Fabric Pretreatment and Digital Textile Print Quality

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Digital image analysis and optical microscopy are used to compare various print quality parameters of pretreated fabrics. In this work, woven and knitted cotton fabrics were treated with various chemical formulations containing ingredients like alginate, silicone based textile softeners and fine silica powder. A special print pattern was designed and printed on paper-supported pretreated fabric samples using a commercially available ink jet printer. Analysis of these print patterns was performed using an optical microscope and a digital image analysis program. The quality of these printed patterns were evaluated in terms of (1) color related metrics (L* a* b*) and (2) appearance related metrics (line width). Results show that digital textile printing quality on plain weave and knitted cotton fabrics is influenced by the fabric pretreatments, the most noticeable being the appearance related quality, i.e., the line width. The print quality on these pretreated cotton fabrics was not significantly affected by the fabric structure and the hydrophilicity of the fabric surfaces as long as the pretreatment can give cotton fabrics a balanced hydrophilic/hydrophobic character. From these studies it is concluded that digital textile printing quality can be optimized with appropriate pretreatments. For the plain cotton weave and knit fabrics studied, a pretreatment containing 2% alginate, 2% silicone softener and 1% silica shows good balance in colorant retention and line width control.

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Introduction

A printed textile fabric can be produced by various methods. In the U. S., rotary screen (69%), flat screen (20%), transfer (10%) and roller (1%) printing are traditionally employed for the manufacture of printed fabrics. Current textile printing speeds are 30 to 60 yards per minute at a 65 inch printing width. The number of colors in a design can be up to 24. However, typical textile print designs have an 8-color pattern. Also, average lot sizes are 3,000 linear yards or longer.[1]

U. S. textile markets are facing challenges from developing economies around world. The U. S. Textile/Apparel Complex has adopted a Demand Activated Manufacturing Architecture (DAMA) to survive into the 21st century. This manufacturing strategy requires "quick response", time-based competition, small lot sizes, large variety, and linkage into the supply chain.[2] It has been recognized that the textile printer can achieve these goals by employing digital printing technology. This provides minimizing printing lead-time, quick sample printing and small lot size. Current digital textile printing based on ink jet technology is limited to proofing and sample production. Further developments in ink formulation, jet design, pre/post processing, and higher throughput will provide the solution for extending digital printing technology beyond the mere preparation of proofing samples. Hopefully, the extension of digital printing into a full production mode will enable the developing textile printing market to thrive into the 21st century.

For successful digital textile printing by ink jet technology, the pretreatment of fabrics is very important in order to overcome the following problems. The low viscosity ink can spread easily on the textile surface leading to poor resolution. The texture of the textile surface can make the resolution even poorer. The wash color fastness of the ink jet printed textiles without pretreatment is not satisfactory for meaningful applications. Therefore, an impetus for developing textile pretreatment system for ink jet printing is very strong and urgent. The patent literature shows that this type of pretreatment was initially developed for paper. For example, Cronlund, et al. recommended a clay based coating for ink jet printing of barcodes on paper.[3] This coating consists of structured clay, hydrated alumina, binder and bivalent metal salts of C_{12} to C_{24} aliphatic acid, such as calcium stearate or zinc stearate, plus optionally a resin. It was applied to carbonless copy paper for a clear barcode printing. A multi-layer coating system was used by Dransmann, et al.[4] This multiplayer coating comprised a substrate, a dye receiving coating and an upper coating. The dye receiving coating contained finely divided inorganic fillers, such as aluminum oxide or aluminum hydroxide and their derivatives. The upper coating contained cationic compounds or polymers as well as the inorganic fillers. A finely divided silicic acid can also be used. Dye-fixing agents, usually cationic in nature, were used in both the dye receiving coating and the upper coating. Rooff, et al. used a sizing

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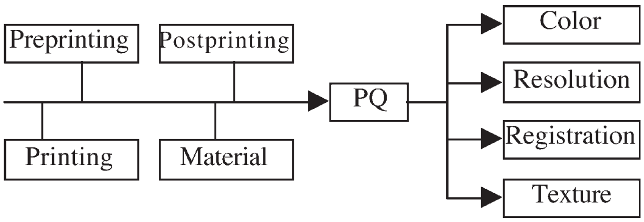

