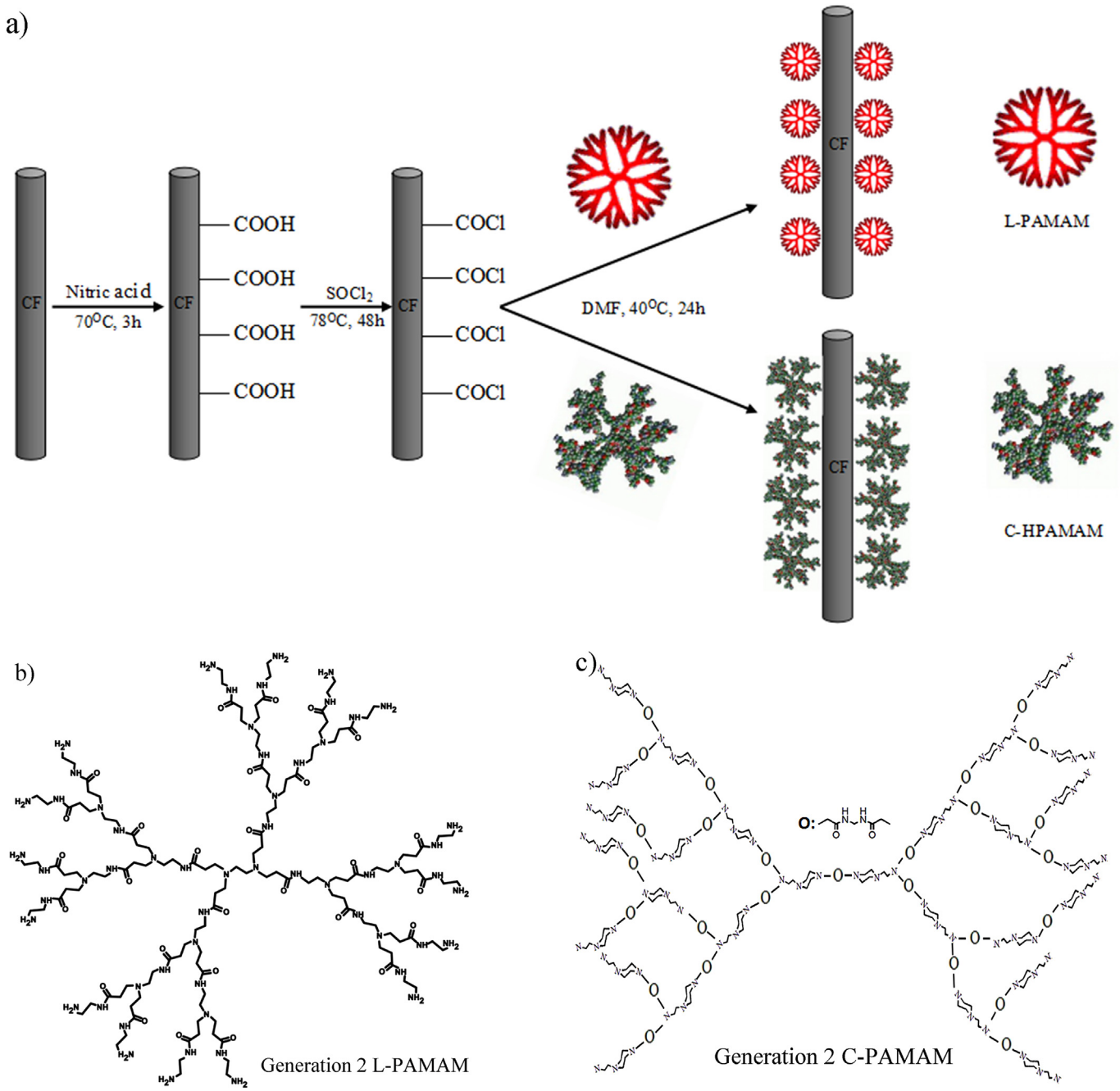


**Scheme 1.** a) the functionalization progress of carbon fiber, b) the molecular structure of L-PAMAM and c) the molecular structure of C-PAMAM.

ray photoelectron spectroscopy (XPS) and SEM were applied to reveal the functional groups and microstructure of the fibers. IFSS was performed to measure the interfacial properties of carbon fiber composites.

## 2. Experiments

### 2.1. Materials

The carbon fibers (JT-400A-3K, average diameter 6.8 μm, the linear density 0.175 ± 6 g/m, the density 1.76 g/cm$^3$) were procured from Jilin Shen Zhou Carbon Fiber Co.,

LTD. Thionyl chloride ($SOCl_2$) and dimethylformamide (DMF) were purchased from Sigma-Aldrich. The matrix system used in this work was 618 epoxy resin (molecular weight 350–400 g/mol) and hardener H-256 (3,3′-diethyl-4,4′-diaminodiphenyl methane, DEDDM). Nitric acid ($HNO_3$, 68%) and other solvents (analytical grade) were purchased from Tianli Chemical Reagent Co. Ltd., China and used as-received.

### 2.2. Preparation of the carbon fiber grafted with different PAMAM

The carbon fibers, extracted with supercritical ace-tone/water at 633 K for 20 min [21], were denoted as desized carbon fiber. The desized carbon fibers were oxidized by nitric acid at 70 °C for 3 h. After that, the fibers were then reacted with a solution of 100 mL