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Dynamic wetting behavior of plasma treated PET fibers

Qufu Wei [a,*], Ya Liu [a], Dayin Hou [b], Fenglin Huang [a]

[a] *Key Laboratory of Eco-textiles, Ministry of Education, Southern Yangtze University, Wuxi 214122, PR China*
[b] *Anhui University of Technology & Science, Wuhu 241000, PR China*

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Abstract

Polyethylene terephthalate (PET) fibers have been increasingly used in textile industries for a variety of applications ranging from filtration, composites, tissue engineering and electronic textiles. The surface properties of these polymer fibers are of importance in various applications. The surface properties of PET fibers can be modified by different techniques. In this study, PET fibers were treated in oxygen plasma for improving surface wettability. The effects of plasma treatment on dynamic wetting behavior were characterized using atomic force microscopy (AFM), X-ray photoelectron spectroscopy (XPS) and dynamic contact angle measurements. The plasma treatment roughened the fiber surface revealed by atomic force microscopy (AFM). The introduction of functional groups was detected by XPS. The roughened and funtionalized surface resulted in the change in advancing and receding contact angles. Both advancing and receding contact angles were significantly reduced, but the contact angle hysteresis was increased after plasma treatment.

Keywords: Plasma treatment; Polyethylene terephthalate; Contact angle; Hysteresis; AFM; XPS

1. Introduction

Fibers are basic elements of textile materials. Natural fibers have dominated the textile market for thousands of years, but the new developments in chemical fiber industry have significantly changed the industry [1]. The use of chemical fibers has been expanding from modern apparel, home furnishings, medicine, aeronautics, energy industry to high performance applications.

For industrial uses, manufactured fibers have been increasingly used to replace traditional materials in applications from super-absorbents, to artificial organs, to construction materials for space programs. The dominant fibers used in technical textiles include olefin fibers, PET fiber and rayon fibers [2].

Since polyester fiber has a lot of special characteristics, such superior strength and resilience, it has become one of the most important materials in various industries. For the applications of PET fibers in sorption related industries, PET materials have to be modified to improve the wettability of the materials. Surface modification by plasma treatment has opened up new possibilities in relation to wettability and adsorption of textile materials [3]. Plasma is a low-temperature glow discharge or a low-pressure partially ionized gas consisting of large concentrations of excited atomic, molecular ionic, and free radical species. Plasma surface treatment causes changes to a limited depth; bulk properties of even the most delicate materials remain unchanged [4].

The wettability of materials can be characterized by contact angle. The contact angle, the angle formed at the intersection of the solid and the fluid interfaces, is routinely evaluated based on the static contact angle [5]. In various dynamic processes, however, static contact angle is not sufficient to characterize the wetting behavior of different materials. Dynamic contact angles are divided into advancing and receding contact angles, which are defined as the contact angles measured when the three phase line is in controlled movement by wetting the solid by the liquid or by withdrawing the liquid over a pre-wetted surface, respectively. The difference between advancing contact angle and receding contact angle forms contact angle hysteresis. Contact angle hysteresis affects the liquid adsorption and/or retention processes of a material [6].

In this study, polyethylene terephthalate (PET) fibers were treated in oxygen plasma for improving surface wettability. The effect of plasma treatment on wetting behavior of the fibers was characterized using dynamic contact angle measurements. The changes in surface morphology and chemistry were also

* Corresponding author. Tel.: +86 510 85913007; fax: +86 510 85913200.
E-mail address: qfwei@sytu.edu.cn (Q. Wei).

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examined using atomic force microscopy (AFM) and X-ray photoelectron spectroscopy (XPS).

2. Experimental

2.1. Materials

Fibers used in this study were polyethylene terephthalate (PET). The PET fibers had an average diameter of 28 μm. The fiber samples were first washed in ethanol followed by twice rinses in distilled water and then they were dried at 40 °C in an oven.

Plasma treatment was performed in a HD-1A vertical laboratory plasma treatment machine. The treatment was carried out using oxygen at a pressure of 15 Pa. Each sample was treated at 50 W for 30, 60 and 90 s, respectively.

2.2. Surface characterization

2.2.1. AFM observation

Scanning probe microscope (SPM), particularly in the form of atomic force microscopy (AFM) provides new tools for examining nanostructures [7]. The AFM used in this study was CSPM4000 produced by Benyuan Company. The vertical resolution of the machine is 0.1 nm, while the horizontal solution is 0.2 nm. The scanning mode used was contact mode in this study, and the scanning range was set at a size of 5.0 μm × 5.0 μm. All samples were scanned at room temperature in atmosphere.

2.2.2. X-ray photoelectron spectroscopy

The XPS used in this study was an ESCA 300 (Scienta Instruments). The XPS utilizes photoionisation and energy-dispersive analysis of the emitted photons to monitor the composition of the surface region of the sample. The experiments were carried out using a monochromatised Al Kα X-ray source (1486.7 eV) at 15 kV and 10 mA. The wide scan spectra for identification of elements were obtained over the range 0–1000 eV, using a pass energy of 150 eV. The same pass energy was also used in obtaining the high-resolution spectra.

