https://doi.org/10.2352/ISSN.2169-4451.2017.32.189

Textile inkjet printing to support US manufacture reshoring

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Abstract

This research involved the examination of pigment-based and disperse dye-based inksets applied to polyester fabric by textile inkjet printing. Colorimetric data were recorded for each color, as well as the mixed colors generated through RIPMaster V11 software. Color Table (CTB) profiles were created to compare spot colors and International color consortium (ICC) profiles were created to evaluate color gamut volumes. Four-color and seven-color disperse inksets were compared, while six-color and eight-color pigment inksets were compared. As expected, the additional colors increased color gamuts significantly. It was also found that the disperse dye-based inkset provided deeper color shades, and excellent wet and dry crock fastness properties. However, the light fastness for disperse dye-based inksets was not as good as the levels obtained using pigment-based inksets.

Introduction and Background

Single pass high-speed textile inkjet printers capable of printing 70m/min are competitive with rotary screen-printing, especially when printing shorter runs or multiple colorways [1-3]. These developments provide new market opportunities for U.S. Manufacturers as digital printing supports mass customerization and quick response. The goal of this larger research project was to integrate digital printing with weaving and cut and sew methodologies, map an optimal workflow for product design and manufacturing. Key components of this program include the development and improvement of fabric pretreatment agents [4-6], evaluation of various colorant sets formulated for Kyocera printheads, and optimization of the digital printing process flow. Specific studies conducted to date cover 1) the effects of pretreatment agents on the application of pigment and disperse dye based ink to polyester fabrics for outdoor products requiring lightfastness of 500 hours or more and 2) color gamut analysis as a function of substrates, colorants and pre-treatment chemistries.

Research Objective and Relevance

This research project is designed to provide a side by side comparison of pigment-based and disperse dye-based inksets on a polyester substrate through visual and instrumental assessment, including color gamut analysis, wet and dry crock fastness, and light fastness, to evaluate their suitability for the outdoor textile applications. Findings of this research will help support the dot.com, quick response, and short run manufacturing models for suppliers of a multinational retail corporation and others implementing digital printing technologies.

Experimental Methodology

An MS JP5Evo equipped with Kyocera print heads was used. Print Mode C2 was used because it is most often employed in production settings requiring a balance between production speed and print quality. Print mode C2 uses seven variable drop sizes (4, 7, 11. 14, 16, 19, and 24); 600x600 dpi, 4 passes, bi-direction, and the carriage speed is "High. On the JP5, there are eight modes (A-H) and three carriage speeds, HQ, High, Max (the mode and speed are intrinsically synced). The RIP can be set to either uni-direction or bi-direction. Each mode has a different droplet range – from 4 to 72.

RipMaster v11 and Xrite i1Profiler version 1.6.3 software were used for calibration and characterization, and for creating profiles for the ink and substrate combinations [7]. Analysis of color performance and evaluation of the colorimetric values of individual inks were measured with an X-rite 2nd generation i1iO spectrophotometer. AATCC Test Method 116-2010: Colorfastness to crocking and AATCC Test Method 16-2004: Colorfastness to light were used to test fastness properties. All samples were assessed with a Datacolor SF600X spectrophotometer equipped with Xrite Color iControl v9.4 software.

Two color profiles were used, a unique CTB profile developed by RipMaster for textile spot color prints and the ICC profile. For CTB profiles, a general color gamut model was created through Origin software. For ICC profiles, the visible color gamut was created and measured using ColorThink Pro v3.0.3 software.

A 7.0 oz/yd^2 woven fabric containing 100% spun polyester (PET) yarns was prepared for printing by scouring, and a resulting wet-pick up of 43% was determined. A pretreatment formulated for digital printing on PET fabric was applied using Mathis AG model HVF padding equipment.

The color shades from individual inks and the color gamut volumes were compared for four inksets: CMYK and CMYKRBV disperse dye-based systems and CMYKRVGO and CMYKRB pigment-based systems, where C = cyan; M = magenta; Y = yellow; K = black; R = red; B = blue; G = green; V = violet, O = orange. DP001 pretreated PET fabric was used to print with Inkset L and DP002 pretreated was used to print with Inkset F. The later pretreatment contained a photostabilizer and anti-migrant.

The printing process for disperse dye and pigment based inks is shown in Figure 1 below. The high temperature heat-setting process can cause a fabric shrinkage issue. The shrinkage ratio depends on the heat-set temperature and duration, therefore, a pre-shrinkage step was conducted before pretreatment. For disperse dye inks, an additional wash-off step is required to remove surface dye that is not fixed to the fabric, because it affects the performance of color fastness properties.

