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Influence of atmospheric pressure plasma treatment on various fibrous materials: Performance properties and surface adhesion analysis

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ABSTRACT

Atmospheric pressure plasma treatment using oxygen gas was applied to wool fibrous materials. The plasma-treated fibrous materials were characterised using advanced instrumental techniques including scanning electron microscopy and X-ray photoelectron spectroscopy. They were also tested for performance properties including tensile and tearing strength as well as change in yellowness using international standard testing methods. Wettability analysis was conducted to study the surface area and surface energy of the plasma-treated fibrous materials. Surface modification regarding the enhancement of their adhesion to other substance, i.e. microcapsule treatment, was investigated.

1. Introduction

Over the decades, low-pressure or high vacuum plasma treatments have been widely used for modifying the properties of textiles and polymer materials [1–3]. However, the disadvantage is that a setup of vacuum equipment is required and it will be costly for low profit margin products such as textiles [4].

Atmospheric pressure plasma treatment has been introduced in recent years to overcome the drawbacks of low-pressure plasma system [5–7]. Many research works were found in literature regarding the applications of atmospheric pressure plasma treatment on textiles [8–10]. However, their researches are mainly focused on a specific fabric property without a detail and correlated characterisation.

In the present study, atmospheric pressure plasma treatment was conducted on wool fibrous materials. A full characterisation has been conducted to study its surface morphologies, chemical composition, tensile and tearing strength, yellowness index and wettability measurement. Surface modification regarding the enhancement of their adhesion to other substance, i.e. microcapsule treatment, was investigated.

2. Materials

100% 2/1 twill wool fabric was obtained from Lun Wah Silk and Piece Goods. A scouring process using non-ionic detergent was conducted and the fabric samples were conditioned subsequently at $21 \pm 1\,^{\circ}C$ and $65 \pm 5\%$ relative humidity for 24 h prior to the atmospheric pressure plasma treatment.

3. Plasma treatment

Plasma treatments on wool fibrous materials were carried out by an atmospheric pressure plasma jet apparatus Surfix Technologies 200 (California, USA). The fibrous materials were moved at various speeds, i.e. 1 s/mm, 1.5 s/mm and 3 s/mm at fixed source to sample distance which is 7 mm. The device employs a capacitively coupled electrode design and produces a stable discharge at atmospheric pressure with 13.56 MHz radio frequency. The treatment was carried out using an APPJ nozzle which covered an active area of $1 \times 25\ mm^2$ and was mounted vertically above the substrate pathway. Helium was used as a carrier gas with the flow rate being 15 L/min and oxygen was used as reactive gas with the flow rate being 0.3 L/min.

4. Experimental

4.1. Surface morphological analysis

Surface morphology of the test specimens was investigated by means of scanning electron microscope (JSM 6490) with 20 kV accelerating voltage.

