Pigment Inkjet Printing Performance of Polyester Fabrics Surface-modified by Atmospheric Plasma

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Abstract

In order to improve the pigment inkjet printing performance of polyester fabrics, surface modification of polyester fabric was carried out with atmospheric air plasma under different experimental conditions. The treated samples were printed with magenta pigment ink. SEM and XPS analysis indicated that the enhanced color performance was mainly contributed by not only the etching effect but also oxygen-containing polar groups induced onto fiber surfaces through plasma treatment. Thereby the surface modification of polyester fabrics using atmospheric-pressure air plasma offers a potential way to fabric pretreatment for pigment inkjet printing with the advantages of environmental friendly and energy saving over traditional pretreatment methods.

Introduction

Polyester fabric is often used as inkjet printing substrate. Nevertheless, owing to having no hydrophilic groups, polyester is hydrophobic in nature and hard to adsorb chemicals. Patterns directly printed on polyester fabrics with pigment inks have poor color yields and bleed easily. Therefore, pretreatment of fabric must be done before printing to obtain better inkjet printing sharpness. Traditional methods cost long time and engender huge consumption of energy and water. As one of the environmental friendly processes, the plasma technique has been widely used to modify the surface properties of polymers and textile materials over the past decade [1-2].

In this article, we presented a study on the effects of atmospheric air plasma treatment on pigment inkjet printing of polyester fabric.

Experimental

1.1 Materials

A 100% polyester fabric (56g/m^2, Wuxi bleaching and dyeing plant of china) and light magenta pigment-based ink (Nanocolorants and Digital Printing R&D Centre of Jiangnan University) were used.

The ST/RI pulse plasma surface modification equipment (Shanghai Textile Research Institute, China) used in this study has an active exposure area of approximately 25 cm × 25 cm between two copper electrodes with 1-6 mm gap separation. The entire dielectric barrier discharge was performed at atmospheric air and lasted for a period of time. The power was kept at 300 W for the entire duration. After plasma treatment had been finished, samples were then removed and handled carefully in order to avoid possible surface contamination to the fabrics.

1.2 Inkjet Printing Procedure

Fabrics were inkjet printed with Mimaki JV4-180 digital printer (Mimaki Company of Japan). Samples were subsequently baked at 150 °C for 3 min with Minni thermo-350 baker (Roaches Company of England).

1.3 Measurements

1.3.1 SEM Observation

The fiber surface morphology was observed using a scanning electron microscopy (SEM JSM-5610) at 4000 magnification. All the samples were coated with gold before SEM testing, and all images were obtained at ambient conditions immediately after plasma treatment.

1.3.2 XPS Analysis

Surface chemical composition of polyester fabric was analyzed with a RBD upgraded PHI-5000C ESCA system (Perkin Elmer) with Mg Kα radiation (hν=1253.6 eV). X-ray anode was run at 250 W and the high voltage was kept at 14.0 kV with a detection angle at 54°. The sample was directly pressed to a self-supported disk (10 × 10 mm) and mounted on a sample holder then transferred into the analyzer chamber. The spectra were normalized with respect to the C-C peak positioned at 285 eV. All measurements were performed shortly after plasma treatment.

1.3.3 Color Properties

The Kubelka-Monk equation defines a relationship between spectral reflectance (R) of the sample and its absorption (K) and scattering (S) characteristics, as follows:

$$K/S = \frac{(1-R)^2}{2R} \quad (1)$$

The change of K/S value will indicate the ink absorption of the polyester fabric. X-Rite Premier 8400 color measurement system (X-Rite Company of America) was used to measure the K/S, L and C values of samples with illuminant D 65 and visual angle 10°.

1.3.4 Wetting Time

Wetting time measurements were performed with DSA-100 drop shape analyzer to evaluate the effects of plasma treatment on fabrics' wettability (Krüss CO. LTD Germany). Distilled water was used as the probe liquid. Five different places were measured and the mean values were calculated.

1.3.5 Anti-bleeding Performance

A DZ3-video focus-exchanged microscope (Union Optical CO.LTD of Japan) with zoom ratio of 14 and total Magnification of 30 to 5880 (with 1/2 CCD and 19" monitor) was used to measure the anti-bleeding performance of the treated and untreated inkjet printing fabrics at 75muitiple.

Results and Discussion

1.1 The Effects of Treatment Time on K/S Values of Inkjet Printing

To study the influence of treating time, air plasma treatments were carried out at 90, 120, 150, 180, and 210 sec durations with working power and dielectrics space fixed at 300 W, 3mm respectively. The K/S values were measured in order to evaluate the treatment effect. The results are summarized in Figure 1.