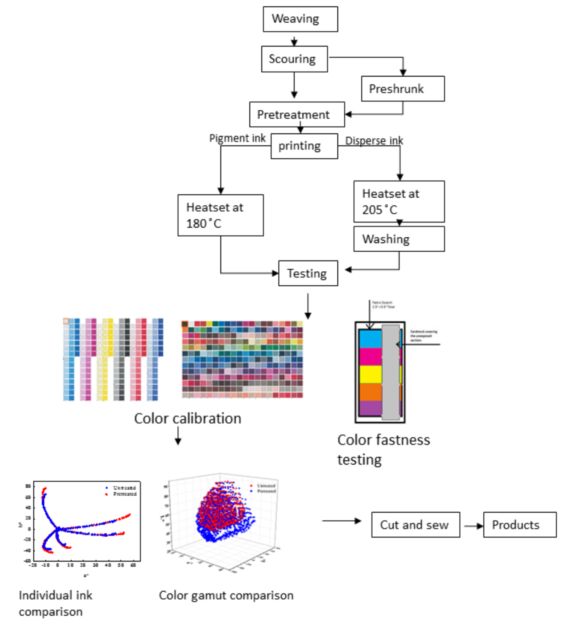

Figure 1. *Printing and testing process used in this investigation.*

Results and Discussion

Disperse Dye Inkset F

The Inkset F is a disperse dye-based ink containing dyes designed for high lightfastness. The first generation inkset was F1, which contained cyan, magenta, yellow and black, and second generation inkset F2 contained blue, red and purple as additional colors. The color values from the seven inks are shown in Table 1, where it can be seen that deeper colors (lower L* values) were obtained by applying the pretreatment agent to PET. Note for black color that L* value decreased from 32.29 to 26.22. Similarly, the chroma for each individual color was increased, especially for yellow, where the C value increased from 64.95 to 80.29.

Table 1. Individual color values from Inkset F.

Pretreated PET				
Ink color	L*	a*	b*	C
Cyan	44.69	-15.05	-28.88	31.12
Magenta	40.31	52.86	18.75	56.08
Yellow	78.24	3.58	82.54	80.29
Black	26.22	1.36	-1.27	1.86
Blue	35.83	3.11	-39.92	40.04
Red	49.5	56.63	40.36	69.54
Purple	29.38	25.06	-33.11	41.52
Untreated PET				
Ink color	L*	a*	b*	C
Cyan	54.09	-18.71	-24.15	30.55
Magenta	49.51	48.95	11.2	50.21
Yellow	78.52	0.95	64.94	64.95
Black	32.29	1.59	-0.46	1.65
Blue	46.49	-2.44	-32.14	32.23
Red	54.41	50.37	32.78	60.09
Purple	39.79	21.92	-32.05	38.82

By looking at the gamut comparison between Inksets F1 and F2 (Figure 2), the color gamut increased more in a* and b* direction for the Inkset F2, due to the addition of blue, red and purple colors.

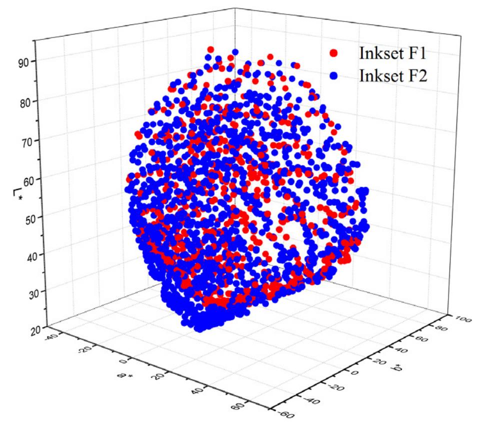

Figure 2. *Color gamut comparison between inksets F1 and F2.*

Pigment Inkset L

The type L pigment inks are among the commercial nano-scale pigment based inks developed for textile inkjet printing. They included eight colors – CMYKRBGO. The first generation (L1) contained six colors (CMYKRB) and the second generation (L2) contained two additional colors (G and O). A DP001 pretreatment was applied to PET before printing. The color values obtained are shown in Table 2 and the color gamuts generated from CTB profiles are shown in Figure 3. It is clear from Figure 3 that inkset L2 covers a larger area in the color space, especially in the L* and b* areas, probably due to the addition of green and orange components.

By comparing the colorimetric values of pretreated fabric printed with inksets L and F, it can be seen that most of the colors in inkset L gave a somewhat lighter color (higher L* value) on PET, except for cyan. For black, the L* value from inkset L was 29.31 and 26.22 from inkset F, which will deepen colors in the overall color gamut. Also, the red and magenta in inkset L gave higher a* values (58.96 for red and 57.44 for magenta), than a* values from inkset F (56.63 for red and 52.86 for magenta). The negative b* value for cyan was greater from inkset F (-28.88) than the one from inkset L (-46.97). The magenta from inkset F gave a positive b* value, which indicated yellow character; while the magenta from inkset L gave a negative b* value that indicated blue character in this color. Generally, the chroma from cyan (45.42) and magenta (58.02) was higher from inkset L compared with the cyan (31.12) and magenta (56.08) in inkset F. However, the chroma values for the other colors were higher from inkset F than inkset L.

