UV Curable Pretreatment of Polyester Fabrics for Inkjet Printing

Hongxia Xue, Qinguo Fan, Yong K. Kim; University of Massachusetts Dartmouth; North Dartmouth, MA/U.S.A.

Abstract

Various woven and knitted polyester fabrics were pretreated with formulations containing waterborne UV curable resins and silica particles to improve inkjet print quality. The UV curable resins and silica were chosen to impart the affinity of acid dye-based and direct dye-based inks onto the polyester fabrics. The low add-on of the selected formulation was applied to reduce the adverse effect on fabric hand without sacrificing the print quality. A print pattern with various areas and lines in cyan, yellow, magenta and black colors was designed and the pattern was inkjet printed on the various pretreated fabrics with a wide-format inkjet printer (Encad Novajet 750) to investigate the effects of the UV curable pretreatment on the print quality. Experimental results show that improved line quality in terms of the line width gain and the edge raggedness was observed for the lines printed on the pretreated fabrics. In particular, the 2 pt-line width of magenta color on the pretreated taffeta fabric was reduced by 13.8% and the 2 pt-line raggedness of yellow color on the pretreated taffeta fabrics was reduced by 80% compared to that on the untreated fabrics. Generally, increase in silica content inhibits inter-color bleeding onto the adjacent colored areas. For example, a 6% pretreatment formula of 10 parts UV curable resin and 6 parts of the silica particles can yield sharply defined images, while the printed fabrics still maintain a very good hand.

1. Introduction

Waterborne UV curable resin systems can meet increasingly stringent environmental legislative requirements. Using water as the main solvent, a waterborne UV curable resin system has low volatile organic content, low toxicity, low skin irritancy and low odor. Waterborne UV curable resin systems are applied in many industries in recent years [1], however, its application in the pretreatment of textile inkjet printing is not common. In published studies, there were some applications of non waterborne UV curable resin systems in textile processes: durable press finishing for cotton fabrics [2], flame-resistant cotton [3], wool fabric shrink-resistant finishing [4], a hydrophilic UV curing coating for cotton to enhance fabric breathability and a flame-retardant system [4], and radiation-curable back-coating for upholstery fabrics [5].

Despite advantages of digital printing [6] [7] [8] [9], ink jet textile printing still has some print quality problems like ink bleeding, low color yield etc. Pretreatment of textile substrates is one of the effective approaches to solve these problems.

Eco-friendliness, water absorbent property, and thinner film obtained due to the easy control of viscosity with water [10] [11] are the major reasons for adopting waterborne UV curable resin system in pretreatment of textiles for inkjet printing in this study.

2. Experimental

2.1 Materials

Polyester fabrics are one of the most commonly used fabric substrate in textile industry. Due to the hydrophobic nature of the polyester fiber, water-based inks bleed badly on polyester fabrics, and wetfastness of print is generally very poor.

In order to study the effect of fabric structures on ink bleeding, polyester fabrics with four different structures were used:

1) Style #730 — Texturized Dacron 56T interlock knit fabric, 106 gm/m^2 (weft knitted fabric)
2) Style #700-12 — PET/Lycra blend, 143.3 gm/m^2 (warp knitted fabric)
3) Style #738 — Taffeta, 147 gm/m^2, (woven fabric)
4) Style #700-4 — Satin, 136.6 gm/m^2, (woven fabric)

The fabrics were purchased from Test fabrics and used as received.

Water soluble photoinitiator Irgacure 2959 (1-[4-(2-Hydroxye thoxy)phenyl]-2-hydroxy-2-methyl-1-propanone, $C_{12}H_{16}O_4$) was supplied by Ciba Specialty Chemical Corporation, High Point, North Carolina.

Ucecoat 6558 is an aliphatic urethane acrylate emulsion in water, supplied by Surface Specialties, Inc., Smyrna, GA

Sylysia 350 is synthetic amorphous silica with high porosity and high purity, supplied by Fuji Silysia Chemical, LTD., Durham, NC.

All the chemicals were used as received.

GS^+ inks with magenta (acid/reactive dye), cyan (direc dye), yellow (acid dye) and black (direct dye) colors were purchased from Encad Inc., a Kodak Company, San Diego, CA.

