https://doi.org/10.2352/ISSN.2169-4451.2017.32.177

Improved color performance of reactive dye inkjet printing on cotton fabrics by controlling ink droplets spreading

Zundong Liu [1], Kuanjun Fang [2, 1, *], Hongguo Gao [3], Xiuming Liu [1], Yuqing Cai [2], Fujie Li [3]
[1] School of Textiles, Tianjin Polytechnic University, Tianjin, 300387, China.
[2] School of Textiles and Clothing, Qingdao University, Qingdao, 266071, China.
[3] Shandong Huanghe Delta Institute of Textile Science and Technology Co., Ltd, Binzhou, 256623, Shandong, China.
[*] Corresponding author: 13808980221@163.com

Abstract

Ink drop spreading is an important factor influencing the ink dots distribution which determines the color performance of reactive dye inkjet printed cotton fabrics. In order to control the ink drop spreading, a higher fatty acid derivative (PT) was introduced in the traditional pretreatment solution of sodium alginate. When compared with the untreated fabric, the ink drop spreading area was reduced from 104.9 to 92.5 and 72.3 mm² on sodium alginate treated and sodium alginate plus PT treated fabrics, respectively. The ink dots on the inkjet printed fabrics with the pretreatment of sodium alginate plus PT were narrow and short. Colorimetric values indicate that the color performance of sodium alginate plus PT treated fabrics was better than that of sodium alginate treated fabrics. Thus, the color performance of reactive dye inkjet printing was improved by the ink droplet spreading inhibitor PT.

Introduction

Textile inkjet printing is growing very quickly because it provides many advantages such as excellent color expressive force, fast response to market demands and cleaner production [1]. Reactive dye inks are commonly used for cotton fabrics inkjet printing. In the printing process, tiny ink droplets ejected from small orifices precisely impact on the particular locations of fabric surface [2]. Colors of the printed pattern are mixed by a “process” method, in the case of the accurate distribution of ink dots. Thus, to acquire satisfied inkjet printing products, it is essential to control ink droplets on the precise positions on fabric surface. However, ink droplets spreading on cotton fabric is an important factor influencing the ink dots distribution. In order to meet the requirement, thickeners (e.g. sodium alginate) are usually applied onto fabrics prior to inkjet printing [3].

The purpose of this research was to study the effect of the pretreatment on the color performance of reactive dye inkjet printed cotton fabrics by controlling the ink droplets spreading. In order to achieve the aim, a higher fatty acid derivative was introduced in the traditional pretreatment solution of sodium alginate to adjust the ink dots distribution. Contact angles and surface energy of the untreated and pretreated cotton fabrics were measured. Micrographs of the ink dots on the inkjet printed fabrics were taken by means of an optical microscope. Color performance of the inkjet printed cotton fabrics was characterized using the colorimetric values of *K/S*, L^* and C^*.

Experimental

1.1 Materials

The fabric used was 100% singed, desized, scoured and bleached cotton twill fabric (136 g/m²) with 133 ends/inch (40^S) and 72 picks/inch (40^S), supplied by Yuyue Home Textile Co., Ltd (China).

Unless otherwise indicated, all chemicals used in this work were of industrial grade. In addition to sodium bicarbonate, urea, resist salt and medium viscosity sodium alginate (Qingdao Bright Moon Group Co., Ltd, China), a higher fatty acid derivative (called as PT, Shandong Huanghe Delta Institute of Textile Science and Technology Co., Ltd, China) was employed. Diiodomethane (A.R. grade) was purchased from Shanghai Macklin Biochemical Co., Ltd (China). Fabrics were printed with four reactive dye inks (cyan, magenta, yellow and black, Hangzhou Honghua Digital Technology Stock Co., Ltd, China).