Figure 1. Print quality metrics

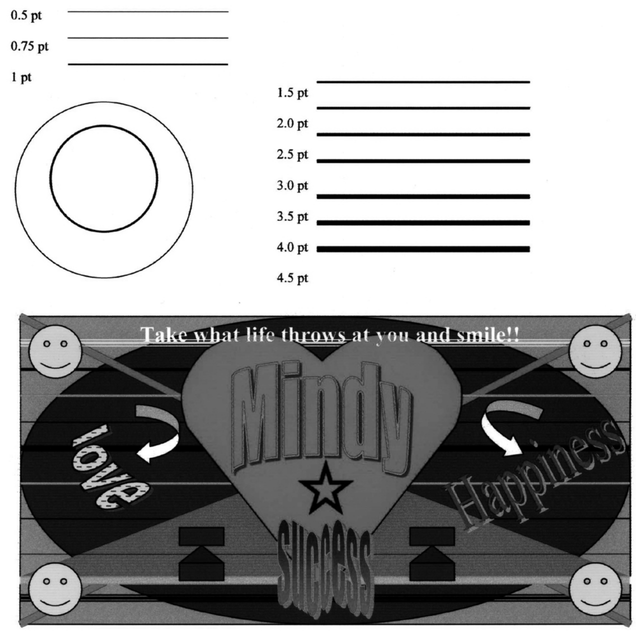

Figure 2. Printing pattern

method at the end of paper manufacturing process to improve the smoothness and strength of the paper.[5] The size comprised gellan gum and a derivatized starch. Encad Corp. had two patents in the area of ink jet printed textiles, both of which used epihalohydrin as the main component for coating.[6,7] A polymer or copolymer of epihalohydrin with polyalkylene polyamide was coated to textile fabrics together with a softener, such as tetraalkylammonium salt and a cationic binder, such as cationic acrylic copolymer. This coating can be applied to almost all common textile fabrics, such as cotton, hemp, rayon, wool, nylon, polyamide, polyester, polyacrylonitrile, and blends of them. The coating can improve the color intensity and wash fastness of the ink. More important is the excellent softness of the coated and ink jet printed fabrics. Nigam (SRI International) filed a patent for textile coating composition.[8] His invention used a coating system based on azetidinium/guanidine polymers. This system can interact with reactive dye inks very well. The images printed on the textile substrate coated with the system were claimed to be bleed resistant, water resistant, detergent resistant with enhanced chroma and hue.

In this study, we approached the problem differently: twelve pretreatments using different materials from these mentioned above were carried out on woven and knit cotton fabrics. The main focus is to find the effect of the proposed pretreatments on final ink jet printing quality of various treated fabrics with photographic quality paper as a control. While image quality and color were addressed, the issues of image stability (light fastness) and durability (wash fastness) are equally as important to the textile industry, however, they are out of the scope of this study and may be explored later.

Textile Print Quality

In present day textile printing, the analog printing technologies based on rotary and flat screens are mainly used. Fabrics made of cotton and cotton blends are the major substrates printed upon. A typical screen printed fabric has different characteristics from a digitally printed fabric, such as spot color versus process color and resolution (150 lines per inch versus 300 dots per inch).[3]

Defects in the digital printing of textile fabrics can be categorized into (a) color related issues (color gamut, color matching, light fastness, wash fastness, color intensity and uniformity) and (b) appearance related issues (line definition, dot geometry, penetration, and color registration). Many print defects relate to mechanical imperfections in the printed-on fabric or in print machinery application mechanisms. Others relate to printing ink rheology. Objective print quality measurement refers to defining and quantifying image elements that determine the overall visual quality of printed textile fabrics regardless of the cause of the defect. The print quality parameters of interest are outlined in Fig. 1. Overall the final print quality can be color related or appearance related (resolution, registration and texture). However, the measurement and quantification of these quality parameters should not eliminate a final subjective visual assessment of the printed surface.

Research presented in this article addresses some preliminary attempts to establish the relationship between the pretreatment and digital printing qualities in order to facilitate the use of digital machine vision and image analysis in the digital textile printing. Here a variety of textile fabric types were evaluated in an effort to determine the effect of fabric surface texture and wettability. The approach was similar to the techniques presently used for printing on paper, as in ink jet, laser and xerography. A special testing pattern was designed and used in this research. This pattern is presented in Fig. 2. It contains a combination of black lines of different widths (points) and colored patterns containing primary colors and their mixtures.