2.2. Preparation of pretreatment solution

2 % of Irgacure 2959 based on the content of water soluble resin Ucecoat 6558 was dissolved in 90 parts deionized water, then 10 parts Ucecoat 6558 were added in the solution, stirred till homogenous, then 1 part silica particles Sylysia 350 was added. Following the same procedures, pretreatment solutions with 2, 4, and 6 parts silica particles were prepared.

2.3. Pretreatment of fabrics

Polyester fabrics of 15 x 15 cm (6 x 6 inches) were dipped in pretreatment solution for 20 minutes, then these fabrics was padded through squeeze rollers. Two-dip two-nip operations were performed with a padding machine. After that the fabrics were placed flat on paper towel and dried at room temperature.

2.4. UV curing

Dried fabrics were placed on the conveyor belt of Mini UV-Curing System manufactured by American Ultraviolet Company, Lebanon, IN. Convey belt speed was set at 6.1 meter per min. (20 FPM) and lamp power 7.9 watt per centimeter (200 WPI) was adapted in this study, which is equivalent to 1 second exposure to UV light through a 10 cm. (4 inches) window.

2.5. Printing

To facilitate measurement of image quality, a square print pattern with 12.7 x 12.7 cm (5 × 5 inches) was generated using Adobe Photoshop 7.0 software in advance. In this print pattern there were four groups of lines with line width of 1, 2, 3, 4, and 5 pt and four solid areas, which were designed to characterize the color changes of four color inks magenta, cyan, yellow and black after pretreatment. Four lines whose line width were 1023nm with magenta, cyan, yellow and black colors were designed on four solid color areas to facilitate the observation of inter-color bleeding. The print pattern was printed on photo paper, untreated satin fabric and pretreated fabrics with Nova Jet 750 wide format printer.

2.6. Characterization

Personal Image Analysis System manufactured by Quality Engineering Associates, Inc., Burlington, MA was used to measure the line width, raggedness. The equipment contains color CCD detector, aperture size of 2.4 mm × 2.4 mm, resolution of 5μm per pixel, viewing geometry: 45° diffuse / 0°.

2.7. Experiments on fabrics

Based on the preliminary experiments on satin fabric (style #700-4), the recipe that produced the best line clarity was used for further experiments. Polyester fabrics with taffeta (style #738), warp-knitted (style #700-12) and weft-knitted (style # 730) structures were pretreated and other procedures were followed as 2.2 to 2.6.

3. Results and Discussion

3.1. Line width

Table 1 shows the add-on of resin and silica on satin fabrics pretreated with solutions containing different silica content. The recipe containing 6 parts silica produced the highest add-on of 6%.

Table 1

Recipe(silica content, parts)	1	2	4	6
Add-on (% o.w.f.*) of resin and silica	4.2	4.9	5.5	6.0

*: o.w.f. = on weight of fabric

From Figure 2, 3 and 4 (figures corresponding to pretreatment formulae with 2 parts and 4 parts silica particle are not presented), it can be seen that the print quality of patterns on pretreated fabrics is improved significantly.

Figure 5 is the line width experimental data obtained from patterns on photo paper, untreated satin and satin fabrics pretreated with 1, 2, 4 and 6 parts silica formulae. It can be seen that all the lines on pretreated fabrics have reduced line width than the lines on untreated satin fabric. Some of the line widths are very close to the line widths on photo paper. The line width of cyan 5pt on fabric treated with 1 part silica solution even smaller than its counterpart on photo paper. The effect of pretreatment on line width printed with magenta, yellow, cyan and black inks is different. For magenta and black, there is a decreased trend of line width with the increase in silica content in pretreatment formulae.