1.2 Preparation of Pretreatment Solutions

A mixed solution was prepared by dissolving sodium bicarbonate (6 g), urea (20 g) and resist salt (2 g) in deionized water (167 g). Then sodium alginate (5 g) was slowly added into the mixed solution with constant stirring by a laboratory mixer (RW20, IKA Group, Germany), and finally made up to a final weight of 200 g with deionized water. The fabric treated with this pretreatment solution was termed as sodium alginate treated fabric.

Another mixed solution was prepared by dissolving sodium bicarbonate (6 g), urea (20 g), resist salt (2 g) and PT (4 g) in deionized water (163 g). Then sodium alginate (5 g) was slowly added into this mixed solution with constant stirring by RW20, and finally made up to a final weight of 200 g with deionized water. The fabric treated with this pretreatment solution was termed as sodium alginate plus PT treated fabric.

1.3 Fabric Pretreatment

Pretreatment solutions were respectively padded onto two pieces of cotton fabrics by using a padding machine (P-B0, Xiamen Rapid Precion Machinery Co., Ltd, China) with the pressure of 2.5 kg/m² and the pick-up of 70%. The pretreated fabrics were dried in an oven (DHG-9123A, Shanghai Yiheng Scientific Instruments Co., Ltd, China) at 80 °C for 5 min.

1.4 Inkjet Printing Process

A digital inkjet printer (VEGA 5000, Hangzhou Honghua Digital Technology Stock Co., Ltd, China) was used in this study. For measuring the colorimetric values, one rectangle pattern of 80 × 150 mm was printed on the pretreated fabrics at the resolution of 720 × 720 dpi and the color coverage of 100%. For observing ink dots, two rectangle patterns of 80 × 50 mm were printed on both the pretreated fabrics and photo paper at the same resolution and the color coverage of 20%. The printed fabrics were dried at 95 °C for 5 min.

Then the inkjet printed fabrics were steamed in a steamer (STM-G2003, Suzhou Industrial Park YAMEI Textile Machine

Co., Ltd, China) with saturated steam at 102 °C for 7 min. The steamed fabrics were finally washed in cold water first, followed by hot water with 2 g/L of standard detergent, and then with warm water until no color could be further removed from the fabrics. After washing, the printed fabrics were dried in an oven at 80 °C.

1.5 Measurements

1.5.1 Contact Angle

Distilled water and diiodomethane were used as the probe liquids which were dropped on the fabric surface using a micro syringe, and the drop volume was 6.9 and 1.4 µL respectively. Contact angles were measured at 20 ± 2 °C and 67 ms after the impact of the liquid drop on the fabric surface by an optical contact angle analyzer (JC2000D, Shanghai Zhongchen Digital Technology Co., Ltd, China).

1.5.2 Surface Energy

As suggested by Fowkes, both of the surface tension of liquid (γ_L) and the surface energy of solid (γ_S) can be split into a dispersive component (γ_L^d, γ_S^d) and a polar component (γ_L^p, γ_S^p). Surface energy of the cotton fabrics without and with pretreatment were calculated using the geometric theory with the following equations (1) and (2) [4]:

$$\sqrt{\gamma_S^d \times \gamma_L^d} + \sqrt{\gamma_S^p \times \gamma_L^p} = 0.5 \times \gamma_L \times \left(1 + \cos\theta_L\right) \quad (1)$$

$$\gamma_S = \gamma_S^d + \gamma_S^p \quad (2)$$

where, θ_L is the contact angle of probe liquid. The surface tension of distilled water and diiodomethane (Table 1) and the contact angles were substituted into equation (1) respectively. By solving the two equations, the values of the two variables (γ_S^d and γ_S^p) were gained. Then, the total surface energy (γ_S) was calculated according to equation (2).

Table 1. Surface tension components of the probe liquids.

