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Behavior of Prepared-For-Print Fabrics in Digital Printing

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ABSTRACT

Engineered print design for sewn products can reduce material waste and facilitate customized design of textile products. But, digital printing systems must produce output reliably and consistently for integration into a production process. This study examined changes in dimension and grain alignment of digitally printed and post-treated prepared-for-print (PFP) cotton fabric. Following post-treatment, substantial shrinkage and some skewing of the printed design was found. Furthermore, dimensional change results from one fabric were not predictive of results for a second fabric. These performance concerns impact end product quality and adaptability to the production environment. Future work should focus on delineating an optimum set of pretreatment conditions for PFP fabrics that will result in proper grain orientation and minimal, predictable shrinkage.

Keywords: Digital textile printing, Print Design, Engineered Print, Ink jet printing, Prepared-for-print Fabric, Printing Quality

Introduction

Digital technology for printing on textiles makes it possible to step forward to mass customization, consumer designed products, and innovative aesthetic design possibilities. With the expanded capability afforded by powerful CAD systems and textile machinery improvement, engineered print design has been studied for mass customization and just in time production applications in apparel. Such engineered design can reduce material waste by supporting improved nesting of patterns for cutting and facilitating development of customized textile design without limitation in size of repeat or number of colors in the design. This technology can be applied to other industries as well, including home furnishings [1].

To reach their potential, digital printing systems must produce output reliably and consistently for integration into a production process. Digital textile printing technology has been adopted by the textile and apparel industry for sampling and short-run production. Currently, printing speed, inks compatible with the full range of fibers and fabrics, enhanced color yield and color matching are being investigated and are improving. One major component of reliability is consistent and predictable performance of prepared-for-print (PFP) fabrics during printing and post-treating. This paper examines the behavior of purchased prepared-for-print fabric in response to the digital printing process. By clarifying the behavior of typical PFP fabrics, the challenges of developing an integrated digital textile printing system can be better understood.

One component of a digital printing system is the printer. Commercial inkjet printers, developed initially for paper and industrial printing, can be divided into two major types based on printing method; drop-on-demand (DOD) and continuous inkjet (CIJ) [2]. With a DOD system, a drop of ink is generated only when required for printing. Two major DOD systems, thermal and piezoelectric, are currently in use. Thermal ink jet, or bubble jet, systems have a resistor that can be heated by computer signal. The vapor bubble created on the resistor causes a drop of ink to be ejected from the nozzle. In a piezoelectric printhead, the computer imposes an electrical current across a piezoelectric material, which causes a contraction and expansion. When the deformation occurs, a drop of ink is ejected. CIJ systems generate a continuous stream of ink drops, and some of those drops are deflected while others are allowed to contact the substrate. CIJ systems can be classified as binary or multiple deflection systems based on the drop deflection method. In a binary system, drops are either charged or uncharged between the jet orifice and a charging plate. In a multiple deflection system, drops are charged varying amounts and deflected to the substrate at different levels (up to 30). Tincher [2] noted that both DOD and CIJ printing systems have advantages and disadvantages for digital textile printing.

The main ink formulations used for printing on textile substrates, are based on dyes or pigments. The colorants have been developed for optimum fixation and a wide color gamut. The choice of colorant and its application, along with the substrate, determines the resulting properties of the ink jet printed textile. Figure 1 shows the classification of colorants used in ink jet printing.

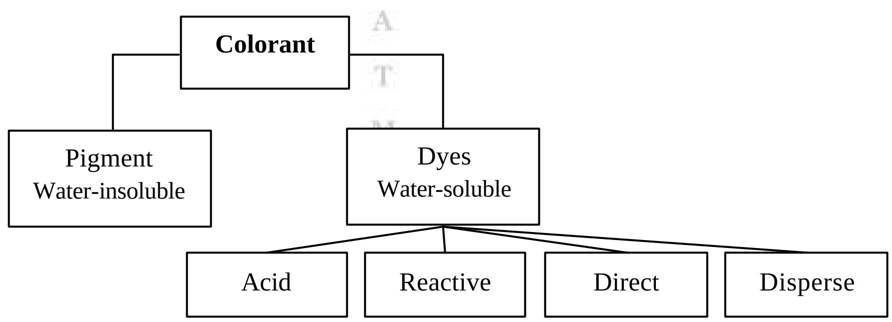

Figure 1. Typical colorants used in ink jet printing [3]

Colorant	Acid dye	Reactive dye	Direct dye	Disperse dye	Pigment
Substrates	Silk, Wool, Polyamide	Cotton, Silk, Linen, wool	Cellulose (not used for ink-jet textile printer)	Polyester	All type of fabric

Table 1. Colorant selection for textile substrates [3]

Different dyes are used for coloration of different fibers based on the properties of each dye (see Table 1). The color durability, such as wetfastness, and lightfastness, differs for each combination.

Unlike printing on paper, in digital textile printing, pretreatment and post-treatment are required to fix the colorants onto the fabrics and yield improved color appearance and durability. Pretreatment chemicals cannot be included in the ink formulations because they affect the physical properties (such as viscosity) of the ink making it unsuitable for jetting from the print head [3]. The post-treatment processes affect dynamically color appearance and change the fabric properties. Because results of the digital textile printing process vary according to the treatment conditions, it is necessary to understand how the printing process and post-treatment impact quality of output in order to predict how fabrics will respond to the process.

