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〈Research Paper〉

Evaluation of Image Quality of Inkjet Printing on the Spun Polyester Fabrics

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Abstract — This paper addresses the factors hindering the image quality of lines in inkjet printed on polyester fabric as printing media. Lines were printed onto different types of polyester fabrics in warp and filling directions. Line image quality including line width, edge blurriness, and edge raggedness was assessed. The effect of capillary wicking on line image quality of printed spun polyester fabric is discussed. The factors on the image quality include printing position(top of the yarn or between the yarn), printing direction(warp or filling), yarn structures(filament or spun), thread size(yarn or fiber), finishing, and ink properties(evaporation rate). More than 30% differences in image quality results were observed by changing the printing location on the spun polyester fabric. The best results of the image quality were obtained with the printed plain and spun polyester fabrics. The fiber sizes may affect capillary size; therefore, the image quality can be dissimilar. Types of finishing materials and inks greatly improve the line image quality on spun polyester fabrics.

Keywords: *Inkjet printing, Image quality, Textile, Polyester*

1. Introduction

Inkjet printing has been widely applied in textile industry for apparel, scarf and tie, carpet, banner, and auto interior fabric. The advantages of Digital Inkjet Printing (DIP) in these areas are speedy response to market and low cost for low volume production. Due to technical barriers of DIP such as low production speed against large volume, reliability and quality [1], usage of textile inkjet printers have been limited. One of the potential applications of inkjet printing is the augmentation of traditional garment label printing techniques to reduce inventory size.

Traditional label printing process requires an engraving plate and label inventory for each garment size. By combining DIP with traditional printing, new approach for labeling printing can be achieved. To accomplish the new method, we need to understand the effects of printing media (filament and staple, weave and knit pattern, fiber and yarn linear densities and diameters), as well as ink/substrate interactions (including wetting, spreading, and wicking) [2].

Tse *et al.*[3] and Fan *et al.*[4,5] discussed tools for quantifying print quality of inkjet printed on unfinished and finished cotton fabrics and reported factors affecting print quality. A commercial desktop inkjet printer was used to print the textile media and the printed media was analyzed by an automated print quality analysis system to quantify quality attributes in terms of line width, image noise, optical density, tone reproduction, and CIELab color. The most significant parameters for unfinished cotton fabrics found to be fabric structure, yarn size and hydrophilic/hydrophobic nature of the fabric while fabric pretreatment is the most important factor for finished cotton fabrics.

This study will address the understanding of inkjet print quality on polyester fabric. The effects

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of fabric structures including filament and staple, weave and knit pattern, fiber and yarn linear densities and diameters, properties of finishing materials and properties of various inks on line image quality will be discussed.

2. Experimental

Polyester fabrics were chosen because polyester fiber has chemically stable structure, totally symmetrical cylinder shape, and low swelling property to ink solvents. As shown in Table 1, nine types of polyester fabrics were obtained from Testfabrics, Inc.[6]. The different fabrics were selected to study effects of fabric construction, such as staple and filament, yarn and fiber size, yarn structure, fabric surface roughness, and woven and knit fabric structures. Some of the fabrics were produced from 100% filament polyester yarns, and others were made from spun polyester fibers .

A VisionJet system with an Ultrajet II inkjet head(Trident International) was used to print on the fabrics. Printing tests were conducted using VersaPrint™ black ink, AllWrite™ black ink, and JetWrite™ black ink by Trident International[7], shown in Table 2. The compositions and properties of these inks can also be found in Table 2.

Polyester fabrics were coated with 24.5% acrylic emulsion(Hyunjin No. 6-pp) or 17.5% polyurethane solution with *N,N*-Dimethylformamide(DMF) solvent (Heungil No. HW 1840). The fabrics were dipped into the coating bath and squeezed with 2 kg/cm^2 of pressure and dried at 80°C for 5 minutes. Pickup ratios of acrylic emulsion coated on various polyester fabrics are shown in Table 3. The roughness of the fabrics was tested via Kawabata system for fabric hand evaluation(KES-FB-4, KES Kato Tech Co., Ltd.), and is shown in Table 1. A Brookfield viscometer(model DV-1) and a ring tensiometer were used to measure the viscosity and surface tension of the ink, respectively.