A brief color gamut comparison between Inkset L1 and L2 was plotted based on CTB profile, which is shown in Figure 4. There are some areas in the color space that were better covered by L2, such as positive a* area, which represents orange and purple colors.

Table 2. Individual color values from Inkset L.

Ink color	L*	a*	b*	C
Cyan	44.03	-2.87	-46.97	45.42
Magenta	50	57.44	-8.19	58.02
Yellow	87.4	-10.8	78.3	79.04
Black	29.31	0.53	1.67	1.75
Blue	40.19	11.29	-37.27	38.94
Red	53.54	58.96	28.45	65.46
Green	68.09	-49.27	14.58	51.38
Orange	63.93	47.97	54.28	72.44

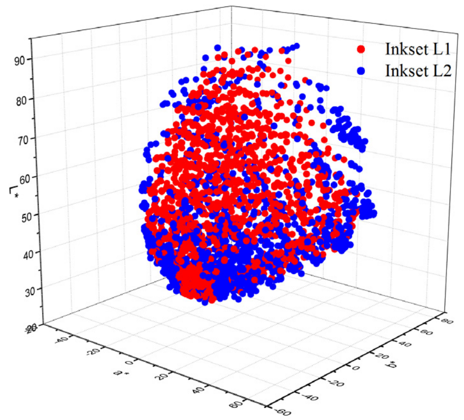

Figure 3. Color gamut comparison between inksets L1 and L2.

ICC profiles were also created for L and F inkset pairs, and color gamut volumes were measured using Color Think Pro software. The gamut volumes for each inkset are shown in Table 3. F1 gave the smallest gamut volume while L2 gave the largest, which is not surprising since L2 contained the most colors in its inkset. Figure 4 shows the 2D color gamuts in a*b* color dimension. The main difference between F1 and F2 was the increased gamut in the blue-purple area, since red, blue and purple were added in to the inkset. Similarly, the addition of green and orange to the L2 inkset increased the color gamut in the orange and yellow-green areas. Comparing inksets F2 and L2, the disperse dye based inkset (F2) afforded a bluish purple component, while the pigment ink (L2) provided a reddish purple component.

Table 3. Gamut volume from the four inksets.

Inkset	Gamut volume
F1	135,687
F2	186,533
L1	152,317
L2	188,426

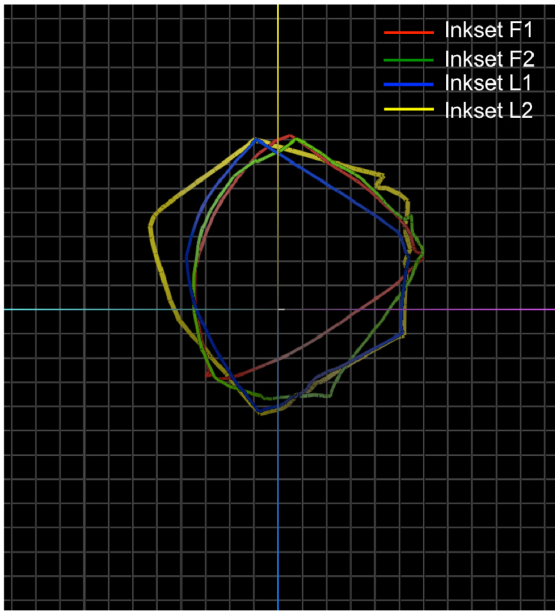

***Figure 4.** 2D gamut comparisons for the four inksets.*

Light fastness and crock fastness testing

To evaluate the color fastness properties of the L and F inksets, light fastness was evaluated at exposure levels of 160, 300, and 500 hours (h) and wet and dry crock fastness were measured in warp and weft directions. The rating scale was 1 (poor) to 5 (excellent), with a minimum rating of 3 acceptable.

The crock fastness ratings from Inkset F were excellent. As shown in Table 4, most of the colors gave a rating of 5, except for wet crockfastness for red in the warp direction, which was still very good at 4.5. However, the crock fastness for Inkset L was much lower, as shown in Table 6. In this case, the highest rating was obtained from green, which was 3; for the others, most ratings were around 2. Overall, these results arise from dye penetration into the fiber structure verse pigment occupying the surface of the fibers. Without a strong binder, pigment particles are more subject to removal by abrasion.