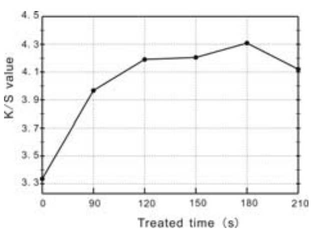


Figure 1. *K/S values of polyester fabrics treated by air plasma for various time. The sample was treated at a power 300 W, dielectrics space 3 mm*

As can be seen, K/S values increased with the increasing of plasma exposure time. This could be attributed to the polar groups and roughness created on fiber surface by plasma. Owing to the enhanced wettability, the amount of ink colorant stayed on per area of the fabric increased.

1.2 The Effects of Gap Distance on K/S Values

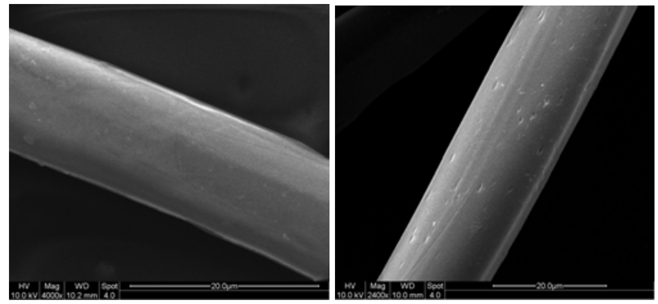
The relationship between gap distance and K/S values are shown in Table 1. The highest K/S value of the five samples was obtained when distance between electrodes was set at 3mm.

Table 1: K/S values of polyester fabrics treated with different gap distance at a power 300W for 180s.

Gap distance between electrodes	2mm	3mm	4mm
K/S values	4.27	4.30	4.16

1.3 Surface Morphology

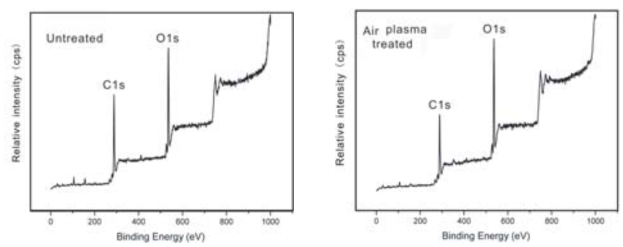
As can be seen in Figure 2 (a), the untreated polyester fiber had smooth surface. However, Figure 2 (b) shows that the polyester fabric treated with air plasma had an evident change with the presence of grooves in the fiber surface morphology.



(a) (b)

Figure 2. *SEM images of the polyester fibers surfaces, (a) Untreated, (b) Air plasma treated. The sample was treated at a power 300 W, dielectrics space 3mm for 180s.*

1.4 Surface Chemistry



(a) (b)

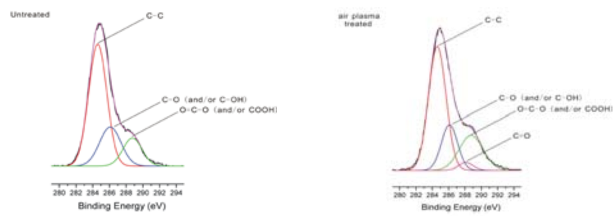
Figure 3. *XPS spectra of untreated (a) and air plasma-treated (b) polyester fabrics*

The XPS spectra of untreated and treated polyester fabrics are shown in Figure 3. The O1s peak of polyester fabric after plasma treatment was higher than that of untreated fabric. According to Table 2, the content of C1s decreases while the content of O1s increases and the O/C ratio on the surface of air plasma treated fabric promoted almost 20% compared to the untreated one.

Table 2: Relative chemical composition and atomic ratios of samples treated at a power 300W, dielectrics space 3mm for 180s.

Sample	Chemical composition (at. %)		Atomic ratio
	C1s	O1s	O/C
Untreated	63.06	29.40	0.47
Air plasma treated	55.12	36.12	0.66

Deconvolution analysis of C1s peaks was performed as presented in Figure 4.



(a) (b)

Figure 4. XPS spectra of PET fibers (a) untreated, (b) air plasma treated, the sample was treated at a power 300W, dielectrics space 3mm for 180s

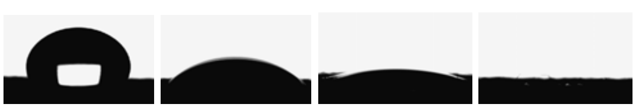
Table 3 shows that the C－C component decreases significantly after plasma treatment, and at the same time, most of the oxygen-containing polar group such as C＝O, C－OH and COOH increase in the surface of treated polyester fibers.