Textiles are impacted by pretreatment and post-treatment processes particularly in terms of dimensional stability and yarn orientation in a woven fabric. Lack of dimensional stability often leads to shrinkage in a textile. Shrinkage can occur when tensions applied during the pretreatment process are released by laundry or steam pressing. The resulting dimensional change affects the final product quality and, in the case of a garment, fit. Yarn orientation is commonly referred to as grain in the sewn products industry. Grain indicates the warp and weft directions in a woven fabric [4, 5]. As a result of the stresses and strains imposed during pre-treatment, warp and weft yarns may not have the proper orientation, that is may not lie at right angles to each other, resulting in fabric that is said to be off-grain. Usually, weft yarns are responsible for the distortion, and they may be distorted off perpendicular but straight (skewed), or in a curved line (bowed), or both. Designs printed on off-grain fabric will not be straight if the fabric recovers to a proper yarn orientation. Also, being off-grain reduces the fabric quality and prevents the fabric from draping properly or hanging evenly in the final product.

Consistent color yield is a crucial factor for printed textile quality. The pre-treatment and post-treatment of digitally printed fabrics affect the consistency of color yield. Yang and Naarani studied the effect of steaming conditions on color consistency of ink-jet printed cotton [6]. Their paper demonstrated the influence of steaming time, temperature, presence of wrapping paper, and the position of the fabric in the steamer on color consistency, and also recommended steaming conditions.

This study examined changes in dimension and grain alignment of digitally printed and post-treated prepared-for-print (PFP) textiles. Product design based on an engineered print requires consistent shrinkage for successful product assembly and minimal grain distortion in order to align the printed design accurately in the finished product. Off-grain fabric can distort the final product to an extent that the product is unacceptable.

Methods

Two rolls of pretreated 100% cotton fabric (cotton duck) were obtained from an industry vendor specializing in pretreated, prepared-for-print fabrics. A Mimaki Textile Jet TX-1600S, a piezoelectric drop-on demand inkjet printer, was used to print the samples for this investigation. The first roll of fabric was divided into two individual sub-rolls and samples were selected from each sub-roll in order to examine the impact of position in the roll on fabric behavior. The test results obtained by testing the two sub-rolls were compared to the results from the second roll in order examine consistency in dimensional change and change in grain alignment between two separate rolls. The impact of the yarn interlacing pattern in a woven fabric (weave structure) was examined by analyzing the dimensional change in a different type of 100% cotton fabric (cotton canvas).

