Applied Surface Science 255 (2009) 9458–9462

Contents lists available at ScienceDirect

Applied Surface Science

journal homepage: www.elsevier.com/locate/apsusc

Influence of argon/oxygen atmospheric dielectric barrier discharge treatment on desizing and scouring of poly (vinyl alcohol) on cotton fabrics

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ARTICLE INFO

Article history:
Received 15 April 2009
Received in revised form 25 June 2009
Accepted 18 July 2009
Available online 25 July 2009

Keywords:
Dielectric barrier discharge
Polyvinyl alcohol
Desizing
Scouring
SEM
XPS

ABSTRACT

The effect of argon/oxygen atmospheric dielectric barrier discharge (DBD) treatment on desizing and scouring of polyvinyl alcohol (PVA) on cotton fabric was studied with respect to the treatment duration of 1, 2, 4 and 6 min. X-ray photoelectron spectroscopy (XPS) analysis indicated that oxygen concentration increased for the plasma treated PVA film. Solubility measurement revealed that plasma treatment increased PVA solubility in hot washing but less effective in cold washing. Scanning electron microscopy (SEM) showed that the fiber surfaces were as clean as unsized fibers after 6 min treatment followed by hot washing. Wickability analysis indicated that the capillary heights of plasma treated fabrics increased significantly as the plasma treatment duration increased. The results of the yarn tensile strength test showed that the plasma treatment did not have a negative effect on fabric tensile strength.

1. Introduction

The application of sizing agents to warp yarns plays an important role in ensuring high weaving efficiency by increasing yarn strength and reducing yarn hairiness [1,2]. PVA is one of the most frequently used sizing agents for cotton yarns with respect to its impressive tensile strength and excellent film-forming properties [3–5]. Size has to be removed through desizing prior to dyeing and finishing processes. However, PVA sized fabrics must be subjected to hot water washing with chemical agents in order to effectively remove the size [6,7]. Even at elevated temperatures, a 100% removal is not always achieved through these wet process methods. In addition to removal problems, the effluent must then be treated to remove all PVA before reusing or releasing the waste water in the recycling process, which results in high energy costs.

Desizing methods with low energy consumption are therefore highly desirable. Plasma treatment is an environmentally friendly technique which introduces polar groups or increases surface roughness to improve surface properties such as wettability, biocompatibility, adhesion, dyeing and printing, as well as finishing properties without affecting the bulk properties [8–13]. However, most of the plasma systems operate at low pressure which makes it difficult to continuously process textiles. Therefore, much attention has been paid to plasmas operating at atmospheric pressure due to advantages of eliminating the expensive vacuum system, on-line processing capabilities, high efficiency, and the scalability to a larger area [14–16]. At atmospheric pressure, there are essentially two methods for producing nonthermal plasmas using either a corona discharge or a dielectric barrier discharge (DBD). DBD is superior to corona discharge because it is more homogeneous [17–20]. An important advantage of the DBD is the simplicity of its operation in strongly nonequilibrium conditions at atmospheric pressure with reasonably high power levels, without using sophisticated pulse power supplies [21,22]. Therefore it could be an ideal surface treatment technique for fibrous materials.

Until now, limited number of papers has been published regarding the application of atmospheric pressure plasma treatment in desizing PVA on cotton fabrics [23–25]. Furthermore, little has been reported about surface wettability change such as wickability of the plasma desized fabrics as compared with the conventional scouring process. It has been suggested that wicking behavior of plasma treated fabrics can be greatly improved [26,27]. The objective of this study was to examine how DBD plasma treatment influences the desizing and scouring

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0169-4332/$ – see front matter
doi:10.1016/j.apsusc.2009.07.058

of PVA on cotton fabrics as a function of treatment time. The plasma desizing effect of PVA on fabrics was characterized by scanning electron microscope (SEM) and the percent desizing ratio (PDR). X-ray photoelectron spectroscopy (XPS) was applied to study the changes of chemical composition of plasma treated films. The capillary height was used to investigate the wicking properties after plasma and conventional scouring treatments. Single yarn tensile strength was measured to probe the plasma treatment effect on cotton fabrics strength.

2. Experimental

2.1. Materials

A plain weave cotton fabric was used with a width of 50 cm and fabric counts of 38/36 (warp/weft)/cm. Atactic PVA granule hydrolyzed 98–99% with a polymerization degree of 1700 was purchased from Jin Shan Petrochemical Company (Shanghai City, China). Hydrogen peroxide was 30% solution, supplied by Jinlu Chemical Company (Shanghai City, China). The penetrating agent JFC and the high-efficiency scouring agent were supplied by Anoky Company (Shanghai City, China).

2.2. Fabric sizing

The cotton fabric was two-dipped-two-nipped in a sizing bath containing 4% PVA with a pickup of (110 $\pm$ 5)%. The padded sample was dried at 90–95 °C, then cut into $5 \times 60\ cm^2$. The percent sizing ratio of the sized fabric used throughout the experiment was 4.5%.