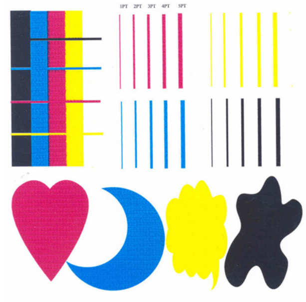

Figure 1 *Pattern on photopaper*

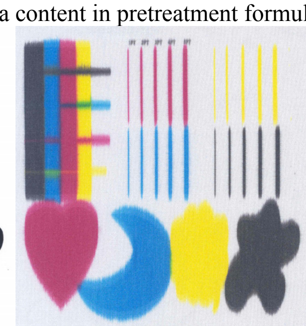

Figure 2 *Pattern on untreated satin*

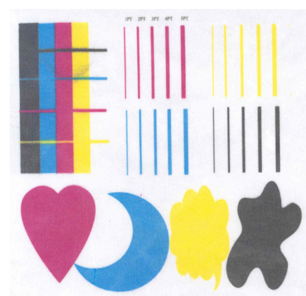

Figure 3 *Pattern on stain with 1 part silica pretreatment*

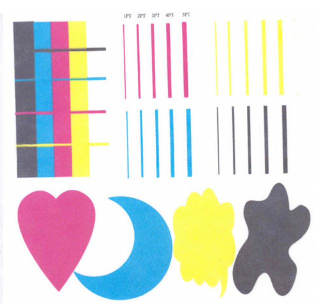

Figure 4 *Pattern on stain with 6 parts silica pretreatment*

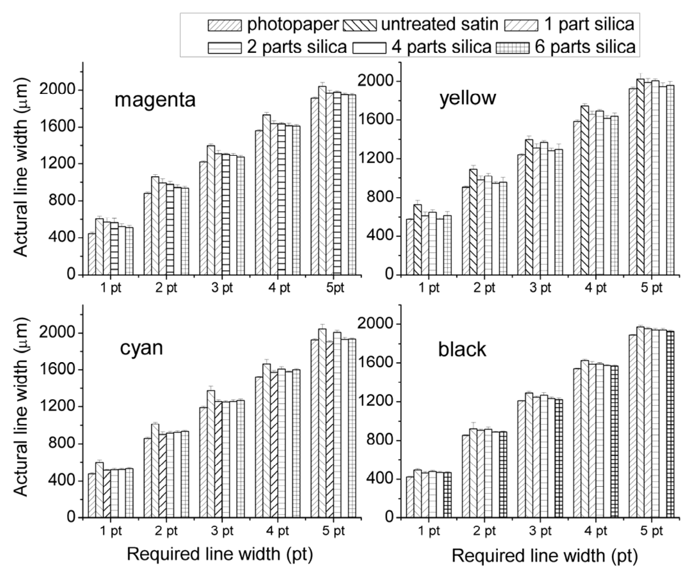

Figure 5 *Line widths on satin fabrics*

For yellow, all the lines on fabric treated with 4 parts silica solution have smallest line width. For cyan, there is an increase trend of line width with the increase in silica content in pretreatment solution. This could be explained by differences in the composition of the inks.

We can also see the ink bleeding in warp direction is worse than in weft direction. Although the data analysis is based on the vertical lines, namely bleeding in weft direction, from the pictures we can see bleeding control in warp direction is very good even better than in weft direction.

Table 2 shows the add-on of resin and silica on four polyester fabrics with different structures treated with 6 parts silica particle formulae. From this table it is observed that although the fabrics were pretreated with the same formula and followed the exactly similar procedure, the add-on of resin and silica on these four fabrics are quite different. The two knitted fabrics have two to three times higher add-ons than those of woven fabrics. This phenomenon agrees perfectly well with the experimental results.

Table 2

Fabric structure	Satin	Taffeta	Warp-knitted	Weft-knitted
add-on (% o.w.f.) of resin and silica	6	6	12.5	18

From Figure 6 and 7, it can be seen that ink on untreated taffeta fabric bleeds badly. As showed by Figure 8, 9 and Figure 10, 11, on warp-knitted and weft-knitted fabrics, very clear patterns can be obtained even without pretreatment. This can be explained by the high liquid absorbance of knitted structure just as demonstrated by the increased add-on of resin and silica particle. Due to the strong liquid absorbance, once the ink is dropped on the fabric, it is absorbed instantly before spreading out. We can see slight bleeding on the warp-knitted fabric; this could be caused by the inclusion of certain amount of Lycra fiber in the yarn, which inhibited the absorption resulting bleeding.

From Figure 12, it can be seen that all the magenta lines on pretreated taffeta fabric have reduced line width than those on untreated taffeta fabric. There are a few exceptions, which are yellow 4pt, cyan 5pt and black 5pt. The reasons for this could be uneven pretreatment or insufficient resin used to fix silica on the fabric. After the fabrics were padded, they were placed on the paper towel to dry at room temperature. The contact between the fabric and paper resulted in the pretreatment solution transfer to paper towel or its adjacent area resulting in unevenness. Insufficient amount of resin cannot fix the silica particle on fabrics completely. It was noticed that these exceptions occurred with relatively wider lines which were generated with a high amount of inks. Therefore, it was postulated that the ratio of silica particles to ink might be too low in those cases, leading to a line width broadening. Although these lines have increased line width, they maintain sharpness due to their dramatically reduced raggedness (discussed later).