Pretreatment of Textile Fabrics for Digital Printing

Textile materials are porous, soft and pliable. In order to achieve well-registered, clear and sharp printing results using water-like printing inks without thickening agents in digital printing, the textile substrates need to be pretreated. In the case of cellulose reactive printing, certain amount of alkali should be used in the pretreatment recipes. The bleeding on untreated fabric in digital printing is another issue that should be taken into consideration. In some cases, washing after printing is not preferred; the pretreatment then should be designed with that in mind.

The following chemicals can be used for the pretreatment of digital textile printing fabrics. High viscosity grade alginate is a good choice as a thickening agent. By using high viscosity grade, the amount used can be minimized, and the versatility of alginate makes it suitable for many different types of dyes including reactive dyes.

TABLE I. Description of Cotton Fabrics Studied

Style	Treatment	Thread Count	Yarn size	Weight (g/m^2)
423 twill	Mercerized	108x72	14/1x14/1 carded	258
428 sateen	Bleached	96x56	20/1x14/1 carded	235
437 knit	Bleached	38x44	30/1 combed	124
407 poplin	Mercerized	100x50	20/1x17/1 combed	189
400M print	Mercerized	80x76	40/1x32/1 carded	107
419 broad	Mercerized	132x72	40/1x40/1 combed	120

Silicone compounds are used for two purposes. One is to compensate for the hard hand caused by the thickening agents. The other is to control the surface hydrophilicity that is crucial to the final sharpness of the printed patterns on textiles. Urea is often used as a humectant for dye fixation. The other important compounds for the pretreatment of digital textile printing are quite unique for digital printing. That means these compounds are used only for digital textile printing and not for traditional textile printing. Silica is one of them. The silica particle size should be very fine. The smaller the particle size, the better for holding the ink in the place where it is applied. Fine silica particles have a very high surface area that should effectively adsorb the dyes temporarily and release these dyes later on in the fixation step.

Experimental

Materials

The cotton fabrics used in this study were obtained from Test Fabrics, Inc., Pittston, PA. A description of these fabrics is presented in Table I. All are woven fabrics except #437which is a cotton Jersey knit.

Fabric Absorbency Measurement

AATCC Test Method 79 was used to evaluate the substrate absorbency. It measures the time the substrate takes to absorb a fixed amount of fluid. The longer the absorption time, the less affinity the fluid has for the substrate.

Fabric Wicking Behavior Measurement

INDA IST 10.0-70 Method 10.3 was used to determine the substrate wicking properties. It measures the distance the fluid front rises up a 1 inch wide strip of substrate during a 5 minute immersion time. A higher value of distance indicates a better wicking behavior. It is a rough measure of the absorption rate of the fluid into the fabric.

Pretreatment of Cotton Fabrics for Digital Printing

Two cotton fabrics, 400M print and 437 knit, were selected based on the absorbency and wicking behavior. 400M has a plain weave structure and 437 knit a Jersey knit structure. The selected fabrics were treated with the recipes listed in Table II. Neither of these fabrics was given any scouring or rinsing before the pretreatments were applied. They were used as received from Test Fabrics, Inc. Prime Alginate T-400 as used here is available from Multi-Kem Co. The silicone softener used was Ultratex CSP and is available from Ciba Specialty Chemicals Co. MEK-ST is the silica (30% SiO_2, 10-20 nm) used and is available from Nissan Chemical Industries. The fabric was padded at a 100% pick-up rate using the solutions listed in Table II. The fabrics were subsequently dried in air at ambient temperature for at least 24 hours before testing.

TABLE II. Pretreatment Recipes

Treatment	Alginate(g)	Silicone(g)	Silica(g)	Water(ml)
1	4.00	0	0	196
2	2.00	0	0	198
3	0	4.00	0	196
4	0	2.00	0	198
5	0	0	2.00	198
6	0	0	1.00	199
7	4.00	4.00	1.00	191
8	4.00	2.00	2.00	192
9	2.00	3.00	2.00	193
10	4.00	3.00	2.00	191
11	2.00	2.00	1.00	195
12	2.00	2.00	2.00	194

TABLE III. Water and 2-octanol Absorbency

	Absorption Time (sec.)	
Fabric	Water	2-octanol
423 twill	2.6	2.1
428 sateen	20.4	1.8
437 knit	>1200	1.0
407 poplin	5.8	10.6
400M print	18.6	14.4
419 broad	11.3	16.6

Digital Printing of Fabrics

The digital textile printing was carried out using an Epson Stylus Color 980 printer that is a drop-on-demand, dye based, four ink (CYMK) printer with 7 pL drop size. A test pattern was designed to facilitate the evaluation of basic printing parameters after printing (see Fig. 2). As shown, the pattern contains different colors, red, blue, yellow, green and brown, and lines of different width from 0.5 point to 4.5 points. Epson Photo Paper for ink jet (S041141 from Epson America, Inc., Torrance, CA) was used to print the same pattern for comparison. Before digital printing, the pretreated fabrics were backed with a pressure sensitive adhesive backed 53 g/m^2 weight paper obtained from Digital Textile Services, Sterling, MA.