Probe liquid	Surface tension (mN/m)		
	γ_L^d	γ_L^p	γ_L
Distilled water	21.8	51.0	72.8
Diiodomethane	49.5	1.3	50.8

1.5.3 Drop Spreading on Fabric

A cyan reactive dye ink drop of 4.3 µL was dropped on the fabric surface using a micro syringe. The time needed for the ink drop to be completely absorbed into the fabric was recorded. Then the dried fabric samples were scanned using a LaserJet (Pro M1213nf, HP, USA) to get digital pictures. The drop spreading area on the fabric was measured on these digital pictures using an image analysis ImageJ software (National Institutes of Health, USA). Five measurements were taken on each fabric, then averaged.

1.5.4 Ink Dots Shape Observation

Ink dots on the inkjet printed fabrics and photo paper, with the color coverage of 20%, were observed by an optical microscope (YYS-80E, Shanghai Yiyuan Optical Instrument Co., Ltd, China) with a magnification of 160 times.

1.5.5 Colorimetric Values

The colorimetric values (*K/S*, L^* and C^*) of the printed fabrics were measured using a spectrophotometer (Color i7, X-Rite, USA) under D65 illuminant, 10º standard observer and 6 mm reflectance apertures. Color difference (ΔE_{ab}^*) between the printed fabrics with the pretreatment of sodium alginate and sodium alginate plus PT was calculated.

Results and Discussion

2.1 Contact Angle

Contact angles of distilled water and diiodomethane drops on the cotton fabrics without and with pretreatment are shown in Table 2. The contact angles of distilled water on the untreated, sodium alginate treated and sodium alginate plus PT treated fabrics were 11.6°, 19.4° and 38.0°, respectively, at 67 ms after the probe drop impact on the fabrics.

Table 2. Contact angles of probe liquids on cotton fabrics.

Pretreatment	Contact angles	
	Distilled water	Diiodomethane
Untreated	11.6°	22.6°
Sodium alginate	19.4°	66.9°
Sodium alginate + PT	38.0°	70.9°

Cotton fabric is composed of cellulose fiber which is a relatively hydrophilic and water-absorbent fiber. There are amount of voids between yarns, between fibers and between fibrils in the untreated cotton fabric. The hydrophilic property and porous structure make water molecules easily penetrate into amorphous regions of the fiber [5]. As a result, the spreading speed of distilled water on the untreated fabric was very fast and the contact angle was small.

Sodium alginates are linear, amorphous and high water-absorbing copolymers. For sodium alginate treated fabric, a sodium alginate film was formed on the surface of cotton fibers. The capillary continuity in the fabric was broken [6] and the absorbency of fabric towards water was improved, which reduced the spreading velocity of water drop on the fabric and enlarged the contact angle. On sodium alginate plus PT treated fabric, the contact angle of distilled water was almost two times of that on sodium alginate treated fabric. This result indicates the hydrophilicity of the fabric pretreated with sodium alginate plus PT had been remarkably reduced due to the presence of hydrophobic chain of PT on the fabric surface.

2.2 Surface Energy

The dispersion component and polar component of the surface energy can accurately denote the wettability of the fabrics. Surface energy of the cotton fabrics without and with pretreatment was listed in Table 3.

Table 3. Surface energy of the cotton fabrics.

Pretreatment	Surface energy (mJ/m^2)		
	γ_S^d	γ_S^p	γ_S
Untreated	35.25	38.54	73.79
Sodium alginate	14.65	54.80	69.45
Sodium alginate + PT	13.74	44.75	58.49

Compared with the untreated cotton fabric, the dispersion component of the surface energy of sodium alginate treated fabric was reduced by 20.6 mJ/m^2, and the polar component was increased by 16.16 mJ/m^2. This was caused by the increase in number of hydrophilic groups introduced by sodium alginate and urea.

Compared with sodium alginate treated fabric, the surface energy of sodium alginate plus PT treated fabric was noticeably reduced as a result of the reduction of the polar component (by 10.05 mJ/m^2) and the dispersion component (by 0.91 mJ/m^2). This may be due to the reduction of molecular attractive force between the pretreatment materials and the fibres.