From Figure 13, it can be seen that most of the lines on pretreated warp-knitted polyester fabric have reduced line width except for magenta1pt, 2pt, yellow 2pt, cyan 2pt, black 1pt, 2pt, 3pt, 4pt. From Figure 8, we can see slight ink bleeding, some of the lines have reduced line width indicate the pretreatment takes effect. For the increased lines the reasons could be the combination result of high add-on of resin and silica, and insufficient resin used to fix silica. Another reason could be the bleeding of relatively wider lines is not obvious compared to their line width, therefore, the line with is fine enough not can be reduced any more.

From Figure 14, it can be seen that all the magenta lines on pretreated weft knitted polyester fabric except for 1pt have very similar line width as lines on untreated fabric. All the yellow, cyan and black lines on this fabric have increased line width than lines on untreated one. This could be the result of high add-on of resin and silica is not favor of reducing line width, or insufficient resin for fixing silica, or the line with is fine enough not can be reduced any more.

Among all the lines, the line width of magenta 2pt on pre-treated taffeta fabric was reduced most, by 13.8% of its counterpart on untreated taffeta fabric.

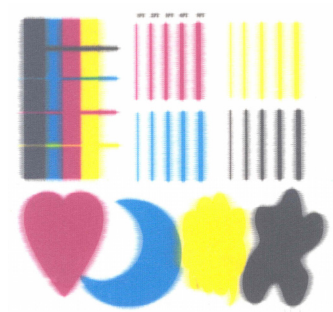

Figure 6 *Pattern on untreated taffeta*

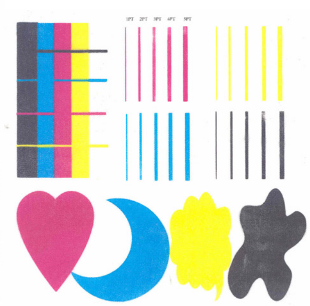

Figure 7 *Pattern on taffeta with 6 parts silica pretreatment*

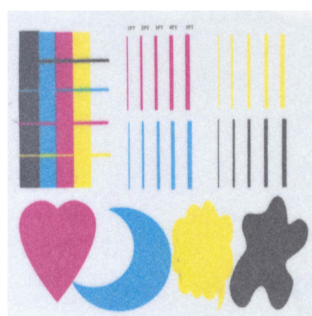

Figure 8 *Pattern on untreated warp knitted fabric*