Printing Quality Evaluation

Eight by ten inch samples of the digitally printed test images were placed under a microscope where line widths were determined using the stage micrometer. The color values (CIE L*a*b*) of the print were acquired from the scanned (using a UMax Astra 2000U scanner, UMax Technologies, Inc., Fremont, CA) images of the printed patterns using color conversion formula for digital image analysis by Adobe Photoshop version 6 (Adobe Systems, Inc., San Jose, CA). All data were an average of four measurements.

Results and Discussion

Fabric Absorbency

As shown in Table III, the absorbency characteristics of these fabrics are different. Notable is the observation that the Knit (437) and the Sateen (428) have a greater affinity for 2-octanol than they do for water. This indicates that these fabrics have hydrophobic surfaces, especially the knit fabric. On the other hand, 400M showed almost equal extent of hydrophobicity and hydrophilicity with very similar absorption times for water and 2-octanol.

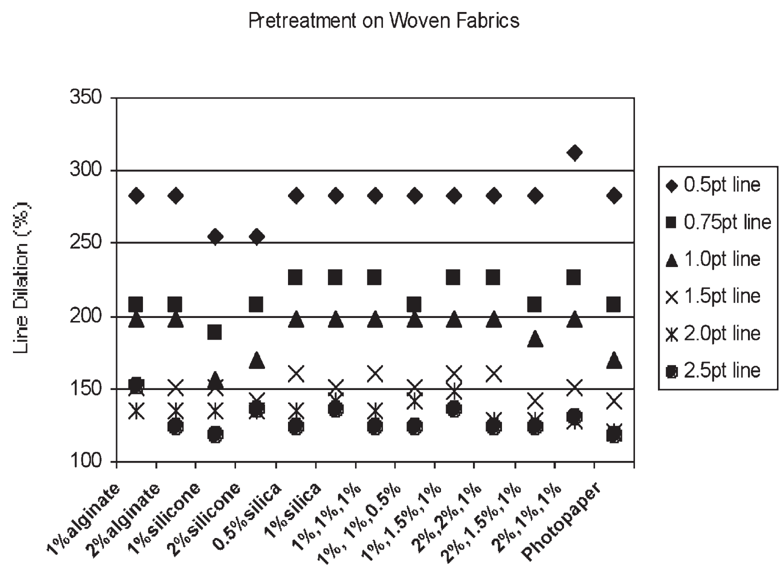

Figure 3. Effect of pretreatments on line width of digitally printed woven fabric

TABLE IV. Water (W), 2-octanol (O) Wicking Rate

Fabric	Fluid	Warp (P) cm	Weft (F) cm	P/F	W/O
423 twill	W	5.87±0.3	5.38±0.2	1.09	1.30
	O	4.70±0.1	3.97±0.1	1.18	
428 sateen	W	3.37±0.1	3.60±0.2	0.94	0.86
	O	4.07±0.1	4.03±0.2	1.01	
437 knit	W	0.20±0.0	0.05±0.0	4.0	0.03
	O	5.80±0.0	5.40±0.1	1.07	
407 poplin	W	5.58±0.1	4.97±0.1	1.12	1.32
	O	4.17±0.1	3.80±0.1	1.10	
400M print	W	4.73±0.2	3.80±0.2	1.24	1.05
	O	4.40±0.2	3.73±0.2	1.18	
419 broad	W	5.75±0.1	4.70±0.2	1.22	1.32
	O	4.32±0.1	3.70±0.1	1.17	

Fabric Wicking Behavior

The results listed in Table IV indicate that a slight wicking anisotropy can exist relative to the warp and weft direction in some fabric types. Here a P/F ratio of 1.00 denotes a uniform wicking behavior of the fabric in the warp and the weft directions. As shown, most of the woven cotton fabrics evaluated wicked fluid at a faster rate in the warp direction than in the weft. W/O ratios (average value of warp and weft wicking rate in water and in 2-octanol) are an index describing the relative ability of the fabrics to wick hydrophobic versus hydrophilic fluids. With the exception of the Sateen (428) and to a much greater extent the knitted (437) fabric, most of the fabrics studied showed a hydrophilic character. This is indicative of the scouring, mercerizing and bleaching treatments given to these fabrics. Alternately, it is suspected that the 437 knit fabric contains a lubricating finish on its yarns as a processing aid. These processing aids have rendered this knit fabric hydrophobic.