Table 1. Description of polyester fabrics

Style #[a]		Fabric[a]	Treatment[a]	Yarn size[b] (mm)	Fiber size[b] (mm)	Roughness[c] (mm)
Filament Polyester	700-3	Poly Taffeta (plain)	Optical brightener	230×250	16	1.32
	700-4	Poly Satin (satin)	Optical brightener	150×380	16	0.62
	700-5	Poly Poplin (plain)	Optical brightener	380×390	17	1.75
	700-7	Hercules (twill)	Optical brightener	255×290	16	1.53
	700-8	Ply Duck (plain)	Optical brightener	380×570	26	2.13
	700-9	Poly Pongee (plain)	Optical brightener	200×250	20	0.36
	738	Polyester Taffeta (plain)	Disperse dyeable	260×330	19	1.43
	748	Polyester Twill (twill)	Disperse dyeable	170×290	15	0.61
Spun Polyester	755	Spun Polyester (coarser than 777; plain)	Disperse dyeable	510×610	13	3.50
	763	Spun Polyester (plain)	Cationic dyeable	470×670	12	2.68
	777	Spun Polyester (plain)	Disperse dyeable	330×440	14	3.19
	769	Spun Polyester (knit)	Disperse dyeable	250	14	2.25

a. Information provided by Testfabrics, Inc.
b. Data measured using SEM.
c. Data measured using KES system.

Table 2. Ink properties

Ink type	Description*	Surface tension (mN/m)	Viscosity (cP)
Versaprint	Polyalkylene glycol: 60 – 80% Polyalkylene glycol alkyl ether: 15 – 40% Solvent black 29	24	70
Jetwrite	Fatty ester: 50 – 60% Fatty acid: 30 – 40% Azine compound, and Aniline: 5 – 15%	30	39
Allwrite	Alkylene glycol alkyl ether: 65 – 75% N-propyl alcohol: 10 – 20% Acrylic resin: less than 5% Solvent black 48	31	14

* Information provided by Trident International.

Table 3. Pick up ratios of acrylic and polyurethane (PU) resins on polyester fabrics

Style #	Pick-up ratio(%)	
	Acrylic resin	PU resin
700-3	19.72	19.31
700-4	10.64	12.10
700-7	13.33	12.00
748	10.75	12.29
755	18.22	22.57
763	21.64	24.09
777	16.14	15.82
769	24.53	25.00

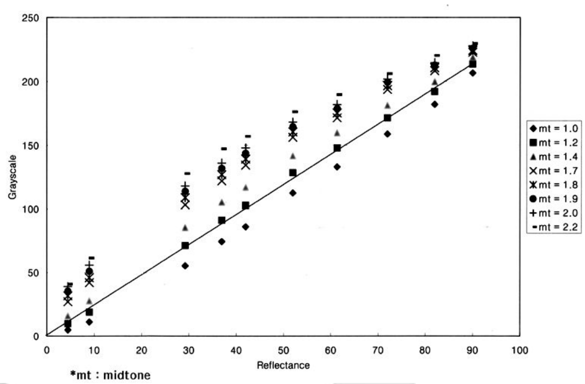

Fig. 1. Relationship between gray scale and reflectance with different midtone values.

INDA IST 10.1(95) Method 10 for non-woven fabrics was used to measure liquid wicking rate. The wicking rate was measured in terms of the height in millimeters to which the liquids rises in five minutes. The tests were conducted with distilled water, 2-Octanol, and ink(VersaPrint™ black ink).

To analyze the printed fabrics quantitatively, a HP Scanjet 8250 scanner was used to measure reflectance from line images. HP Scanjet 8250 scanner's gamma correction, called 'midtone', was adjusted to get linear relationship between reflectance and 8-bit gray scale. Standard reflectance tiles from Ceram Technology were used to get the value of midtone of the scanner that produced a linear relationship between reflectance and grayscale as shown in Fig. 1.

Analytic tool based on standard(ISO/IEC DIS 13660) was developed to analyze the scanned images using a MATLAB program. The output of the tool was print quality in terms of line width, edge blurriness, and edge raggedness. Line width is width of the line measured normal to the line between both edge thresholds. Line width is width of the line measured normal to the line between both edge thresholds. Edge blurriness is the haziness or indistinctness of outline. Edge raggedness is the geometric distortion of a straight lined edge from its ideal position. The value of Raggedness is the standard deviation of the residuals calculated perpendicular to the fitted line.

3. Results and Discussion

A study was conducted to investigate the effects of fabric geometric structures of spun polyester fabrics on the image quality. Fig. 2 shows front and backside images of printed Satin filament polyester fabric, and illustrates that the main