Before plasma treatment or H_2O_2 desizing, the sized fabrics in dry state were weighed (W_0) using a microbalance with an accuracy of $\pm$100 μg.

2.3. Preparation of PVA film

In order to study the influence of plasma treatment on PVA size more precisely, a PVA film was used as a model system which excludes the influence of base cotton fabric on chemical composition change of the PVA coating before and after the plasma treatments. PVA granule (6 g) was dissolved in 200 ml deionized water by heating at 95 °C under moderate stirring over 2 h. The cooled and degassed 3 wt% solution was cast on a flat polyester film. After 3 days drying at room temperature, PVA film was detached and cut into the sizes of $2.5 \times 30\ cm^2$ pieces. The thickness of the film was about 40 μm measured by a thickness gauge (within an accuracy of $\pm$1 μm).

2.4. Plasma treatment

The sized fabrics or films were treated by a dielectric barrier discharge (DBD) system manufactured by the Institute of Physics, Chinese Academy of Sciences, China. The distance between the electrodes was about 3 mm. The electrodes were rectangular ($100 \times 10\ cm^2$); the discharge was homogeneous; and the frequency was set at 3KHz. The power of the machine was set at 1.75 kVA and the voltage across the plates can be up to 3 kV rms. The carrier gas was argon with a flow rate of 6 l/min (LPM) and 0.036 LPM (0.6%) oxygen was added. The mixed gas was delivered through a gas distribution system with several outlets distributed along the length of the electrodes to ensure even distribution of the gases over the whole width of the treatment area. The films were treated for 2 min. In order to investigate the influence of exposure time on the desizing effect of plasma treated fabrics, a series of discharges (1, 2, 4 and 6 min) were carried out. A detailed schematic diagram of the DBD plasma treatment apparatus was given in our previous publications [28].

2.5. H_2O_2 desizing and NaOH scouring

The sized fabrics were two-dipped-two-nipped in a desizing bath containing 0.6% H_2O_2 (30%) and 2 g/l JFC penetrating agent with a pickup of 80 $\pm$ 5%. The padded samples were streamed at 95–98 °C for 5 min, then subjected to a hot wash or a cold wash. Scouring was carried out in boiling solution for 2 h, and then the samples were washed thoroughly.

2.6. Washing

The plasma treated fabrics and the control were subjected to a hot wash and a cold wash, then dried at 90–95 °C and weighed. In the hot wash, the fabrics were immersed in deionized water at a temperature of 60 °C at liquor: fabric ratio of 40:1 and stirred for 20 min. The cold wash was performed in the same way except the temperature of water was 25 °C.

The percent desizing ratio (PDR) was calculated as mass reduction of the desized fabric divided by the total original mass of the size on the fabric. Here, the original mass of the size on the fabric was 4.5% of the fabric mass.

2.7. Wickability measurement

The capillary rise method was employed to evaluate the wettability improvement for plasma treated fabrics. The fabric were cut into $3 \times 25\ cm^2$ warp direction strips and were suspended vertically with the lower end dipped into a 0.5% potassium dichromate aqueous solution. Spontaneous wicking occurred due to capillary forces. Yellow coloration of chromate solution on the white fabric clearly indicated the capillary rise height and a ruler marked in mm assembled along the strip was used to make the height measurements. The capillary rise height readings were made after 30 min. The heights of three specimens for each sample were recorded to calculate the average height value within the measurement error ($\pm$1 mm).

2.8. Tensile strength measurement

Single yarn specimens were tensile tested at a gauge length of 50 cm and a strain rate of 50 cm/min using YG061F Electronic Single Yarn Strength Tester with a 3000 CN capacity load cell. Twenty specimens were tested for each treatment group and the test was carried out at 20 °C and 65% relative humidity. One-way analysis of variance (ANOVA) and Tukey's pair-wise multiple comparisons were adopted to compare yarn tensile strengths among different treatment groups. A p-value less than 0.05 was considered significant.

2.9. Surface morphology analysis (SEM)

The cotton fabric surface morphology was examined using a SEM machine (model JSM-5600LV). The specimens were inspected at 5000× magnification to reveal the surface morphological changes caused by the plasma treatments. Before the SEM observation, the fabrics were coated with a thin layer of gold to induce conductivity.

2.10. Surface chemical composition analysis (XPS)

Surface chemical composition of the PVA film was investigated by X-ray photoelectron spectrometer (XPS) model ESCALAB 250 (Thermo Electron VG Scientific, USA). The X-ray source was Al Kα (1486.6 eV), operating at 150 W. The pressure within the XPS chamber was 10^{-7} to 10^{-8} Pa. Photo emitted electrons were collected at a take-off angle of 45° and the deconvolution analysis of C1s peaks was carried out using XPS Peak software.