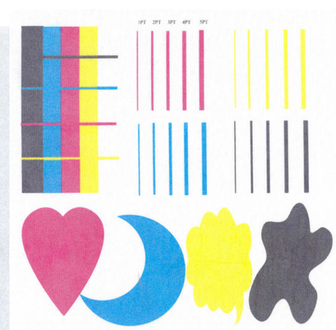

Figure 9 *Pattern on warp knitted fabric with 6 parts silica pretreatment*

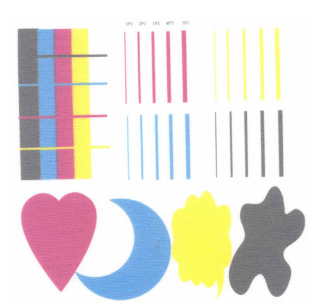

Figure 10 *Pattern on untreated weft knitted fabric*

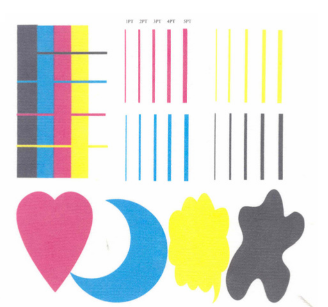

Figure 11 *Pattern on weft knitted fabric with 6 parts silica pretreatment*

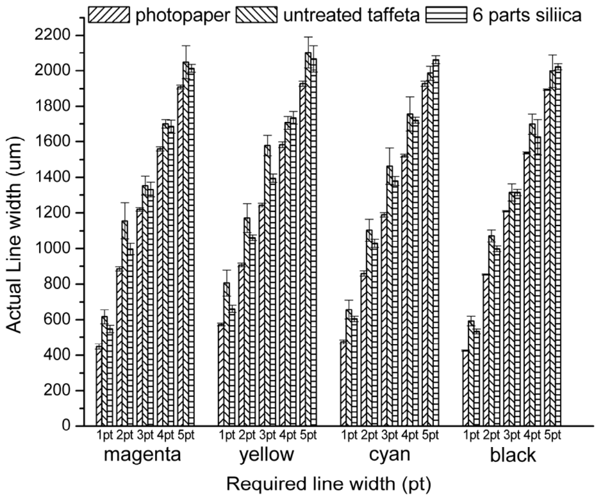

Figure 12 *Line widths on taffeta fabrics*

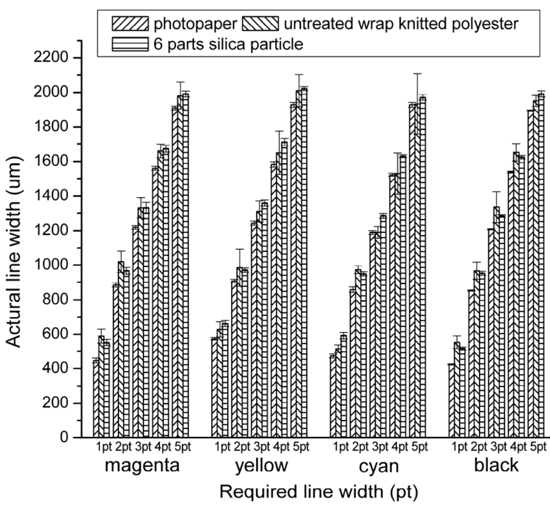

Figure 13 *Line widths on warp knitted fabrics*

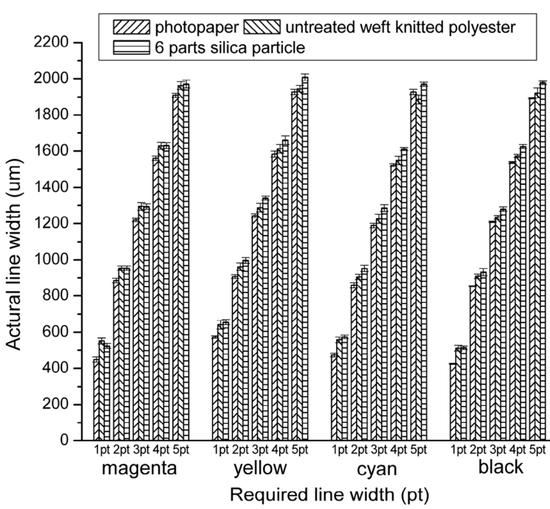

Figure 14 *Line widths nf weft knitted fabrics*

3.2. Raggedness

According to ISO: 13660 Measurement of image quality attributes for hardcopy output—Binary monochrome text and graphic images, the raggedness is "the appearance of geometric distortion of an edge from its ideal position. The measure of raggedness is the standard deviation of the residuals from a line fitted to the edge threshold of the line (calculated perpendicular to the fitted line)". A ragged line appears rough or wavy on the edges rather than smooth or straight.

From Figure 15, 16, 17 and 18, it can be seen that all the lines on pretreated fabrics with different structure have reduced raggedness than those on their untreated counterparts. Although the extent of reduction is different from line to line, they were all reduced dramatically. Yellow 2pt on taffeta has the reduction extent of 80%. The reduced raggedness can explain why some of the lines that have increased line width still have very clear edge.