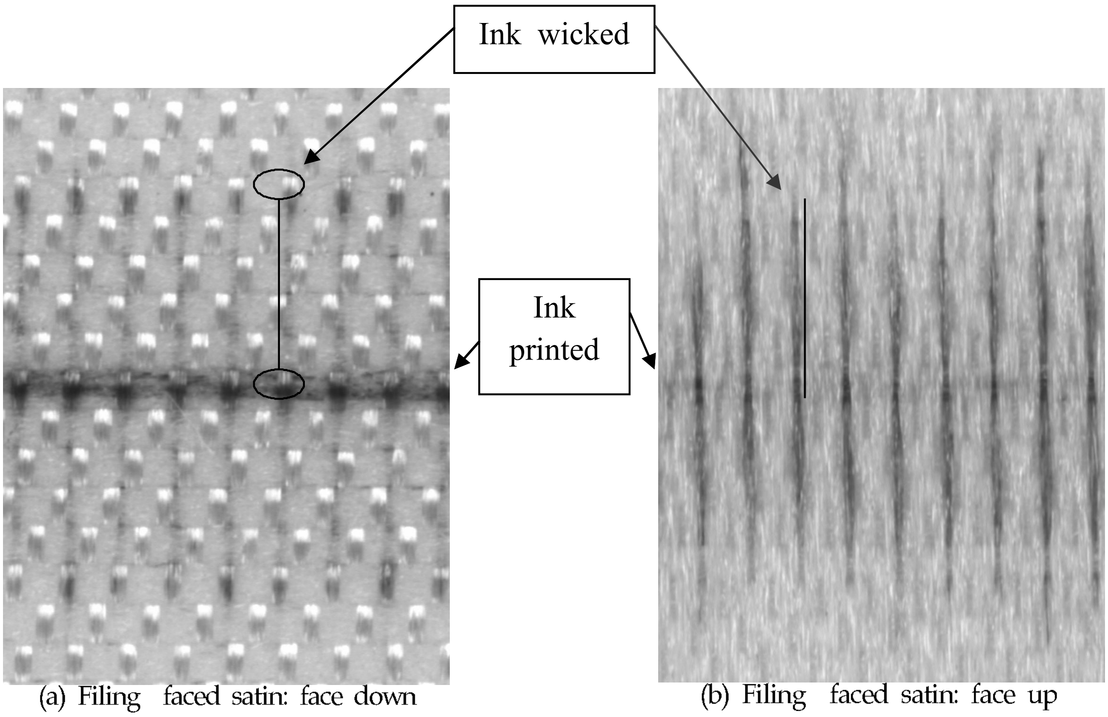

Fig. 2. Half point line printing along warp directions on #700 4 satin polyester fabrics using JetWriteTM ink.(optical resolution of 4800dpi)

reason for bad image quality on textile media is capillaries in the yarn that is perpendicular to printing direction. Inks spread in the perpendicular to the printing direction, i.e., ink spreads through filling direction when it is printed on warp direction. Fig. 2 (a) shows ink was printed on face-down side of the polyester fabric. When the ink was exposed on filling yarn, the ink wicked through the exposed filling yarn. In Fig. 2 (b), we can see the wicking path through the filling yarn on face-up side of the polyester fabric, where wicking processes are caused by capillary in the filling yarn. The wicking patterns are very important on image quality and varied by geometric structure of the polyester fabrics.

Observations of the wicking test with spun polyester fabric are shown in Fig. 3 that illustrates pictures after five-minutes in the wicking tests for (a) unfinished #755 fabric and (b) acrylic resin finished #755 fabric. VersaPrint^{TM} ink is used, and the warp yarns are oriented vertically with printing direction. There are two major differences between unfinished and finished spun fabrics: wicking rate and wicking processes. The wicking rate of the finished fabric is much slower than that of the unfinished fabric. It is because acrylic resin blocks almost all capillaries inside and between the both warp and filling yarns. In addition to wicking rate, wicking processes of unfinished and finished spun polyester fabrics are important. This wicking processes of spun polyester fabrics is similar to the filament polyester fabrics, but the wicking rate on spun polyester fabric is slower than on filament yarn, which shown in previous research[8].

Generally, wicking on the unfinished fabric occurred in yarns running perpendicular to the ink liquid surface, yarns parallel to the liquid surface, and spaces between the yarns. Ink first wicks into the yarns running perpendicular to the ink surface. A leading edge of ink rises above the ink surface and ink vertically runs the yarn perpendicular to surface of ink and covered area is referred to as Region I. The ink begins to fill into the parallel yarn to the ink surface, after the leading edge rises a certain distance. This process occurs first close to the ink surface and continues upward for whole test time. The region is referred to as Region II. After the wicking starts in the parallel yarns to the surface, ink starts to fill smaller spaces between yarns. After Region I and II are formed, almost all of the spaces between warp and filling yarns are filled with ink which is referred to as Region III.

For the finished fabrics, only Region II and III are observed, but not Region I. Ink wicks the interior of the fabric and appears to fill both parallel and perpendicular yarns simultaneously at very slow wicking rate. A leading edge of ink rises above the ink surface and the region where ink covered is referred to as Region II in Fig. 3.