Effect of Pretreatments on the Line Widths

Some preliminary digital printing studies were conducted on all the fabric samples described in Table I. The results indicate that the cotton knit (437) and the plain print (400M) fabrics were the fabrics that were deemed suitable for our further digital printing experiments. Overall, this was expected since twill, sateen, poplin and broad fabric styles have inherently coarse surface textures. Furthermore, these fabric styles are rarely used in textile printing. Therefore fabric 437 cotton knit and the 400M cotton print were the only two fabrics selected for the detailed pretreatment studies herein reported (see Table II). Line dilation data are presented as the percentage increase of the line width compared to the intended line width.

From Fig. 3, it can be seen that the 1% silicone softener pretreatment on the woven fabric gives an overall good line width reproduction. The line dilation on the 1% silicone treated 400M woven fabric was even lower than that achieved on the photo paper printing surface.

Figure 4 shows almost the same effects for the knit fabric as in Fig. 3. However, silica pretreatment alone gave better line width control. 1% silica pretreatment gave the lowest line dilation for all line widths. For the thinnest line, 0.5 point, it even gave better results than the photo paper. There is a trend that the thicker the intended line width the less the line dilation. This is expected because line thicknesses were normalized as a percentage of the "original" line width. For line thicknesses up to 4.5 points, the line dilation was close to 100%. This indicates that the reduction of line dilation is maximized for the thick lines after the pretreatment.

It can also been seen from Figs. 3 and 4 that 2% alginate, 2% silicone and 1% silica (shown as 2%, 2% 1% in the figures) pretreatment gave the balanced line width control for all lines printed on both woven and knit fabrics.

Effect of Pretreatment on Lightness

Where color is concerned, the CIE L*a*b* color system is used in many applications for color specification. L* is the lightness, a* is the red-green aspect and b* is the yellow-blue aspect of a specific color. The higher the L* value the brighter the color, the higher the a* value the redder the color, and the higher the b* value the yellower the color. The data is shown for the fabrics with various pretreatments in Figs. 5 through 10.

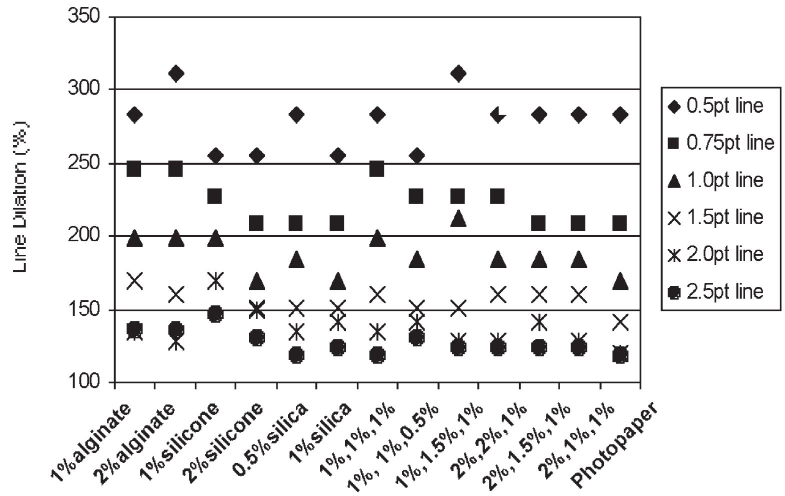

Figure 4. Effect of pretreatments on the line width on digitally printed knit fabric