2.3 Drop Spreading on Fabric

A cyan reactive dye ink drop of 4.3 μL was used to study the spreading situation on the fabrics without and with pretreatment. After the drop impacting on the fabrics, the time need for completely spreading was 2, 7 and 12 s respectively on the untreated, sodium alginate treated and sodium alginate plus PT treated fabrics. The increasing trend of the spreading time was consistent with that of the contact angles of distilled water on these fabrics. This was owing to the fact that the total proportion of water and solvent was more than 80% in reactive dye based ink formulations.

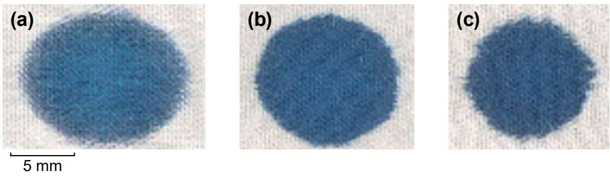

Figure 1. Spreading results of the cyan ink drop of 4.3 μL on the different fabrics, (a) untreated, (b) pretreated with sodium alginate and (c) pretreated with sodium alginate plus PT

Figure 1 shows the spreading results of cyan reactive dye ink drops on the untreated, sodium alginate treated and sodium alginate plus PT treated fabrics respectively. It is clear that the shape of the spreading area was elliptical on the untreated fabric. This came from the difference in the wicking rates along the direction of warp and weft yarns. However, it was almost like a circle on the pretreated fabrics. The roundness (Table 4) of the spreading area quantified the difference of the shape.

Table 4. Spreading results of cyan ink drops on untreated and pretreated fabrics; the drop volume was 4.3 μL; the roundness equals 4 × (*Spreading area*) / (π × *Long axis*²).

Pretreatment	Spreading area (mm^2)	Roundness
Untreated	104.9	0.79
Sodium alginate	92.5	0.90
Sodium alginate + PT	72.3	0.91

As can be seen in Figure 1 and Table 4, the spreading area was reduced in the order of the untreated, sodium alginate treated and sodium alginate plus PT treated fabrics. It obviously demonstrated that sodium alginate could restrict ink drop spreading on cotton fabrics, and the capability can be enhanced with the hydrophobic compound PT. This was attributed to the formation of sodium alginate film on the fabric surface and the reducing of the fabric surface energy after pretreatment.

2.4 Ink Dots Shape

On the inkjet printed photo paper (Figure 2(a)), the ink dots look like circle. However, the ink dots are strip-like on the inkjet printed fabrics (Figure 2(b) and 2(c)). The differences in the structure and surface property of the photo paper and fabric resulted in the different diffusion of ink droplets. On cotton fabrics, strip-like ink dots were formed because the ink droplets spreading speed along the length direction of the fiber under the capillary action was faster than that along the diameter direction of the fiber.

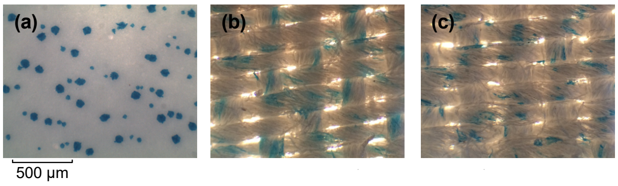

Figure 2. Ink dots on the cyan inkjet printed substrates: (a) photo paper, (b) sodium treated fabric, before steaming and (c) sodium alginate plus PT treated fabric, before steaming; the color coverage was 20%

From Figures 2(b) and 2(c), it can be found that the ink dots were narrow and short on sodium alginate plus PT treated fabric. This implied that pretreatment agent PT was useful to control ink drop spreading after the droplets impacting on the pretreated fabric in the inkjet printing process.