The picture of cross sections of the leading edge clearly shows the different wicking on both Region I and II. They show that ink fills in some

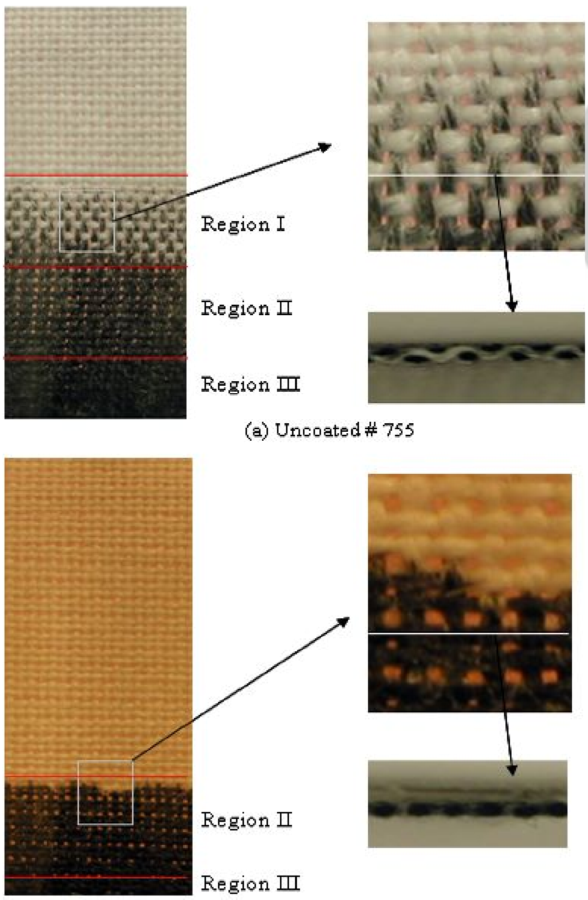

Fig. 3. Images of wicking on plain spun polyester fabric with VersaPrintTM ink. Wicking in (a) warp directions on unfinished fabrics and in (b) warp directions on an acryl finished fabric.

of the parallel yarns as well as some of the perpendicular yarns for the finished fabric while ink fills only perpendicular yarns for the unfinished fabric. After the leading edge rises a certain distance, ink is observed between warp and filling yarns(Region III in Fig. 3) just above the ink supply surface.

Since the main reason of wicking is capillary force, which is affected by the geometric fabric structure (printing position, warp or filling yarn, staple or filament yarn, fiber size, and weaving structure for filament and spun polyester). Thus the image quality based these fabric structures will be presented first, and then the effects of coating properties and will follow.

3.1. Effect of printing positions

In the previous studies [9,10], the equilibrium diameter of ink drop impacted in between fibers is bigger than that on the top of fiber due to the structural barrier in the radial direction. Thus, line image quality is expected to be different when printed at different position even on the same fabric. When sample fabrics are randomly printed, almost 5% of the samples were printed between printing-direction yarns. Fig. 4 visually shows lines that printed in different positions. AllWrite™ ink was printed along filling or warp direction on #700-8 filament polyester fabrics in Fig. 4 (a) and (b). Fig. 4 (a) shows that ink was printed on top of filling yarn while (b) shows that the ink was printed on position between filing yarns. In Fig. 4 (a), wide periodic peaks on every warp yarn and narrow and dark line on a filling yarn can be observed, and in Fig. 4 (b), wide and consist lines on both filling and warps can be observed.

VersaPrint™ ink was printed along filling or warp direction on #748 spun polyester fabrics in Fig. 4 (c) and (d). Fig. 4 (c) and (d) shows that ink was printed on top of filling yarn and between filing yarns, respectively. The printing on the spun polyester fabric does not show effect of printing position as clear as the printing on the filament polyester fabric; however, there are more than 30% different of image quality results on printing position between Fig. 4 (c) and (d), as shown in Table 4.

Table 4. Various image quality results with different printing position

Samples/Printing direction	Printing position	Original data (mm)			Difference (%)		
		LW*	Blur*	Rag*	LW*	Blur*	Rag*
700_5/ filling	P1**	0.260	0.374	0.229	16.2	6.0	146.1
	P2**	0.291	0.390	0.073			
748/ warp	P1**	0.239	1.865	0.479	53.9	33.3	79.0
	P2**	0.351	1.472	0.270			
755/ warp	P1**	0.267	1.208	0.281	15.9	43.2	38.8
	P2**	0.239	0.888	0.213			
763/ warp	P1**	0.250	0.642	0.359	13.1	13.2	27.3
	P2**	0.228	0.585	0.295			
763/ filling	P1**	0.255	1.419	0.203	21.4	31.5	54.6
	P2**	0.219	1.134	0.300			
777/ warp	P1**	0.287	0.456	0.164	15.9	11.5	44.1
	P2**	0.257	0.420	0.224			

* LW: Line width, Blur: Blurriness, and Rag: Raggedness
** Position 1 and Position 2