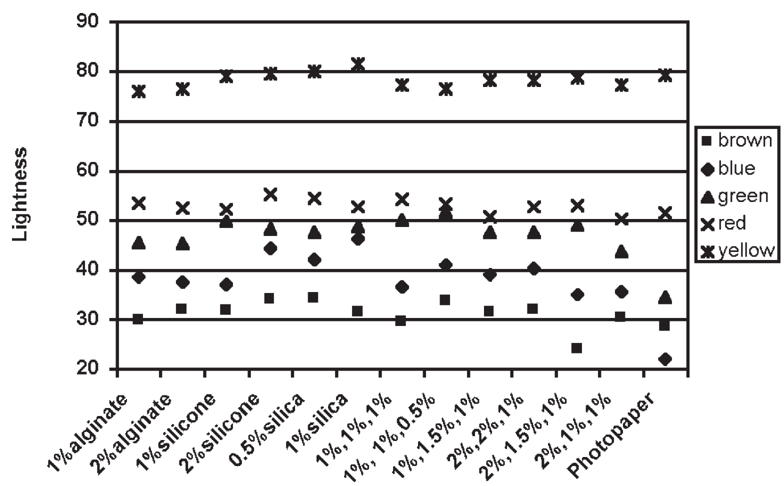

Figure 5. Effect of pretreatment on lightness of colors on woven cotton fabric

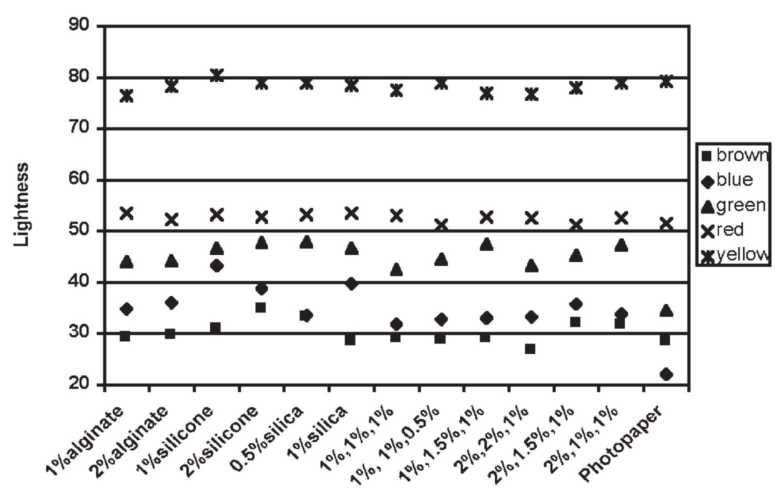

Figure 6. Effect of pretreatment on lightness of colors on knit cotton fabric

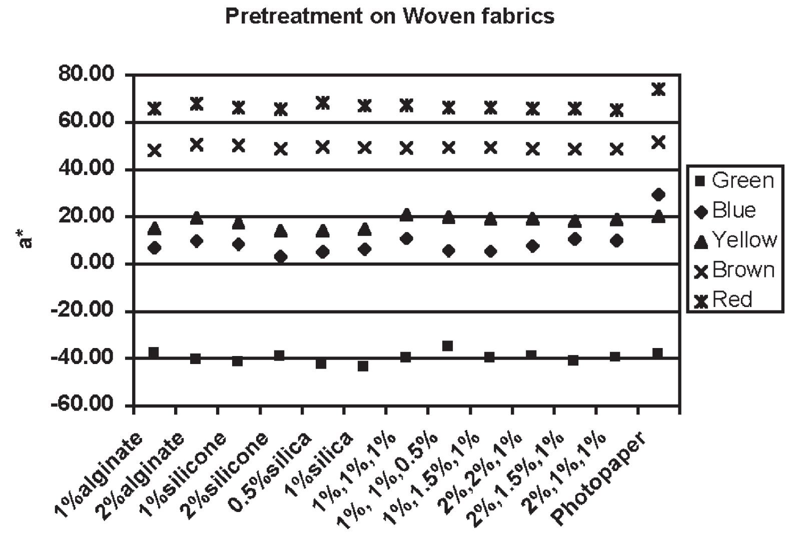

Figure 7. Effect of pretreatment on a* value of colors on woven fabrics

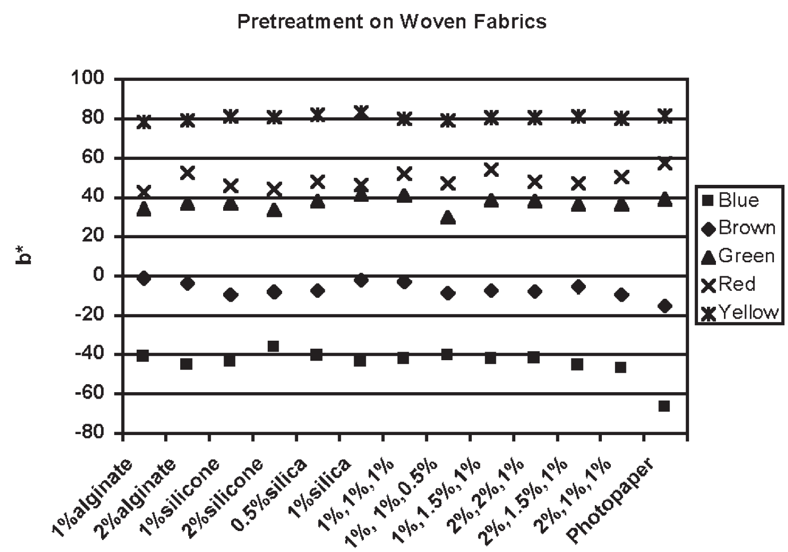

Figure 8. Effect of pretreatment on b* value of colors on woven fabrics

It is observed in Fig. 5 that the pretreated woven fabric with 2% alginate, 1.5% silicone and 1% silica (shown as 2%, 1.5%, 1%) pretreatment shows good results in color retention for all 5 color shades used. The lightness of five colors on 2%, 1.5%, 1% treated 400M print were all very close to that on photo paper.

On knit fabric, the combination of 2% alginate, 2% silicone and 1% silica gave the lowest lightness when compared to the photo paper.

From Figs. 5 and 6, it can be seen that the recipes containing 2% alginate, 1.5-2% silicone and 1% silica were adequate to achieve dark shades of all five colors (red, yellow, blue, brown and green) on both woven and knit fabrics. That means this combination would render the most intense colors on the treated cotton fabrics.

Effect of Pretreatment on a* and b* Values

It can been seen from Fig. 7 that all pretreated woven fabrics, 400M, were slightly greener (lower a* values) compared to the photo paper except for the green color itself which showed no big difference between the pretreated fabrics as well as between the pretreated fabrics and the photo paper. This green effect could be from the fabric itself or from the pretreatments leading to the unnoticeable color shift.

As far as the b* value is concerned, the pretreatments did not show too much influence on the woven fabrics as shown in Fig. 8, while the blue color appeared more blue on photo paper, which could be related to the reason discussed above. The unnoticeable green color from the pretreatments could also contribute some yellowness to the final color, making the color on the pretreated fabrics less bluer.

From Fig. 9, no pretreated knit fabrics showed significant a* value shifts, which is similar to the results shown in Fig. 7. However, because the colors on the pretreated knit fabric, 437 knit, also showed a greener tone, it is believed that the pretreatments may be the cause for the color variation.