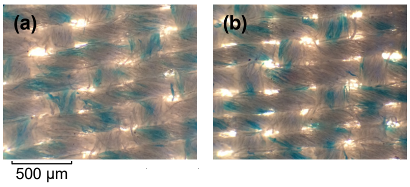

Figure 3. Ink dots on the inkjet printed cotton fabrics with the pretreatment of (a) sodium alginate and (b) sodium alginate plus PT, after steaming and washing; the color coverage was 20%

After steaming and washing, the ink dot became bigger on both sodium alginate treated fabric (Figure 3(a)) and sodium alginate plus PT treated fabric (Figure 3(b)). This can be explained that during steaming the pretreatment materials, such as urea and sodium alginate, absorbed more moisture to swell cotton fibers and facilitate the dissolution and diffusion of reactive dyes in the ink dots [7]. However, the ink dots were darker and brighter on sodium alginate plus PT treated fabric, which means that the dye was concentrated in an area on the fabric surface. It can be concluded that the pretreatment minimizing the ink droplets spreading was helpful to attain higher color yield of the inkjet printed fabric.

2.5 Colorimetric Values

The lightness (L^*) of the inkjet printed fabrics are shown in Table 5. Results demonstrated that, the inkjet printed fabric with the pretreatment of sodium alginate plus PT was darker (smaller of L^* value) when compared with sodium alginate pretreated fabric.

Table 5. The lightness (L^*) of the inkjet printed fabrics.

Pretreatment	Cyan	Magenta	Yellow	Black
Sodium alginate	49.7	44.6	86.8	21.1
Sodium alginate + PT	47.2	42.3	86.4	19.2

Figure 4 shows the *K/S* values of the inkjet printed fabrics with different pretreatments. It is clear that the *K/S* values of the inkjet printed fabrics treated with sodium alginate plus PT were bigger than that of the fabric treated with sodium alginate.

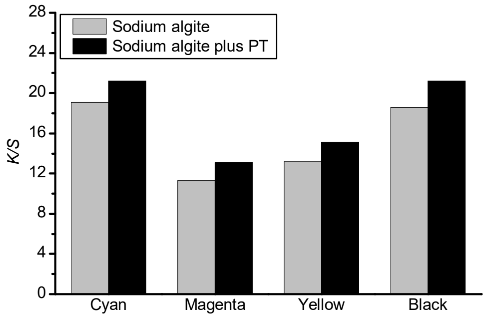

Figure 4. *K/S values of the inkjet printed fabrics with different pretreatments*

As shown in Figure 5, for the cyan, magenta and yellow dye inkjet printed fabrics, the saturation (C^*) of sodium alginate plus PT treated fabrics were higher than that of sodium alginate treated fabrics. This implied that PT improved the brightness of the reactive dye inkjet printed fabrics. It was contrary for the black dye inkjet printed fabrics.

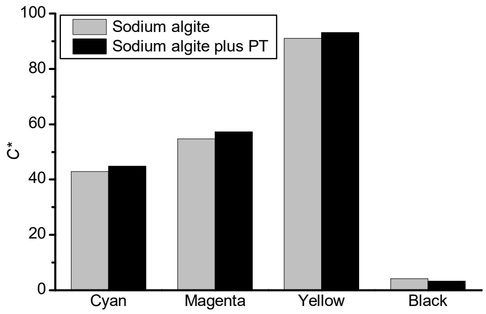

Figure 5. *The saturation (C^*) of the inkjet printed fabrics with different pretreatments*

The color difference between the inkjet printed fabrics with the pretreatment of sodium alginate and sodium alginate plus PT were calculated and shown in Figure 6. There was a big color difference ($\Delta E^*_{ab} > 2.0$) between the two fabrics with different pretreatments. Combined with the colorimetric values of *K/S*, L^* and C^*, it was found that the sodium alginate plus PT treated fabrics had a better color performance when compared with the sodium alginate treated fabrics.