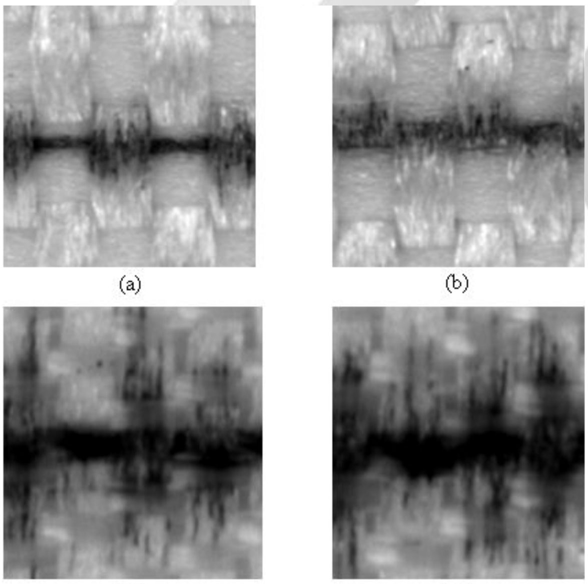
(a) (b) (c) (d)

Fig. 4. Effect of printing position on image qualities for #700 8 filament polyester fabrics with AllWriteTM ink printed along warp direction; (a) top of filing yarn, (b) position between filing yarns and for #748 spun polyester fabrics with VersaPrintTM ink printed along warp direction; (c) printed on top of warp yarns, (d) printed between warp yarns.

In (c), wide periodic peaks on every warp yarn and narrow and dark line on a filling yarn can be observed and in (d), wide and consist lines on both filling and warps can be observed. The only data obtained from printed polyester fabrics on top of yarn were used in this study.

3.2. Effect of warp and filling yarns in different weaving structure

The effect of printing direction on line image quality for unfinished fabrics is important for polyester woven fabrics, particularly with fabrics having asymmetrical interlacing. One of good examples is an unfinished twill fabric illustrated in Fig. 5, which shows that the long floats on the surface of the fabric. Fig. 5 (a) shows SEM and scanned images of printed filling-faced twill polyester fabric along a filling yarn, notice that two out of three of the filling yarns run over the warp yarns. As shown in Fig. 2, the ink drop on these warp yarns wicks in the warp yarn direction, which is transverse to the printing direction. When ink falls on the filling yarn, it is noticed that wicking in the warp direction is extremely small.

Fig. 5 (b) shows a SEM and scanned images of printed twill polyester fabric along a warp yarn. Since two out of three of the filling yarns run over the warp yarn, most of the ink falls on the filling yarn. Ink falling on the filling yarn, tends to wick in the filling direction. When the ink drops hit the