2.2.3. Dynamic contact angles

The dynamic contact angle measurement of individual fiber was performed using a CDCA-100F produced by the Camtel Ltd. in the UK, The dynamic contact angles were determined by Wilhelmy technique [8], where a solid sample was immersed and withdrawn into and out from a liquid while simultaneously measuring the force acting on the solid sample at 20 °C. The advancing and receding contact angles could then be determined from the obtained force curve.

3. Results and discussion

3.1. Surface morphology

The AFM images of 5.0 μm × 5.0 μm in Fig. 1 reveal the surface structures of the PET fibers. The series of images show the change in surface morphology of the PET fibers before and after plasma treatment. The groove-like structures of the untreated PET fibers are clearly observed by AFM examination, as illustrated in Fig. 1a. They are formed by the fibril structure of the polymer fiber. It can also be seen from the AFM image that the fibrils are oriented in the direction of the fiber axis. These fibril structures are formed during the fiber drawing processing. The effect of oxygen plasma treatment is presented in Fig. 1b–d. The surface of the PET fiber is obviously roughened after the plasma treatment for 30 s, as shown in Fig. 1b. The fibril structure is not visible any more and aggregate structures with various sizes can be seen on the fiber surface. The different sizes of the aggregates indicate the uneven effect of the surface etching by plasma

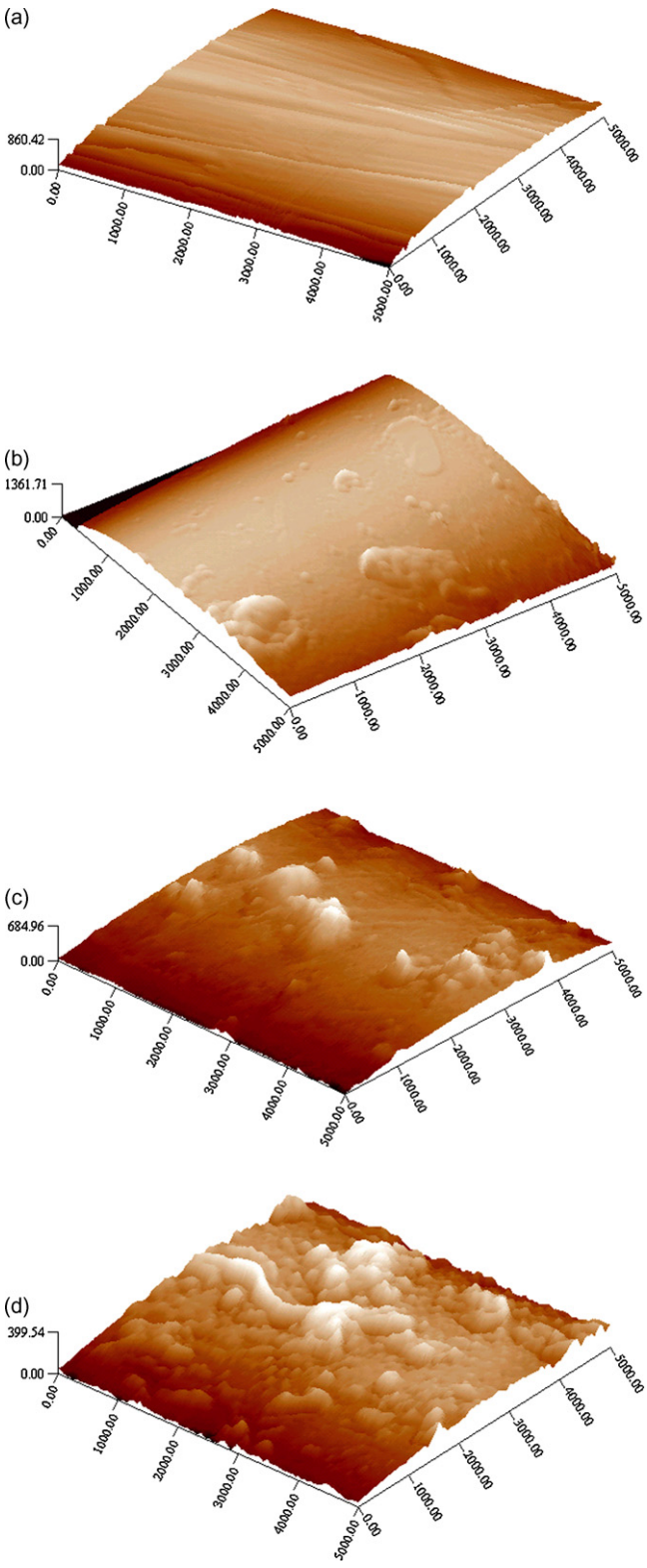

Fig. 1. AFM images of PET fiber: (a) untreated; (b) plasma treated for 30 s; (c) plasma treated for 60 s; (d) plasma treated for 90 s.

treatment. Oxygen plasma treatment for 60 s further roughens the PET fiber surface, resulting in the formation of the pit-like structures on the fiber surface as displayed in Fig. 1c. The plasma treatment for 90 s causes the degradation of the fiber surface due to the etching effect, as exhibited in Fig. 1d.