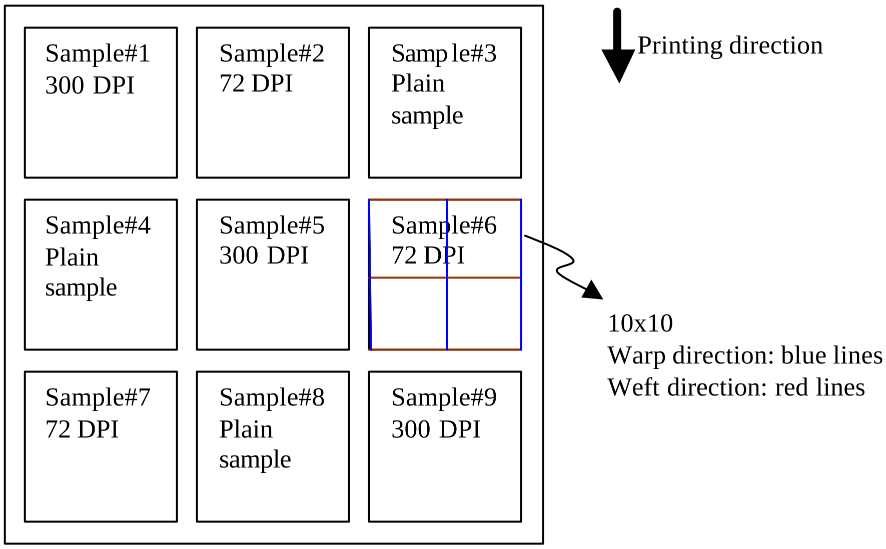

Figure 2. Diagram of sample arrangement on fabric

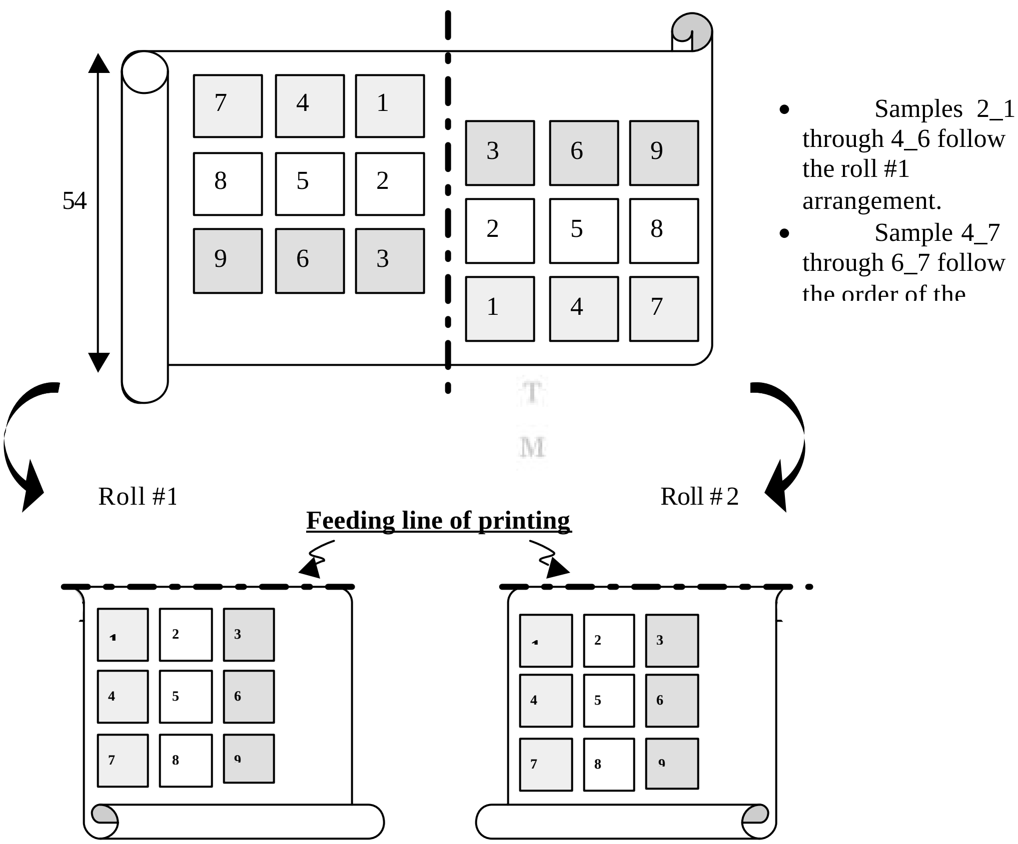

Figure 3. Sample specification

Test specimen preparation

Samples to be printed were laid out according to AATCC Test Method 135-2003 Dimensional Changes of Fabrics after Home Laundering [7]. Three printed samples each of two different resolutions and three blank samples were used for each trial. Variations in printing were done to examine how varying ink drop size and amount of ink applied in the printing process affected the dimensional change of a textile and also the changes in grain alignment. Figure 2 diagrams the cutting layout for samples in relation to the fabric. Three lines were drawn on each sample in warp and weft directions for measurement of dimensional change. The sample size was 15 x 15 (inches) and each marked line was 10 inches. Four trials using separate sets of sample layouts were completed yielding a total of 36 samples of fabric (12 for each experimental condition) and 108 measurements each for warp and weft directions. For pre-testing purposes and compatibility with the printer feeding mechanism, the first fabric roll was divided into two sub-rolls of fabric. Figure 3 shows how each of samples were positioned in relation to the original roll of the fabric.

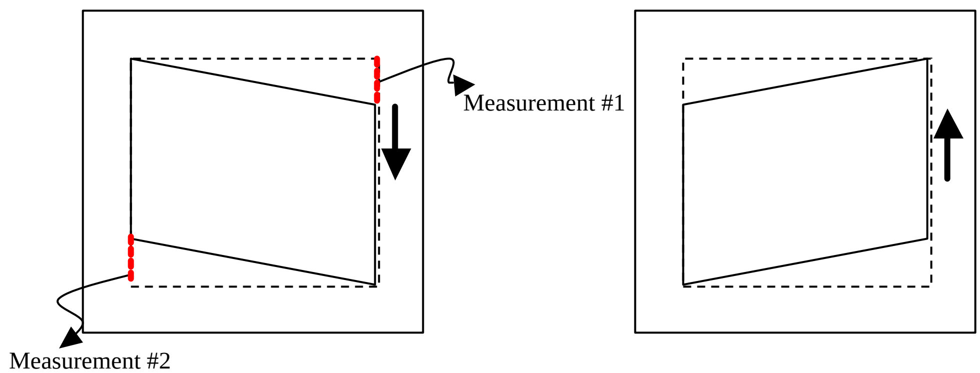

Figure 4. Measurement for Skewness

Post-treatment

After printing, all the samples were treated in the Xorella AG steamer at 100°C for 10 minutes to fix the dye. Steaming time was determined according to the type of fabric. A home washer and dryer were used for laundering following steaming. As recommended by the ink supplier, samples were pre-washed twice with cold water, then laundered for 10 minutes with a typical home laundering detergent in a hot water wash followed by a cold water rinse. Drying time was 25 minutes in a tumble dryer.

Sample Measurement

Dimensional change of fabric after post-treatment

The final samples were carefully pressed without stretching or moisture to remove wrinkles. After steaming, laundering, and pressing, the three marked lines of each sample were measured. In Table 2, the measurements are indicated. The average measurement for each printing condition is also shown.

Skewness

After post-treatment, the samples were measured to assess the impact of skewness in the PFP fabric. Measurements #1 and #2 were taken to determine how much the printing had distorted from its original position perpendicular to the edge of the fabric roll (see Figure 4). Also, the direction that the printing was skewed was recorded.

Calculations

Dimensional Change

The original dimension of each marked line on each sample was 10 inches, yielding an initial average measurement of 10 inches in both the warp and weft directions. The average measurement for each different printing condition was used for the average dimension after steaming and laundering.

Equation 1*: % DC=100(B-A)/A

Where:

% DC= Average dimensional change expressed as a percentage

A= Average initial dimension (10 inches)

B= Average dimension after laundering

* Note that a positive result is indicative of growth, and a negative result indicates shrinkage.

Skewness

Measurements #1 and #2 were averaged to calculate the skewness of the printing on the samples.

