Surface Characterization of Helium Plasma Treated Nano-SiO_2 Sol-gel Coated UHMWPE Filaments by Contact Angle Experiments and ATR-FTIR

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Abstract: Ultrahigh molecular weight polyethylene (UHMWPE) Filaments has a low surface free energy and therefore modification of their surface properties before any use is often needed. Atmospheric pressure plasmas treatment is a convenient and environment friendly way to obtain these modifications by introducing new chemical groups at the surface without affecting the bulk properties. This paper studies the influence of nano-SiO_2 Sol-gel coated pretreatment on atmospheric pressure jet (APPJ) treatment of UHMWPE fibers with helium used as the treatment gas. The surface properties of the plasma-treated UHMWPE Filaments are characterized using contact angle measurements and ATR-FTIR spectroscopy. The UHMWPE Filaments show a remarkable increase in surface free energy after plasma treatment. ATR-FTIR spectroscopy of the plasma-treated UHMWPE Filaments reveals that plasma treatment introduces oxygen-containing functionalities, such as ketones, aldehydes, alcohols and carboxylic acids on the UHMWPE Filaments surface leading to the increase of surface free energy.

Keywords: Plasma jets, UHMWPE, contact angle, fourier transform infrared spectroscopy.

1. Introduction

Ultra-high molecular weight polyethylene (UHMWPE) filaments with outstanding characteristics such as high tensile strength, high Young’s modulus, low density etc. has been widely used in various fields ranging from civil to military applications [1]. Nevertheless, surface treatments of the UHMWPE filaments have received great interests with a view to improving its shortcomings such as low surface energy and chemically inert surface as a result of the poor interfacial adhesion between the UHMWPE filaments and matrix in the recent decades [2].

Therefore, extensive researches focusing on surface treatments of the UHMWPE have been carried out including flame-oxidation; chemical etching and ultraviolet initiated grafting by introducing chemically active groups onto the surface of the UHMWPE filaments with an aim of improving interfacial adhesion of UHMWPE-reinforced composites [3]. For instance, Moon et al. reported that oxygen plasma treatment introduces micro pitting on the UHMPE filament surface, which not only improved interfacial adhesion and flexural properties, but also decreased impact properties of UHMWPE filament/epoxy composites and UHMWPE filament/vinylester composites through mechanical interlocking [4]. Then, Cho et al. reported that the interfacial bonding strength between UHMWPE and PMMA bone cement considerably improved by c-ray irradiation method [5]. Osterom et al. showed that the adhesion properties of UHMWPE improved to various degrees after the surface treatments including UV/Ozone, corona, abrasion, glow discharge and a combination of abrasion and glow discharge treatment [6]. Yet, till now, there are limited papers related to coating technology applied to the UHMWPE surface modification. Yet pretreatment of nano-particles is an essential procedure for the purpose of achieving the relatively specific dispersion of the nano-particles on the fiber surface, otherwise the advantages of nanoparticles do not exhibit since nano-particles have a strong tendency to agglomerate induced by its high surface energy [7]. In our previous work, a series of commercialized nano-fillers including nano-SiO_2, nano-TiO_2, nano-ZnO particles, carbon

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nano-tube and montmorillonite have been successfully modified and activated with the aim of achieving uniform dispersion of nano-fillers in the polypropylene/ polylactic acid (PP/PLA) matrix and increasing the cohesive affinity of the matrix by using atmospheric pressure plasma jet [8-11].

The attenuated total reflectance Fourier transform infrared (ATR-FTIR) spectroscopy has been used successfully to obtain structural information of plasma-treated polymer surfaces [12,13]. In this article, it will be shown that by choosing the appropriate ATR accessory, ATR-FTIR spectroscopy is able to detect structural alteration upon plasma surface treatment nano-SiO_2 coating UHMWPE filaments. This work focuses on ATR-FTIR analysis of plasma-modified nano-SiO_2 coating UHMWPE filaments. The plasma treatment was performed using APPJ. The surface properties of the plasma-treated nano-SiO_2 coating UHMWPE filaments are characterized using contact angle measurements, surface free energy calculations and ATR-FTIR.

2. Experimental

2.1. Materials

Nano Silicon dioxide (nano-SiO_2) obtained from Hong Sheng Materials Technology Co., Ltd. The UHMWPE fiber with an average single fiber diameter of 28 μm supplied from Ningbo Dacheng Chemical Fibers Company (Zhejiang, China).

2.2. Plasma treatment

The surface of UHMWPE filaments by sol-gel dip-coating technique was deposited with Nano-SiO_2 particles. Nano-SiO_2 sol-gel with a primary size of 14 nm in acetone was employed. After the diluted solution was filtered, it was coated on the surface of UHMWPE filaments by dip coating. By changing the concentration of nano-SiO_2 sol-gel and the speed of dip coating, the coverage of nano-SiO_2 particles on UHMWPE filaments can be tuned. In this paper, the concentration of nano-SiO_2 colloid was about 0.5 wt %, and the speed of dip-coating was 0.13 mm/s.

After coating, these filaments were treated by an APPJ (Atomflo-R, Surfx Company, USA) with 100% Helium gas. The APPJ was a small plasma jet with a length of around 15cm, consisting of two concentric electrodes with a 1.6mm gap through which the working Helium gas flows. The gas discharge was ignited by applying a low 13.56MHz radio frequency power, which enabled the jet to produce a stable discharge and to avoid the arc transition.

The distance between the nozzle and the top of the nano-SiO_2 coating UHMWPE filaments was 5mm. The substrate circumrotated underneath the plasma jet at a speed of 10mm/s. Other plasma treatment parameters were set as follows: flow rate of helium gas was 20L/min, output power was 40W, treatment nozzle temperature was 60℃ and sample treatment or stationary time was 3.3s.

2.3. Contact angle measurement

Contact angle measurement was performed to determine the wettability of the fiber surface using sessile drop technique in which the shape of the distilled water droplets attached to the fibers were recorded as digital images taken by the JC2000A Stable contact angle analyzer (Powereach Digital Equipment, Shanghai, China) as described by Carroll [14]. Each contact angle reported was an average of at least 15 different measurements and at least 5 fibers were used. The single fiber specimen fixed by an adhesive tape on a frame with a certain amount of tension and the length of the fiber was about 2.5 cm. The water droplets were sprayed onto the single fiber during the test.

2.4. Fourier transform infrared (FTIR)

Infrared (IR) absorption spectra of the UHMWPE filaments was acquired in attenuated total reflection (ATR) on a Nicolet 5700 FTIR spectrometer (Thermo Nicolet) equipped with a Smart Performance accessory (Thermo Nicolet) with a ZnSe crystal. The spectral region spanned from 4000 to 500 cm^{-1}, with a resolution of 4 cm^{-1}, and 256 acquisitions were gathered.