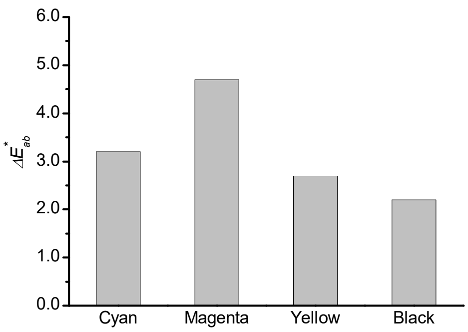

Figure 6. *Color difference between the inkjet printed fabrics with the pretreatment of sodium alginate and sodium alginate plus PT*

The color of the inkjet printed fabric is determined by the light source irradiation on the fabric, light absorption, reflection, transmission and scattering of fabric and observer together. The distribution of the dye on the fabric has a great influence on the light absorption and reflection. The promotion of the color performance was mainly due to the restricting effect of PT on ink drop spreading and penetration into fabric which leading to most of the dye fixed on the fabric surface.

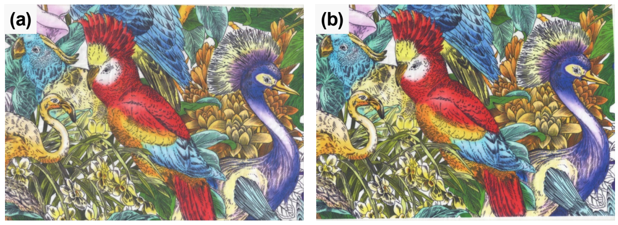

Figure 7. *Scanned images of the inkjet printed fabrics: (a) pretreated with sodium alginate and (b) pretreated with sodium alginate plus PT*

Figure 7 presents the scanned images of the inkjet printed fabrics with different pretreatments. In comparison with sodium alginate untreated fabric, the color of sodium alginate plus PT treated sample was more vivid.

Conclusion

Surface energy of the cotton fabrics was evidently reduced from 73.79 to 69.45 and 58.49 mJ/m^2 after the pretreatment with sodium alginate and sodium alginate plus PT respectively. Correspondingly, the ink drop spreading area on these fabrics decreased from 104.9 to 92.5 and 72.3 mm^2. Furthermore, on the sodium alginate plus PT treated fabric, the strip-like ink dots were narrow and short, which means the dye was concentrated in an area on the fabric surface. Based on the colorimetric values and the appearance of the inkjet printed fabrics, it was readily demonstrated that the hydrophobic compound PT could enhance the ability of sodium alginate for controlling the spreading of ink droplets, thereby improving the color performance.

References

[1] K J Fang, S H Wang, C X Wang et al, "Inkjet printing effects of pigment inks on silk fabrics surface-modified with O_2 plasma", J. Appl. Polym. Sci., 107, 2949 (2008).
[2] C Cie, Ink Jet Textile Printing (Elsevier, Cambridge, 2015) pg. 92.
[3] A Soleimani-Gorgani and N Shakib, "The effect of reactive dye structure on the inkjet printing of cotton", Prog. Color Colorants Coat., 7, 19 (2014).
[4] P Pransilp, M Pruettiphap, W Bhanthumnavin, et al, "Surface modification of cotton fabrics by gas plasmas for color strength and adhesion by inkjet ink printing", Appl. Surf. Sci., 364, 208 (2016).
[5] A D Broadbent, Basic Principles of Textile Coloration, (SDC, Bradford, 2001) pg. 73.
[6] S-k Liao, H-y Chen and C-w Kan, "A Study of Quality Factors for Cotton Fabrics in Ink-Jet Printing", RJTA, 13, 33 (2009).
[7] C W M Yuen, S K A Ku, P S R Choi et al, "Study of the factors influencing colour yield of an ink-jet printed cotton fabric", Color. Technol., 120, 320 (2004).

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. Now he works at Qingdao University and Tianjin Polytechnic University. His work has focused on the development of textile inkjet printing technology. He is the corresponding editor of Coloration Technology.