Table 3: Percent peak area of XPS C1s core level spectra, treated at a power 300W, dielectrics space 3mm for 180s.

Binding energy (eV)	Untreated (at. %)	Treated (at. %)	Possible functional groups
284.6	61.9	56.2	C - C/C - H
6.1	23.2	19.1	C - O (and/or C□OH)
288.1	0	3.0	C = O
288.75	14.9	21.7	O = C - O (and/or COOH)

1.5 Wetting Times

Figure 5 shows the snap shots of the distilled water droplets spreading on untreated and air plasma treated polyester fabrics.



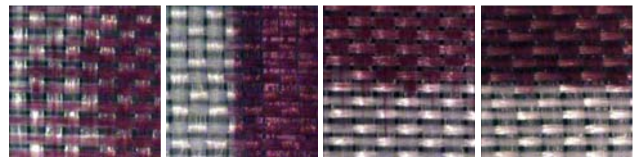
(a) (b) (c) (d)

Figure 5. Views of drop shapes on polyester substrates: (a) 30 seconds after being dropped on untreated fabric, (b) 90 seconds after being dropped on untreated fabric, (c) 1 second after being dropped on treated fabric, (d) 2 seconds after being dropped on treated fabric

As can be seen from Figure5 (a, b) it was difficult for the droplet to spread on untreated polyester substrate. Nevertheless, fabrics treated with air plasma got obvious improvement in hydrophilicity. Figure 5 (c, d) points out that the droplet spread fully on the substrate within 2 seconds after being dropped on it. The effect can be attributed to that plasma treatment not only brought etching effect to the surface of polyester fiber, but also introduced polar groups (－OH, －COOH, －C＝O) into the surface layer.

1.6 Anti-bleeding Performance

Figure 6 (a) - (d) shows the anti-bleeding performance of polyester fabrics before and after air plasma treatment. As shown in Figure6 (a, c), the bleeding performance of untreated polyester fabric was severe along the weft and warp edge of inkjet printed patterns, especially for the weft edge. The anti-bleeding performance of the treated samples was dramatically improved with excellent sharpness after air plasma treatment as seen in Figure6 (b, d). This can be attributed to the polar groups introduced onto the surface layers of polyester fibers.



(a) (b) (c) (d)

Figure 6: Anti-bleeding images of polyester fabrics at 75 multiple: (a) Weft untreated; (b) Weft treated; (c) Warp untreated; (d) Warp treated. The sample was treated at a power 300W, dielectrics space 3mm for 180s

1.7 The Effects of Air Plasma on Color

The color measurement results of treated and untreated polyester fabrics are listed in Table 4. It shows that K/S value increased after air plasma treatment; color turned deep; L value decreased; lightness turned dark and C value increased; chroma turned vivid.

Table 4: Color measurement results, treated at a power 300W, dielectrics space 3mm for 180s

Samples	K/S	L	C
Untreated	3.34	54.72	49.06
Air plasma treated	4.30	52.41	51.94

Conclusion

Atmospheric air plasma treatment can improve the pattern sharpness of pigment inkjet printing of polyester fabric. The results show that plasma-treated polyester fabrics had much better anti-bleeding performance and fresher color comparing with untreated samples. Therefore, atmospheric air plasma offers a potential pretreatment method and an attractive prospect to pigment inkjet printing of polyester fabrics with good printing effects.

References

[1] M. G. McCord, Y. J. Hwang, P. J. Hauser, et al, “Modifying Nylon and Polypropylene Fabrics with Atmospheric Pressure Plasmas”, Text. Res. J., 72, 491 (2002).

[2] S. M. Gawish, S. R. Matthews, D. M. Wafa, et al, “Atmospheric Plasma-aided Biocidal Finishes for Nonwoven Polypropylene Fabrics I Synthesis and Characterization”, J. Appl. Polym. Sci., 103, 1900 (2007).

Author Biography

Kuanjun Fang received his BS from Qingdao University (1984), MS and PhD from Donghua University (1990 and 1993). He had worked at Jiangnan University and Qingdao University. Now he works at the Laboratory of Fiber Materials and Modern Textiles, GBSKL, Qingdao University. His work has focused on the development of textile inkjet printing technology. He is the corresponding editor of Coloration Technology, Fellow of SDC (FSDC), Chartered Colorist (CCol) and Chairman of SDC China.