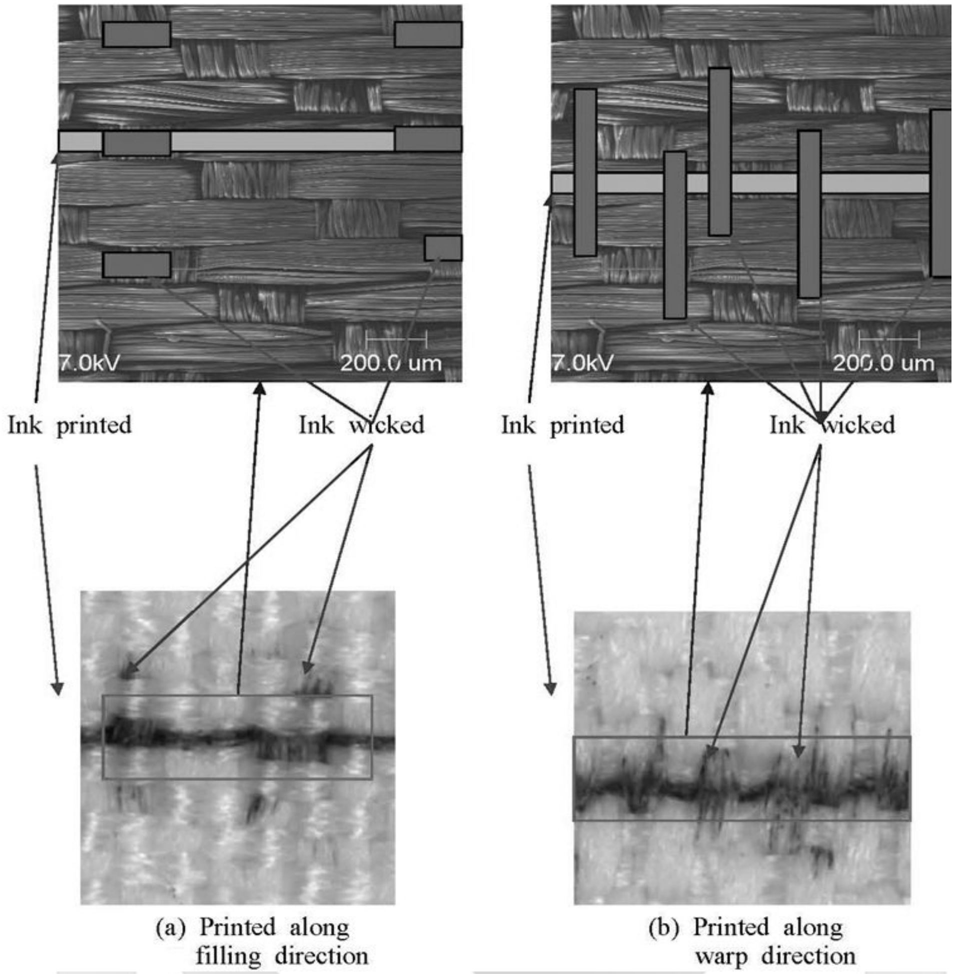

Fig. 5. SEM (X100) and scanned images (optical resolution of 4800dpi) of filling faced twill polyester fabrics printed in the directions of: a) filling and b) warp.

filling yarns which interlace over the warp yarn, wicking along the filling direction occurs. Since these filling yarns float over up to two warp yarns, the wicking distance is far, causing line image quality to be poor. Consequently, for this twill fabric, line image quality including line width, edge raggedness, and blurriness of printing in the filling direction is better than warp direction.

This illustrates how fabric structure plays an important role in line image quality for unfinished fabrics. Since the fabric structure affects directly to structure of interlacing, line image quality for the plain and satin weaves is expected to be different from those of the twill weaves. SEM and scanned images of printed plain and satin weaves are illustrated in Fig. 6. Since the satin fabric has less interlaced structure while the plan fabric has more yarn interlaced, It is expected that line image quality of plain weave structure is better than that of satin, which are the cases as can be seen in Table 5.

Table 5. Line image quality for unfinished fabrics and conditions

Fabric	Print Direction	Line Width (mm)	Blurriness (mm)	Raggedness (mm)
700-4 Satin Weave	Filling	0.57	0.45	0.062
	Warp	1.42	0.98	0.43
700-3 Plain Weave	Filling	0.32	0.39	0.23
	Warp	0.43	0.51	0.22
700-5 Plain Weave	Filling	0.28	0.38	0.20
	Warp	0.35	0.54	0.19
700-7 Twill Weave	Filling	0.30	0.55	0.35
	Warp	0.43	0.59	0.36

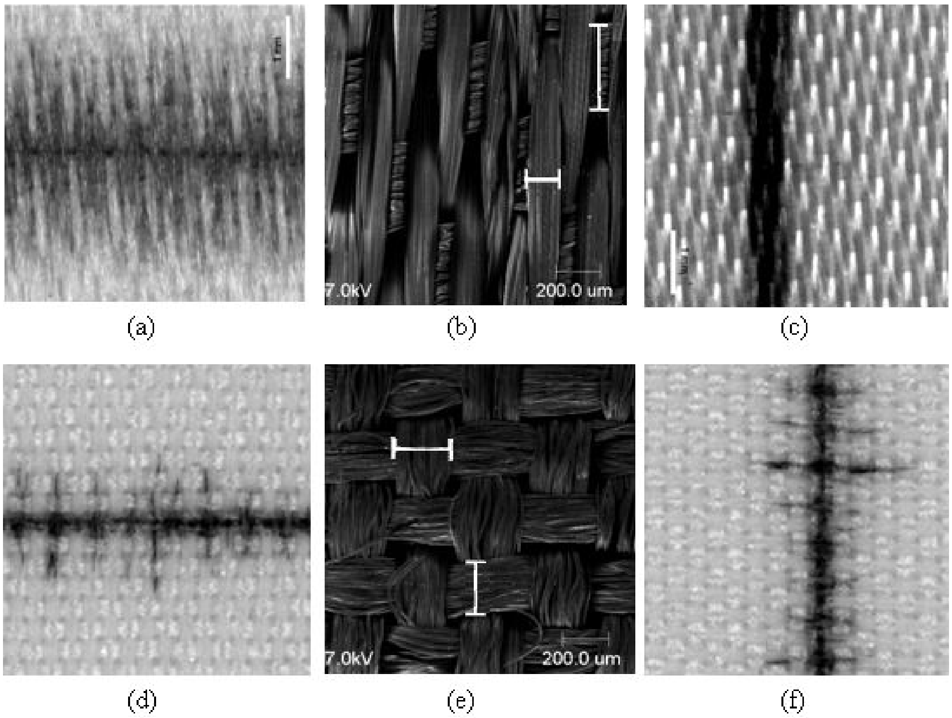

Fig. 6. Effect of warp and filling yarns in different weaving structures on image qualities using VersaPrintTM ink on: (a) #700 4(satin; printed along warp direction), (b) #700 4 (satin, SEM X100) (c) #700 4(satin, printed along filling direction) (d) #700 3 (plain, printed along warp direction), (e) #700 3(plain, SEM X100), and (f) #700 3(plain, printed along filling direction).