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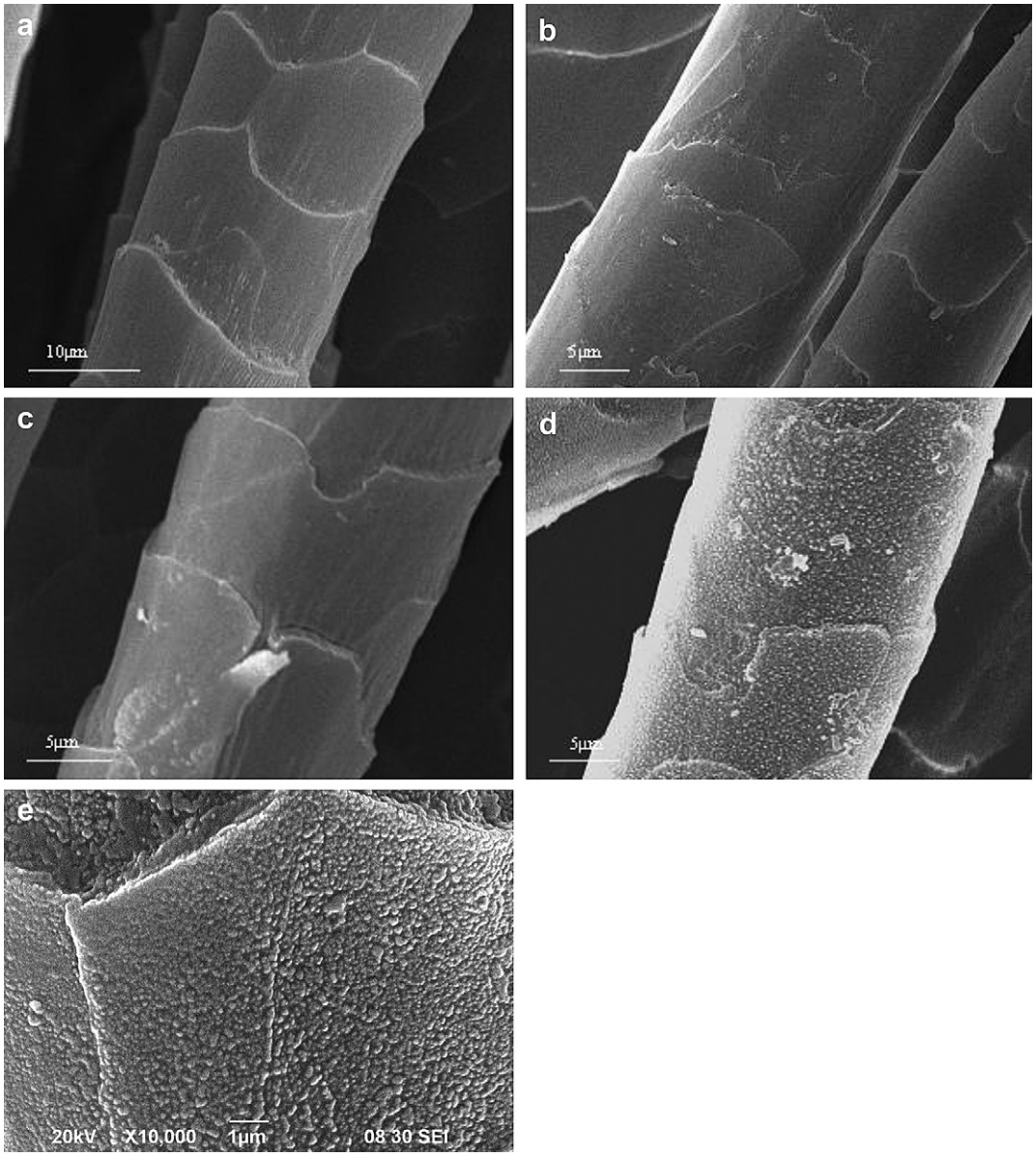

Fig. 1. (a)–(d). SEM images of untreated & atmospheric pressure. (e). SEM images of nano-scale atmospheric pressure plasma-treated wool fibres.

4.2. X-ray photoelectron spectroscopy analysis

The chemical composition of the fibre surface was investigated by X-ray photoelectron spectroscope (XPS; SKL-12, China), modified with a VG CLAM 4 multichannel hemispherical analyser. X-ray source is a dual anode source from VG (type XR3E2) but non-monochromatic Mg K_α radiation (1253.6 eV) at 10 kV and 15 mA. The analysis was carried out under an ultra high vacuum condition of 8×10^{-8} Pa.

4.3. Fabric performance properties

4.3.1. Tensile strength

According to the ASTM D 5034–95, the tensile strength properties and elongation at break of the test specimens were measured using the Instron Tensile Tester 4411 (Instron, USA).

4.3.2. Tearing strength

According to the ASTM D 1424–96, the tearing strength of test specimens was evaluated by using Elmendorf Tearing Tester (Thwing-Albert Instrument Co., USA).

4.3.3. Yellowness index

The yellowness index of the plasma-treated wool fibrous materials was measured in accordance with the ASTM Designation: E313-05 using the reflectance spectrophotometer, GretagMacbeth Colour-Eye 7000A.

4.4. Wettability measurement (surface contact angle and wetting time)

Contact angle and wettability measurement were conducted using a contact angle goniometer (ramé-hart instrument co., NJ, USA) equipped with an Imaging System. A microlitre dispenser was

Table 1
Surface elemental analysis and atomic ratio of 1.5 s/mm plasma-treated wool fibres.

Samples	Element conc., wt%				Atomic Ratio	
	C_{1s}	N_{1s}	O_{1s}	S_{2p}	C/N	O/C
Control	70.7	6.2	21.6	1.5	11.4	0.3
1.5 s/mm	44.0	19.7	33.9	2.4	2.2	0.8