Equation 2: Average measurement (inches)/10 x 100 = % Skewness

	WARP						WEFT					
	After Steaming			After Laundry			After Steaming			After Laundry		
NO	Plain	300 DPI	72 DPI	Plain	300 DPI	72 DPI	Plain	300 DPI	72 DPI	Plain	300 DPI	72 DPI
1_1	9.92	9.88	9.92	9.39	9.38	9.36	10.00	10.05	10.02	10.02	10.06	10.00
1_2	9.94	9.88	9.92	9.39	9.38	9.36	10.00	10.05	10.03	10.03	10.05	10.00
1_3	9.91	9.89	9.91	9.39	9.38	9.38	10.00	10.03	10.02	10.03	10.05	10.00
1_4	9.92	9.92	9.92	9.36	9.38	9.41	10.03	10.03	10.02	10.05	10.00	10.00
1_5	9.91	9.92	9.94	9.38	9.38	9.41	10.03	10.03	10.02	10.03	10.02	10.00
1_6	9.91	9.91	9.92	9.38	9.38	9.38	10.03	10.02	10.02	10.05	10.00	10.00
1_7	9.91	9.91	9.91	9.38	9.38	9.33	10.03	10.03	10.03	10.02	10.03	10.05
1_8	9.92	9.92	9.91	9.38	9.36	9.34	10.03	10.03	10.02	10.02	10.02	10.05
1_9	9.92	9.92	9.91	9.38	9.38	9.38	10.02	10.03	10.02	10.02	10.02	10.05
2_1	9.94	9.92	9.94	9.42	9.36	9.39	10.03	10.05	10.03	10.03	10.05	10.02
2_2	9.95	9.92	9.94	9.44	9.38	9.39	10.03	10.03	10.03	10.03	10.05	10.00
2_3	9.92	9.91	9.92	9.44	9.41	9.41	10.03	10.03	10.02	10.02	10.05	10.00
2_4	9.94	9.94	9.91	9.38	9.41	9.38	10.06	10.03	10.00	10.06	10.00	10.00
2_5	9.94	9.94	9.91	9.41	9.41	9.38	10.05	10.03	10.00	10.05	10.00	10.00
2_6	9.91	9.92	9.91	9.42	9.39	9.38	10.05	10.03	10.02	10.05	10.00	10.00
2_7	9.94	9.91	9.94	9.47	9.38	9.39	10.05	10.03	10.03	10.05	10.03	10.05
2_8	9.94	9.91	9.94	9.44	9.36	9.39	10.05	10.03	10.03	10.05	10.03	10.05
2_9	9.94	9.91	9.94	9.45	9.38	9.42	10.05	10.03	10.03	10.05	10.03	10.05
3_1	9.94	9.91	9.92	9.41	9.34	9.38	10.03	10.03	10.03	10.03	10.05	10.03
3_2	9.94	9.91	9.92	9.41	9.38	9.39	10.03	10.03	10.03	10.02	10.05	10.02
3_3	9.94	9.89	9.92	9.41	9.38	9.41	10.03	10.05	10.03	10.02	10.03	10.02
3_4	9.92	9.94	9.92	9.36	9.41	9.41	10.06	10.08	10.06	10.03	10.03	10.03
3_5	9.91	9.94	9.91	9.39	9.41	9.41	10.05	10.06	10.05	10.03	10.05	10.03
3_6	9.91	9.94	9.92	9.42	9.42	9.41	10.03	10.05	10.05	10.06	10.06	10.03
3_7	9.92	9.91	9.91	9.38	9.41	9.38	10.02	10.03	10.05	10.03	10.05	10.05
3_8	9.91	9.92	9.89	9.36	9.39	9.34	10.02	10.03	10.03	10.02	10.03	10.03
3_9	9.94	9.92	9.88	9.38	9.41	9.38	10.02	10.03	10.06	10.02	10.03	10.05
4_1	9.92	9.91	9.92	9.38	9.34	9.34	10.03	10.05	10.03	10.03	10.05	10.03
4_2	9.92	9.88	9.91	9.36	9.34	9.38	10.03	10.05	10.03	10.03	10.05	10.03
4_3	9.92	9.88	9.91	9.38	9.38	9.38	10.03	10.05	10.03	10.03	10.06	10.03
4_4	9.91	9.92	9.92	9.34	9.38	9.38	10.03	10.03	10.03	10.05	10.03	10.03
4_5	9.91	9.94	9.92	9.36	9.39	9.38	10.03	10.03	10.03	10.03	10.03	10.03
4_6	9.91	9.91	9.94	9.38	9.39	9.38	10.03	10.03	10.03	10.03	10.03	10.03

4_7	9.94	9.92	9.92	9.39	9.38	9.36	10.03	10.05	10.03	10.03	10.03	10.03
4_8	9.92	9.94	9.91	9.39	9.38	9.38	10.03	10.05	10.03	10.03	10.03	10.03
4_9	9.91	9.94	9.91	9.38	9.38	9.38	10.03	10.05	10.05	10.03	10.03	10.03
Mean	**9.92**	**9.91**	**9.92**	**9.39**	**9.38**	**9.38**	**10.03**	**10.04**	**10.03**	**10.03**	**10.03**	**10.02**
STDEV	**0.01**	**0.02**	**0.01**	**0.029**	**0.02**	**0.02**	**0.01**	**0.01**	**0.01**	**0.01**	**0.02**	**0.02**
% DC	**-0.77**	**-0.86**	**-0.83**	**-6.08**	**-6.20**	**-6.21**	**0.31**	**0.38**	**0.29**	**0.33**	**0.33**	**0.24**
AVG	**-0.81 % DC**			**-6.14 % DC**			**0.31 % DC**			**0.33 % DC**		

Table 2. Dimensional change test results and statistics

Results and Discussion

Dimensional change of fabric
Table 2 shows the DC data and summarizes the test result with mean, standard deviation, and dimensional change. As can be noted in Table 2, shrinkage in the warp direction following post treatment was more than 6%. The printing condition had virtually no impact on the DC in either direction, so results are also shown averaged across conditions. As shown Figure 5, the location of the sample on the fabric had an effect in that the middle and end of the roll of the fabric tended to be more stable in the warp direction.