3.3. Effect of filament and spun polyester

Different surface morphology of filament and spun polyester fabrics are shown in Fig. 7. The fabric used in Fig. 7 (a) and (b) is weaved with filament yarn, whose surface is relatively smooth and has a well oriented structure. Continuous capillary spaces exist in the yarn. Fig. 7 (c) and (d) show SEM and a scanned image of the printed spun polyester fabric with a VersaPrint^{TM} ink, which consists of short staple polyester fibers; thus, end of staple fiber comes out of surface of spun yarn and makes the fabric hairy. As described earlier, clear wicking phenomena along filling direction which is perpendicular to printing direction is observed for filament fabric in Fig. 7 (b). However, in addition to wick perpendicular to printing direction, the scatter dots are observed, which may be caused by ink scattered on hairs of spun polyester fabrics. Results of the image qualities of printed spun fabric along filling are 0.2 mm as line width, 0.55 mm as edge raggedness, and 0.23 mm as edge blurriness, while 0.18 mm as line width, 0.28 mm as edge raggedness, and 0.04 mm as edge

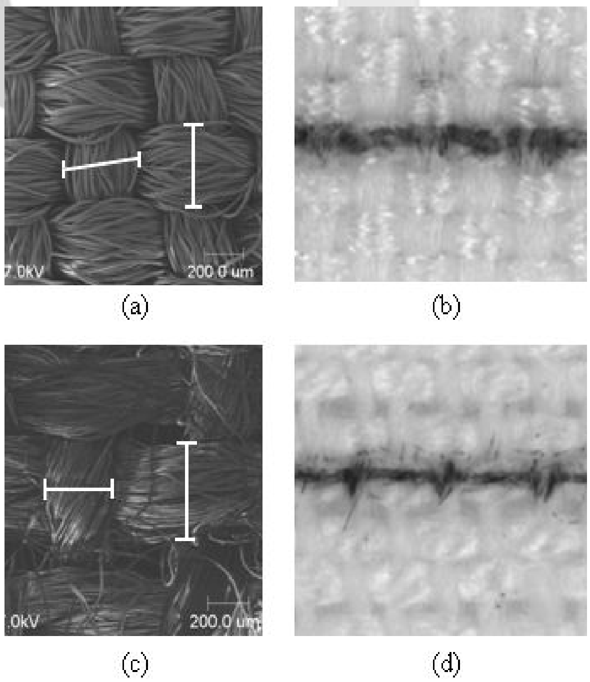

Fig. 7. Effect of yarn structures(spun and filament yarns) on image qualities using VersaPrintTM ink (a) SEM picture of #700 5 (plain, filament), (b) scanned image of #700 5 printed along filling direction, (c) SEM picture of #777(plain, spun), and (d) scanned image of #777 printed along warp direction.

blurriness are obtained with filament fabrics. Apparently the image quality of printed spun fabric is better than that of filament fabric. These may be caused by the structure of capillary in the fabric. The capillary of filament fabric is continuous, while the capillary of spun fabric is random.

3.4. Yarn size and fiber size

Table 6 and Fig. 8 show the results of printing qualities on yarn sizes for spun and filament yarns. The samples for comparison have the same fiber size, weaving pattern, and fiber treatment. There are not much image quality differences on yarn sizes, which is very similar results on cotton fabrics in a previous research [1]. The fabric with bigger yarn sizes is slightly better than the fabric with smaller yarn size. The main reason should be that the different yarn sizes might not affect the total volume of capillary in the fabrics while the fiber sizes do greatly affect the capillary volume in the yarn. In the earlier research, polyester fabric #700-5 and 700-8 were used for comparison with different fiber sizes. The fabrics constructed with the sample weaving pattern, fiber treatment, and filling yarn size. The fiber sizes are 17 μm for #700-5 and 26 μm for #700-8. Image qualities including line width, blurriness, and raggedness for #700-5 are better than those for #700-8 because usually large fiber make more capillary space inside a yarn.

3.5. Finishing and ink properties

Line image qualities of various polyester fabrics are different with capillary volume, structure, and size, which can be changed by fiber size, weave construction, and yarn structure. Finishing is usually required to improve the image quality of lines printed on polyester fabric. As shown in earlier work[8], acrylic finishing on polyester fabric weaved with filament yarn affects image quality, while poly urethane finishing did not affect much on polyester fabric. The results shown in Table 7 reveal that line image quality of fabric finished with acrylic and polyurethane resin is better than those of unfinished(Table 3 and Fig. 2). Unlikely with polyester filament fabrics, image quality of fabrics finished with polyurethane resin is better than some unfinished spun polyester fabrics. Both acrylic and polyurethane resins are effectively covered the surfaces of hairy spun polyester fabrics and then the different image quality results are more dramatic than those for filament fabrics.