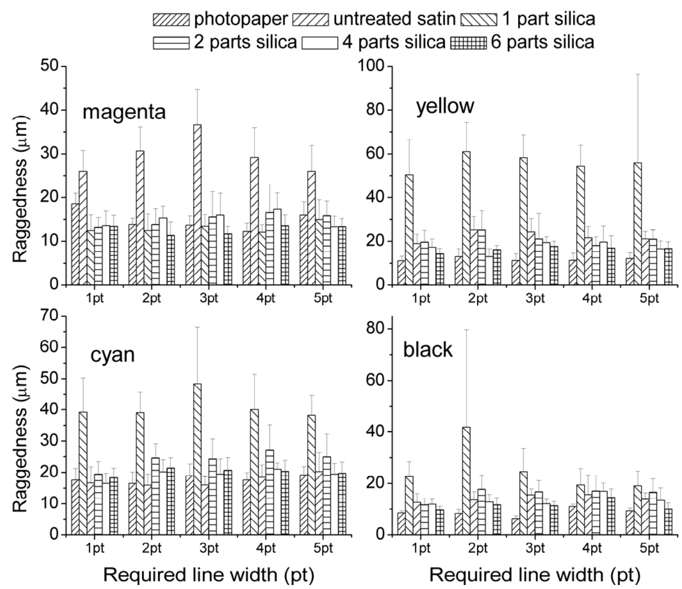

Figure 15 *Raggedness on satin fabrics*

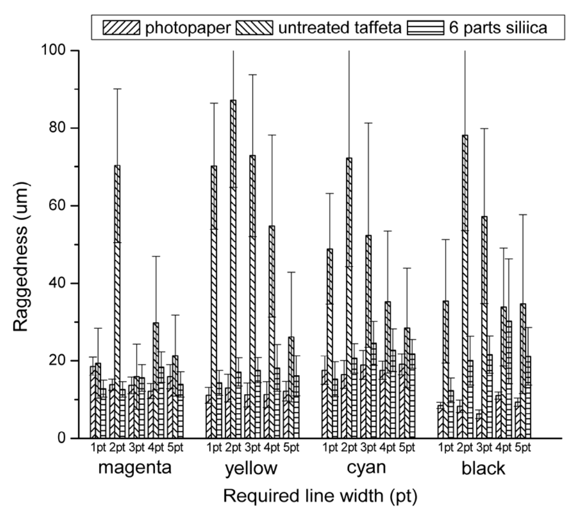

Figure 16 *Raggedness on taffeta fabrics*

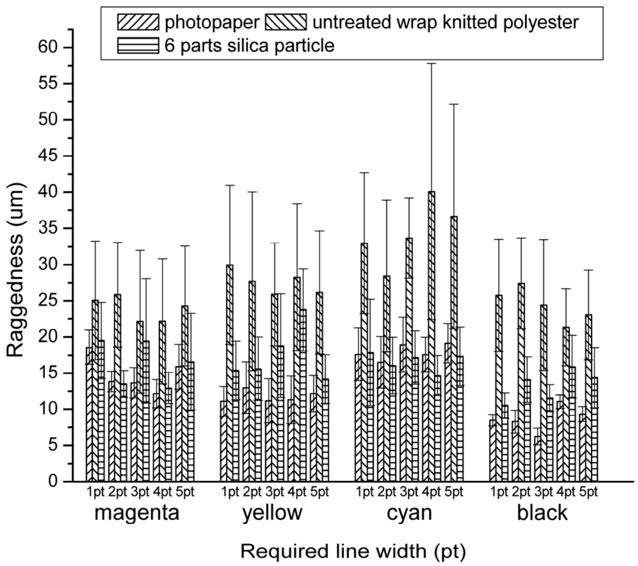

Figure 17 *Raggedness of warp knitted polyester*

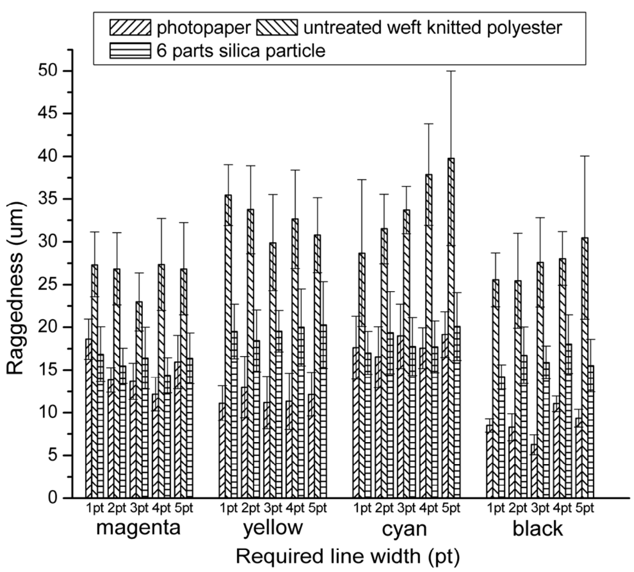

Figure 18 *Raggedness of weft knitted polyester*

3.3. Inter-color bleeding

Black, cyan, magenta, and yellow lines with 1.023 mm (2.9 pt) width were cross-printed on solid color black, cyan, magenta and yellow bands [12] to facilitate the observation of inter-color bleeding.