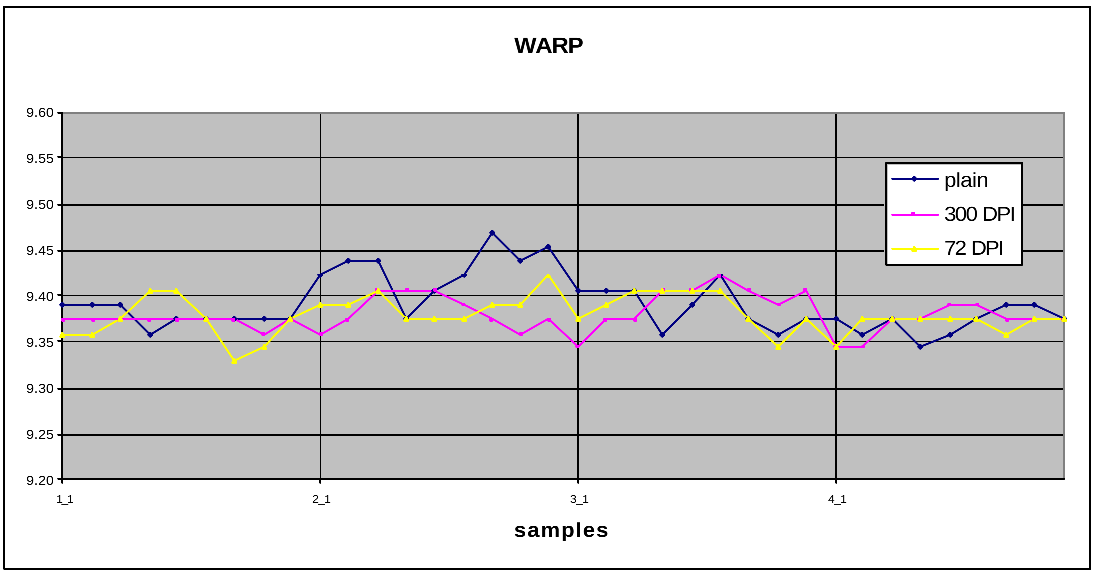

Figure 5. Measurement distribution of the warp direction

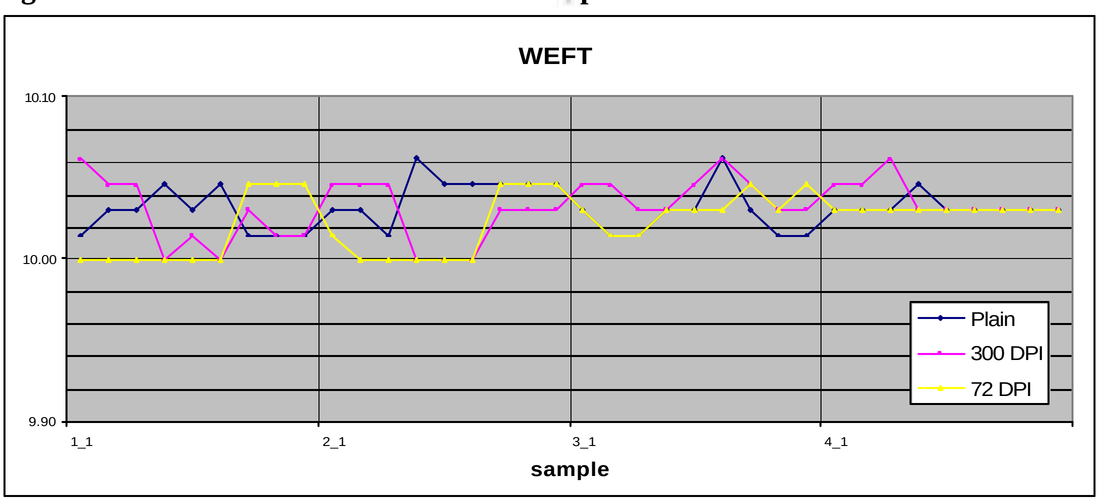

Figure 6. Measurement distribution of the weft direction

Table 2 and Figure 6 show the dimensional change test results for the weft direction. The samples only changed (grew) about 0.3% in the weft direction. The middle and end of the roll of the fabric tended to be more stable in the weft direction. In this fabric, the impact of both steaming and laundry post-treatment processes differed in warp and weft directions.

	WARP		WEFT
	After Steaming	After Laundry	After Laundry
Mean	9.44	9.30	9.91
STEV	0.03	0.03	0.01
% DC	-5.46	-7.00	-0.94