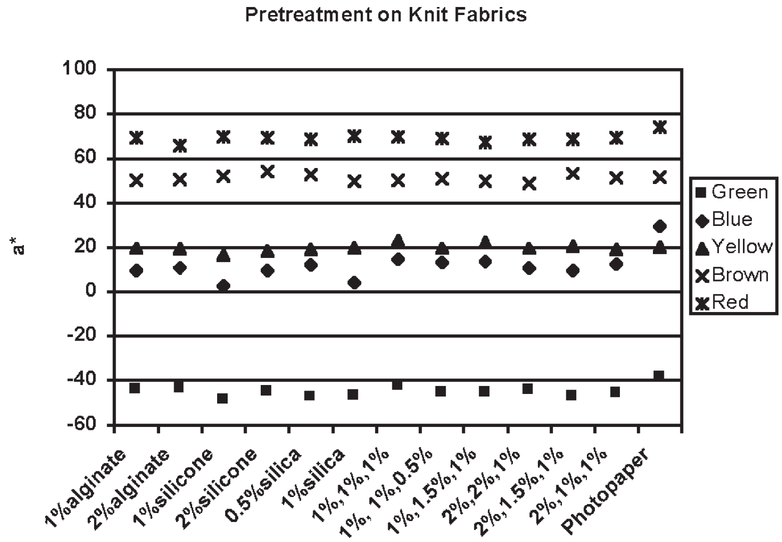

Figure 9. Effect of pretreatment on a* value of colors on knit fabrics

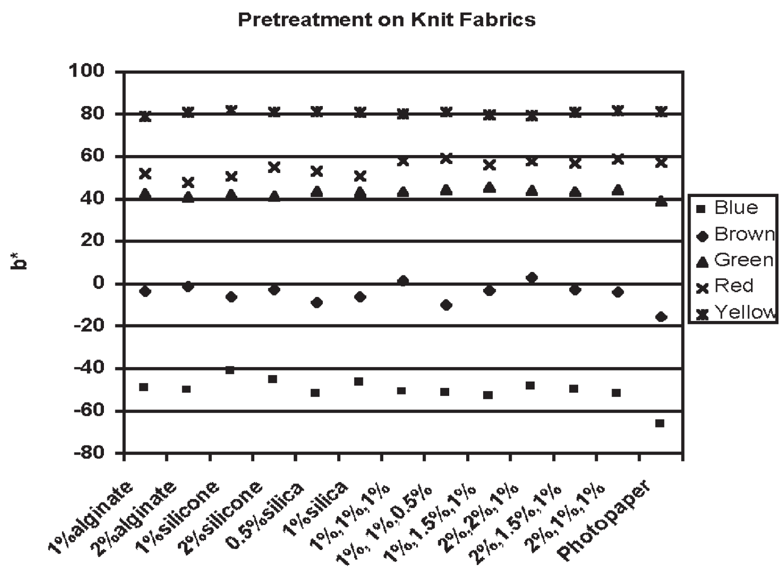

Figure 10. Effect of pretreatment on b* value of colors on knit fabrics

Overall, Figs. 7 through 10 show that the color gamut was affected only slightly by the pretreatments. It can be seen that the a* values (Figs. 7 and 9) of fabrics, both woven and knit, did not change much with different pretreatments, even though the photo paper seems a little redder. The b* values (Figs. 8 and 10) showed the similar independence of pretreatment, except that the photo paper had a little bluer tone.

Based on the experimental data available from the current conditions of our lab, the printer, and the associated print media, a pretreatment recipe of 2% alginate, 2% silicone softener and 1% silica is recommended for the digital printing of cotton fabrics, woven and knit.

Conclusions

Several digital print quality characteristics were measured on a variety of pretreated cotton fabrics. Fabric absorbency, and fabric wicking behavior were measured. The knit and sateen fabrics were found to have the most hydrophobic surfaces. Woven fabrics show some anisotropic wicking behavior. Effects of fabric pretreatments on the quality of digital printing on a plain cotton weave and a knit fabric were studied in detail. A special print pattern for quality analysis was designed for use in this study. In the experimental work, a number of recipes derived from the different combinations of alginate, silicone softener and silica were used as pretreatments for the cotton fabrics. Overall this study showed that digital textile print quality is influenced by fabric pretreatments, the most noticeable being the appearance related quality, i.e., the line width. The print quality was not significantly affected by fabric structure, or the hydrophilicity of the untreated fabric surfaces. Pretreatments can give cotton fabrics the required characteristics of digital printing substrates, i.e., the balanced hydrophilic/hydrophobic characteristics.

It was found that digitally printed cotton fabric with the optimum pretreatment can have as good a quality as that of the digitally printed photo paper substrate. This indicates that quality digital printing onto textile fabrics is achievable. Once an effective solution for fabric pretreatment is developed, it is believed that digital textile printing can be used not only for preparing prototype samples but also for production quantity and quality printed textile fabrics.

References

1. W. Tincher, F. Cook, W. Carr, and B. Failor, Keynote Paper: Printing on Textile Substrate, *Proceedings of IS&T's 46th Annual Conference*, IS&T, Springfield, VA, 1993, p. 368.
2. B. Hunting, R. Buffer and S. Derby, Issues Impacting the Design and Development of an Ink Jet Printer for Textiles, *Proceedings of IS&T's 11th International Congress on Advances in Non-Impact Printing Technologies*, IS&T, Springfield, VA, 1995, p. 374-377.
3. M. Cronlund and W. Subsara, U. S. Patent 5,709,738 (1998).
4. G. Dransmann, C. Junger and H. Westfal, U. S. Patent 5,911,855 (1999).
5. L. Rooff and C. Bennett, U. S. Patent 6,290,184 (2001).
6. D. Alfekri, G. Staley, B. Chin, B. Hardin, and C. Siswanto, U. S. Patent 6,001,137 (1999).
7. D. Alfekri, G. Staley, B. Chin, B. Hardin, and C. Siswanto, U. S. Patent 6,479,412 (2002).
8. A. Nigam, U. S. Patent 6,478,980 (2002).
9. M. K. Tse, J. C. Briggs, Y. K. Kim, and A. F. Lewis, Measuring Print Quality of Digitally Printed Textiles, *Proceedings of NIP14*, IS&T, Springfield, VA, 1998.