The light fastness results from Inkset F are shown in Table 5 and indicate that color faded appreciably as the exposure time increased, with ratings at the 500-h exposure level no higher than 2. The highest ratings were generally 2-3 at the 300-h exposure level. As shown in Table 7, however, the light fastness ratings from Inkset L were above 3 even after the 500-hour exposure, except for the orange pigment. Black and magenta gave a rating of 4 after 500 h, while cyan, yellow and blue gave a 3.5 after 500-h. Overall, these results reflect the particulate structure of organic pigments, giving layers of molecules rather than the mono-molecular arrangement of disperse dyes inside the fiber. The latter makes the colorants more accessible to photodegradation and the solution is the co-adsorption of a suitable photostabilizer to facilitate energy dissipation from excited dye molecules.

Table 4. Crock fastness ratings from Inkset F.

D/W	Color	Weft Yarns	Warp Yarns
D	Cyan	5	5
	Magenta	5	5
	Yellow	5	5
	Black	4.5	5
	Red	4.5	5
	Blue	5	5
	Orange	5	5
W	Cyan	5	5
	Magenta	5	5
	Yellow	5	5
	Black	4.5	5
	Red	4.5	4.5
	Blue	5	5
	Orange	4.5	5

Table 5. Light fastness results from Inkset F.

Color	Exposure levels (h)	Ratings
Cyan	160	2.5
	300	2.5
	500	2
Magenta	160	3.5
	300	3
	500	2
Yellow	160	3.5
	300	3
	500	2
Black	160	3.5
	300	2.5
	500	2
Red	160	3.5
	300	2.5
	500	2
Blue	160	3
	300	2
	500	1.5
Violet	160	2.5
	300	1.5
	500	1

Table 6. Crock fastness ratings from Inkset L.

D/W	Color	Weft	Warp
D	Cyan	1.5	2
	Magenta	2	2
	Yellow	2	2
	Black	2	2
	Red	2	2
	Blue	2	2
	Green	2.5	3
	Orange	2	2
W	Cyan	1.5	1.5
	Magenta	2.5	2.5
	Yellow	2	1.5
	Black	2	2
	Red	2	2.5
	Blue	2	2.5
	Green	3	3
	Orange	2	2

Table 7. Light fastness results for Inkset L.

Color	Exposure levels (h)	Ratings
Cyan	160	4.5
	300	4
	500	3.5
Magenta	160	5
	300	4.5
	500	4
Yellow	160	4.5
	300	4.5
	500	3.5
Black	160	4.5
	300	4.5
	500	4
Red	160	3.5
	300	3
	500	3
Blue (L)	160	4
	300	4
	500	3.5
Green	160	4
	300	3.5
	500	3
Orange	160	3.5
	300	2
	500	1

Conclusion and Future work

Ink jet printing on PET benefits from a fabric pretreatment step, whether disperse dyes or organic pigments are used in the inks employed. This enhances fiber receptiveness for the inks, leading to increased color intensity and color gamut. In addition, expansion of the standard CMYK color combination (inkset) to 7 (disperse dye-based systems) or 8 (pigment-based systems) significantly increases the color gamut, as would be anticipated. Pigment-based inksets and disperse dye-based inksets bring advantages and disadvantages to the table. In this regard, the particulate nature of pigments can lead to superior light fastness over disperse dye-based inks. In the present study, the disperse dye based inksets did not give satisfactory light fastness at 300-500 h exposure levels, unlike the pigment systems. On the other hand, the inability of pigment particles to diffuse into the fibers during the fixation step can lead to crock fastness problems. Compared with the pigment inksets, the disperse dye inksets provided deeper color shades on PET, the L* of black color was much lower in Inkset type F than in Inkset type L, which would be helpful in increasing the color intensity for the prints, when using the black ink individually, or when mixing it with other colors.

It should also be noted that the high temperature heat-setting process can cause fabric shrinkage – requiring a preshrinking step. For disperse dye inks, a wash-off step is required to remove surface dye that adversely affects color fastness.

The fastness properties of the inksets used in this study merit further study with various photostabilizers and polymeric binders to enhance disperse dye lightfastness and pigment crockfastness, respectively. Of interest would be to determine whether optimum results are obtained in a pretreatment or post-treatment step.

References

[1]. Kan CW and Yuen CWM. Research Journal of Textile and Apparel 2012, *16,* pg.2.

[2]. Gupta S. Indian journal of fibre a textile research 2001; *26*, pg.156.

[3]. Dawson TL and Hawkyard CJ. Review of Progress in Coloration and Related Topics 2000; *30,* pg.7.

[4]. Cie C. Ink Jet Textile Printing. Cambridge, UK, 2015.

[5]. Ujiie H. Digital printing of textiles, Woodhead Publishing, 2006.

[6]. Hees, U., Freche, M., Kluge, M., Provost, J., & Weiser, J., Society of Dyers and Colourists, Bradford, 2004, pg.44.

[7]. DPInnovation.com. RipMaster Manual 2013.

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