Table 3. DC results for 2nd roll of cotton duck

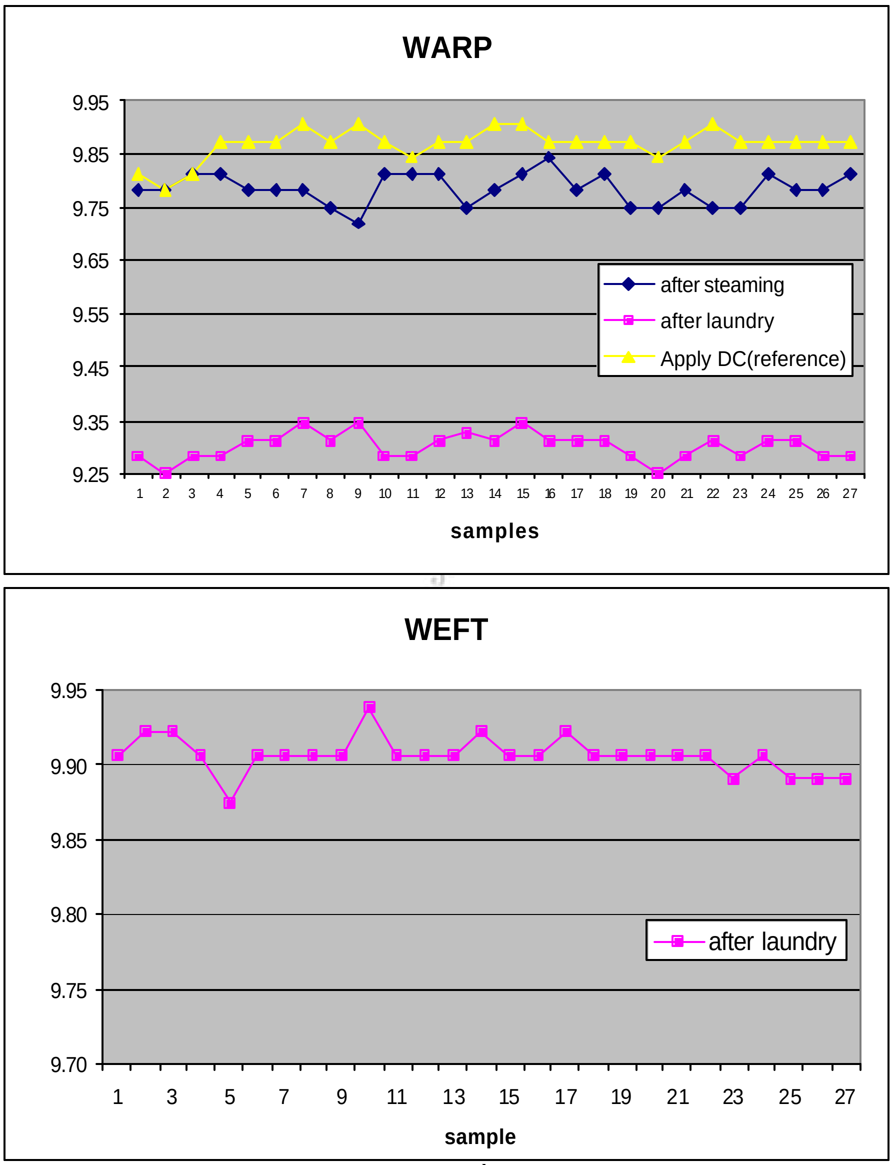

Figure 7. Dimensional change for 2nd roll of cotton duck

To evaluate the consistency of dimensional change from one roll of cotton duck to the next, testing was repeated using a second roll of cotton duck acquired from the same vendor. Table 3 summarizes the DC results for the second roll of cotton duck fabric. Although the difference in DC following post-treatment was statistically significant in both the weft (t=35.009, p=.0000) and warp (t=16.732, p=.0000) directions, the difference could be compensated for in application. With mean DC less than 1/8” different in both directions, and the range of measurements only about 1/8”, results from testing one roll could be used to adjust design work for a second roll of the same fabric from the same vendor with a successful result.

To examine the applicability of the results of the DC investigation to a different type of cotton fabric, 100% PFP cotton canvas was purchased from an alternative vendor. The thread count of the cotton canvas (86x28) was lower than that of the cotton duck (80x51). Thread count is indicative of fabric quality and higher counts are associated with less shrinkage, reduced raveling of seam edges and improved durability [3]. In addition to thread count, the two cotton fabrics varied in that the purchased cotton canvas was a 2x1 basket weave while the cotton duck was a plain weave. Because there are fewer interlacings per square inch in a basket weave than in a plain weave, a basket weave fabric is more flexible and has a greater potential for dimensional change. The dimensional change differed between cotton canvas and cotton duck, not only statistically (warp: t= 40.097, p=.0000; weft: t= 100.515, p=.0000) but with practical implications. In the warp direction, the difference in the mean dimensional change was ¼”, but in the weft direction it was over 3/8”. So, results of testing the first fabric could not be applied to the second fabric for successful compensation in design.

	WARP			WEFT		
NO	After steaming	After washing	After drying	After steaming	After washing	After drying
1_1	9.81	9.22	9.14	9.75	9.75	9.59
1_2	9.78	9.19	9.14	9.75	9.73	9.61
1_3	9.78	9.17	9.13	9.75	9.73	9.63
2_1	9.78	9.16	9.14	9.75	9.63	9.63
2_2	9.78	9.13	9.09	9.75	9.59	9.59
2_3	9.75	9.19	9.11	9.75	9.66	9.61
3_1	9.73	9.19	9.19	9.75	9.63	9.63
3_2	9.73	9.20	9.19	9.75	9.63	9.63
3_3	9.75	9.19	9.13	9.75	9.63	9.63
4_1	9.78	9.22	9.13	9.75	9.63	9.59
4_2	9.78	9.13	9.09	9.75	9.61	9.61
4_3	9.75	9.22	9.06	9.75	9.63	9.61
5_1	9.75	9.19	9.16	9.77	9.63	9.66
5_2	9.78	9.19	9.19	9.78	9.63	9.66
5_3	9.78	9.19	9.17	9.78	9.69	9.66
6_1	9.75	9.19	9.19	9.75	9.63	9.59
6_2	9.75	9.16	9.16	9.75	9.56	9.59
6_3	9.72	9.16	9.17	9.73	9.59	9.59
7_1	9.75	9.19	9.19	9.69	9.56	9.59
7_2	9.75	9.16	9.14	9.72	9.56	9.58
7_3	9.75	9.16	9.14	9.72	9.58	9.63
8_1	9.75	9.19	9.19	9.75	9.66	9.63