The results of image quality with different inks, shown in Table 6, are similar with those of filament polyester fabrics. VersaPrint™ ink was used to obtain the results presented in the previous sections, which is used as a basis for many commercial inks. When glycol-based ink is printed on spun polyester fabrics, the ink is absorbed into the substrate and wicking can be a problem when printed on the textiles.

To show the importance of the ink ingredients, we used an oil based JetWrite™ ink and an alcohol based AllWrite™ ink. The results were very similar to earlier works on filament polyester fabrics. AllWrite™ ink brought best results of all on the spun polyester fabrics because the ink is volatile enough to evaporate before significant wicking can occur.

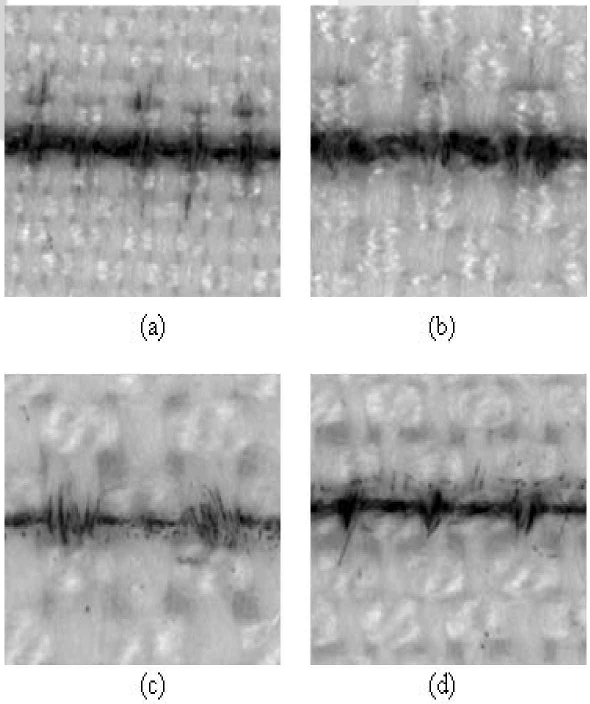

Fig. 8. Effect of yarn sizes on image qualities of printed polyester fabrics printed along warp direction using VersaPrintTM ink. (a) #700 3(filament; yarn size: 230 × 250) (b) #700 5(filament; yarn size: 380 × 390) (c) #755(spun; yarn size: 510 × 610) (d) #777(spun; yarn size: 330 × 440).

Table 6. Image quality on yarn sizes of spun polyester fabrics

Spun Polyester					
Ink Type	Style #	Print Direction	Line Width (mm)	Blurriness (mm)	Raggedness (mm)
VersaPrint	755	filling	0.24	1.69	0.25
		warp	0.25	1.05	0.25
	777	filling	0.20	0.55	0.23
		warp	0.27	0.44	0.19
JetWrite	755	filling	0.31	0.72	0.14
		warp	0.29	0.45	0.12
	777	filling	0.31	1.27	0.12
		warp	0.34	0.45	0.12
AllWrite	755	filling	0.18	0.55	0.12
		warp	0.18	0.40	0.18
	777	filling	0.18	0.84	0.21
		warp	0.20	0.32	0.15
Filament Polyester					
Ink Type	Style #	Print Direction	Line Width (mm)	Blurriness (mm)	Raggedness (mm)
VersaPrint	700-3	filling	0.32	0.39	0.23
		warp	0.43	0.51	0.22
	700-5	filling	0.28	0.38	0.20
		warp	0.35	0.54	0.19
JetWrite	700-3	filling	0.39	0.38	0.10
		warp	0.44	0.43	0.18
	700-5	filling	0.33	0.41	0.10
		warp	0.40	0.53	0.13
AllWrite	700-3	filling	0.19	0.26	0.07
		warp	0.18	0.27	0.10
	700-5	filling	0.18	0.28	0.04
		warp	0.24	0.71	0.06

4. Conclusions

The effects of capillary wicking on line image quality of printed spun polyester fabric were discussed. Capillary wicking depends on the volume and the diameter of available capillary for inks, and it can be reduced by printing position (top of the yarn or between the yarn), printing direction (warp or filling), yarn structure (filament or spun), thread size (yarn or fiber), finishing, and ink properties(evaporation rate).

1. The effect of printing position for the spun polyester fabric may not be shown in the scanned images; however, there are more than

30% differences in image quality values.

2. Since the plain fabric has more yarn interlacing than other fabric structure, line image qualities is better for plain textile structure and worse for the satin weaves.
3. Apparently the line image quality on spun fabric showed higher image quality than fila - ment fabric.
4. The fiber sizes in polyester spun fabrics may greatly affect image quality while the yarn sizes do not.
5. Acrylic resin finishing to polyester fabrics can improve line image quality by reducing capillary volume in the fabric.
6. Inks with fast drying time can greatly improve line image quality.

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