From Figure 2, 3 and 4, it can be seen that inter-color bleeding on pretreated satin fabric is improved significantly. Inter-color bleeding control is improved with the increase in silica content. From Figure 1 and 4, it can be seen that yellow-cyan, yellow-black inter-color bleeding on pretreated satin fabric is slightly obvious, and other inter-color bleeding is satisfactory compared to the pattern on photo paper. On satin fabric, inter-color bleeding in warp direction is worse than in weft direction. We obtained satisfactory inter-color bleeding in warp direction, so we can obtain the same result on weft direction.

From Figure 6, 7, 8, 9, 10 and 11, it can be seen that satisfactory inter-color bleeding control is obtained on pretreated taffeta, warp- knitted and weft-knitted fabric. Although yellow-cyan inter-color bleeding on pretreated satin and taffeta is slightly obvious, it is very good on weft-knitted polyester, this may be the combination result of the structure of the fabric and the pretreatment.

3.4. Fabric hand

In this study, for satin fabric, the fabric's hand became softer with the increase in silica content. This could be caused by the discontinuity of the film due to the increased silica content. For taffeta, warp-knitted, and weft-knitted polyester fabrics pretreated with 6 parts silica solution, we also obtained the soft hand.

4. Conclusions

(1) The UV curable pretreatment containing water-soluble UV curable resin and silica particle effectively improved the inkjet print quality in terms of line quality and inter-color.

(2) The ink bleeding is strongly influenced by the structure of the polyester fabrics. The ink bleeds most severely on woven fabric, and bleeding extent in warp and weft direction is different with the structure of the fabrics. On knitted fabric, ink bleeding is restricted significantly; very clear image can be obtained even without pretreatment.

(3) Increased silica content in formula improved inter-color bleeding, but not the same with every color on unprinted area.

(4) 10 parts resin content in the pretreatment formulae is the resin amount for obtaining well defined lines, but it may not be enough to fix silica particle completely on the fabrics.

5. References

[1] Nimalakirthi Rajasinghe, Waterborne UV Report on Integration of Optimum Rapid Drying System and Radiation Curing Technologies, www.optimumaircorp.com/uv_curing.htm accessed on September 15, 2005

[2] Skoufis, John, Elastomeric Radiation-curable Binders for Textile Printing, (Textile Chemist and Colorist, 11, No. 5, May, 1979), p 45-50

[3] Harris, James A.; Keating, Esmond J.; Goynes, Wilton R. Jr, Flame-resistant Cotton Textiles by a Continuous Photocuring Process, (Journal of Applied Polymer Science. 25, (10),1980), p 2295-2304

[4] Dodd, K. J. and Carr, C.M. Byrne, K. Ultraviolet Radiation Curing Treatments for Shrink-resistant Wool Fabric, Part I: Monomer Systems, (Textile Research Journal, v68, 1998), p10-16

[5] B. Neral, S. Sostar-Turk, B. Voncina, Properties of UV-cured Pigment Prints on Textile Fabric, (Dyes and Pigments 68, 2006) 143-150

[6] Holme, Digital Ink Jet printing of Textiles, (Textiles Magazine, no. 1, 2004), p11-15

[7] L. Lin and X. Bai, Ink-jet Technology: Status Quo and Future-relevance to Surface Coatings, (Pigment & Resin Technology, v 33. No. 4. 2004), p238-244

[8] Ming-Kai Tse and John C. Briggs, Yong K.Kim and Armand F. Lewis, Measuring Print Quality of Digitally Printed Textiles, (Recent Progress in Ink Jet Technologies II, chapter 8, Textile Printing), p548-554

[9] Teri Ross, a Primer in Digital Textile Printing, http://www.techexchange.com/-thelibrary/DTP101.html accessed on June 28, 2006
[10] J.-P. Fouassier, Photoinitiation, Photopolymerization and Photocuring Fundamentals and Applications, (Hanser, 1995), p274
[11] Martin Gerlitz and Rami Awad/Solutia Austria GmbH GmbH, Graz, Austria, New Generation of Waterborne UV-Curable Resins, Paint & Coatings Industry, 2004
[12] Personal Image Analysis System User's Guide, Quality Engineering Associates, Inc.

Author Biography

Qinguo Fan, an Associate Professor at the University of Massachusetts Dartmouth, earned his Ph. D in Color Chemistry from Leeds University, UK in 1995. Before joining the faculty at UMD in 1998, he was a Textile Chemist in charge of R&D, dyeing and finishing, wastewater treatment and customer service in Novel Textile Ltd. in Mauritius. His research interests include nanotechnology, digital printing, color science, polymeric materials, and textile chemistry.