8_2	9.75	9.17	9.16	9.77	9.69	9.59
8_3	9.75	9.16	9.19	9.75	9.63	9.63
9_1	9.73	9.19	9.19	9.75	9.63	9.63
9_2	9.75	9.16	9.19	9.75	9.59	9.64
9_3	9.73	9.19	9.16	9.72	9.59	9.56
Mean	**9.76**	**9.18**	**9.15**	**9.75**	**9.63**	**9.61**
% DC	**-2.42**	**-8.22**	**-8.48**	**-2.53**	**-3.69**	**-3.87**

Table 3. Dimensional change for cotton canvas

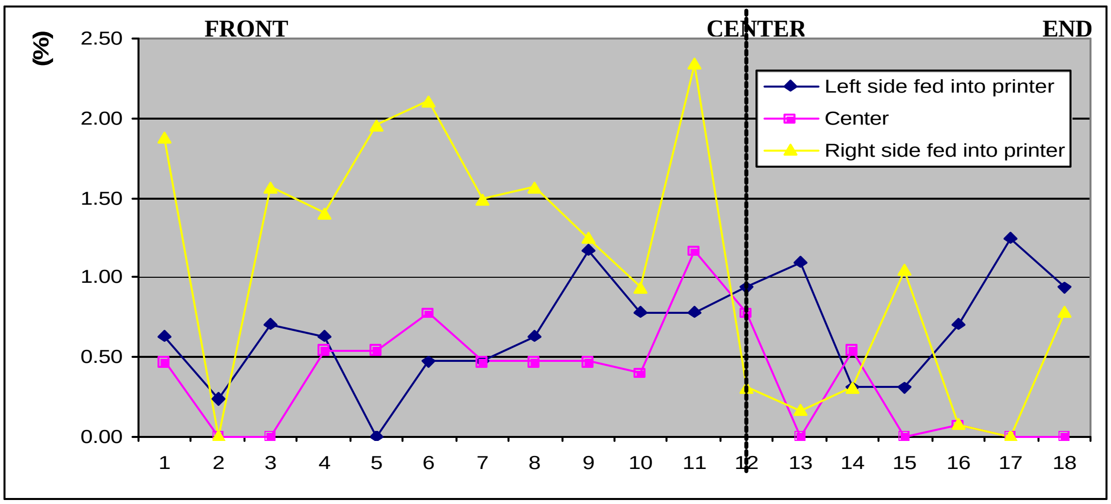

Figure 8. Skewness of each sample

Skewness

Using a total of 54 samples of cotton duck, the skewness was measured and plotted in Figure 8. Like the dimensional change distribution, the samples positioned at end of the fabric roll and in the middle of the fabric tended to be more stable. Sample positions were illustrated in Figure 3. Figure 8 illustrates the change in printing orientation on the fabric samples following printing and post-treatment. Figure 9 displays the skewness direction of each sample in relation to the original fabric roll, and Figure 10 illustrates the yarn orientation of the original roll, based on the direction of skew in the post-treated samples. The PFP fabric acquired from the commercial vendor was off-grain when printed. It tended to be bowed across its width resulting in skewed samples following post-treatment.

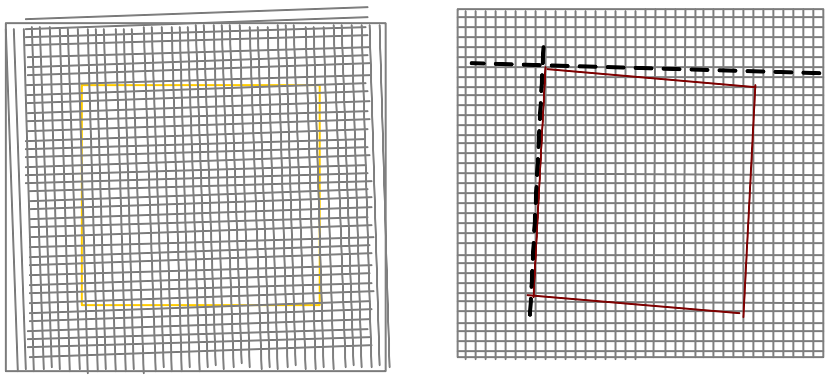

Figure 9. Orientation change in printed

Plain		300 DPI		72 DPI	
NO	% Skew	NO	% Skew	NO	% Skew
1_3	0.63	1_1	1.88	1_2	0.47
1_4	0.00	1_5	0.00	1_6	0.23
1_8	0.00	1_9	0.70	1_7	1.56
2_3	0.63	2_1	1.41	2_2	0.55
2_4	1.95	2_5	0.55	2_6	0.00
2_8	0.78	2_9	0.47	2_7	2.11
3_3	0.47	3_1	1.48	3_2	0.47
3_4	1.56	3_5	0.47	3_6	0.63
3_8	0.47	3_9	1.17	3_7	1.25
4_3	0.78	4_1	0.94	4_2	0.39
4_4	2.34	4_5	1.17	4_6	0.78
4_8	0.78	4_9	0.94	4_7	0.31
5_3	1.09	5_1	0.16	5_2	0.00
5_4	0.31	5_5	0.55	5_6	0.31
5_8	0.00	5_9	0.31	5_7	1.05
6_3	0.70	6_1	0.08	6_2	0.08
6_4	0.00	6_5	0.00	6_6	1.25
6_8	0.00	6_9	0.94	6_7	0.78
AVG	0.694	**AVG**	0.734	**AVG**	0.679

Table 6. Skewness of cotton duck

Skewness of the second roll of cotton duck was checked using 9 samples obtained from the beginning of the roll. The average skewness of the samples was 0.83%, like the first roll less than 1% skew.

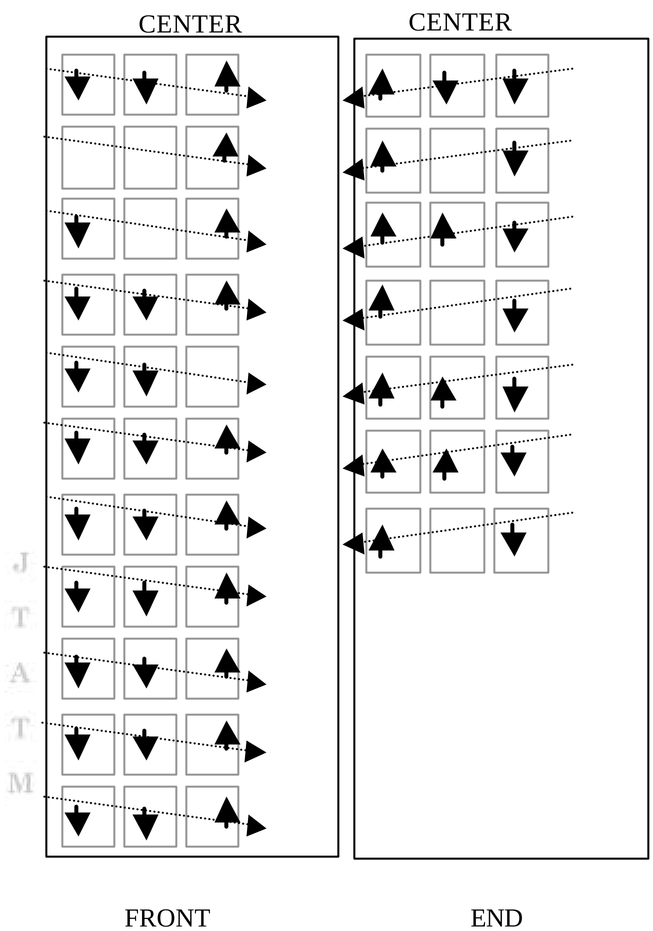

Figure 10. Skewness directions of the samples

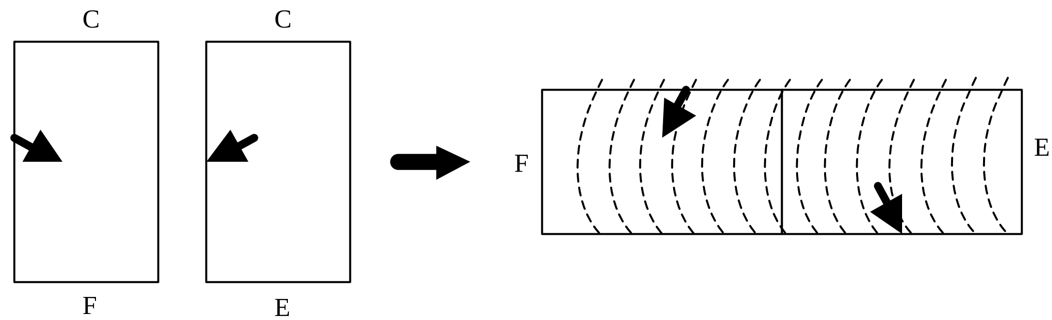

Figure 11. Projected yarn orientation in original fabric roll

Conclusions

For current industrial and design users of digital printing technology, it is important to investigate the dimensional stability and grain alignment of PFP fabrics prior to more extensive use. Some time invested in testing dimensional stability, bow and skew of each roll of PFP fabric can reduce the challenges of working with the technology. Understanding the potential DC of fabrics, and the grain alignment, allows a user to compensate in the design and development process. Though test results weren't consistent throughout a roll of fabric, the insight provided by testing even a few samples at one end of the roll could have a tremendous positive impact on the resulting product.

In the pretreatment process, fabric may be placed under a certain amount of tension in the warp and weft direction to dry evenly. Dimensional change of the fabric can occur after steaming and laundering when the fabric recovers from this processing. Much of the variation in the DC among fabrics, and within a roll of fabric, can be explained by variations in the pretreatment process. To manufacture a product with an engineered design and precisely matched pieces, it is important to standardize the DC of the fabric. The fabric used for this investigation had different DC across the fabric and the fabric orientation was bowed and skewed. Furthermore, DC test results from tests of one PFP fabric were not predictive of results for a second fabric. These performance concerns impact the end product quality and must be resolved to adapt digital printing technology to production environment. Before PFP textiles will be of sufficient quality for widespread use in a commercial production environment, companies producing PFP textiles need to improve pretreatment processes to minimize residual shrinkage To yield consistent end product quality, an optimum set of pretreatment conditions need to be confirmed and applied consistently to PFP fabrics resulting in proper grain orientation and minimal, predictable shrinkage.

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