Comparison of Textile Print Quality between Inkjet and Screen Printings

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Abstract

This research investigated cotton print qualities by inkjet printing and screen printing. The acrylic binder, S-711, with a pigment-to-binder ratio of 1:2 by weight were used to produce one set of inkjet ink whereas BR-700 for another set of screen ink. Fume silica was added to the screen ink to increase its viscosity. Viscosity and flow behavior of both inks were acceptable. Both ink viscosity and particle size distribution were slightly increased during ambient storage for two months. The inkjet ink printed fabrics were pretreated with a solution of poly(ethylene oxide) having 2 to 3 million Dalton molecular weight. The printed fabrics from both inks were analyzed for color saturation, color gamut and its volume, density, tone reproduction, stiffness, air permeability, and crock fastness. Both inks have the same color saturation and color gamut, and ink tone reproduction. The color gamut volume, stiffness, air permeability, and crock fastness of the inkjet inks are superior to those of screen inks. The crock fastness of inkjet inks was superior to the screen printing ink, the print qualities of inkjet printing on cotton fabric are thus better. However, the printed cotton fabric needed to print three times to produce the same color and tone reproduction.

Introduction

Traditionally, textile inks are often printed by a screen printing process. One of the disadvantages of screen printing is machine efficiency and tedious wash time. Inkjet ink inherits many advantages due to its simplicity and mass customization. To overcome these disadvantages including machine downtime, textile printing by inkjet printing has been predicted as a trend for textile production in the new millennium because inkjet textile printing offers easy technologies and benefits. Therefore, it is worthwhile to investigate print qualities of cotton fabric printing by inkjet ink in comparison with screen ink using the same pigment dispersion.

Experimental

Preparation of Non-treated Cotton Fabric

Unfinished cotton fabric was washed with soap, then cleansed with water and dried at ambient atmosphere. The dry cotton fabric was ironed to gain a flat and smooth surface.

Preparation of Pretreated Cotton Fabric

Poly(ethylene oxide) (PEO from Meisei Chemical Works, Kyoto, Japan) 3 wt% was slowly added into de-ionized water and stirred by a magnetic stirrer at 50°C until it became a clear solution. The non-treated cotton fabric was cut into an A3 size backed by a flat plastic sheet suitable for screen printing. The non-treated cotton fabrics were padded with the pretreatment solution to obtain a 100 % pick up using a padding machine (Tsuji Dyeing Machine Mfg, Osaka, Japan). The padded cotton fabrics were dried in an oven at 80°C for 10 min. The pretreated cotton fabric was cut into an A4 size, which was taped with a double-sided sticky tape onto a smooth and flat plastic surface as a backing material of a uniform thickness for inkjet printing.

Preparation of Aqueous-Based Pigmented Inks

Inkjet Ink

The recipe for the pigmented inkjet ink composed of 4 wt% of each pigment dispersion (cyan, magenta, yellow, and black from Mikuni Color Works, Himeji, Hyogo, Japan), 10 wt% diethylene glycol, 15 wt% glycerin, and 16.49 wt% acrylic binder (S-711) with a binder-to-pigment ratio fixed at 2 to 1. They were added sequentially in de-ionized water with a continuous agitation. Sodium hydroxide solution was added to the ink to adjust the solution pH to around 9. The ink was then filtered through a filter of 0.5 nm mean pore size. The coarse particles were thus eliminated to prevent clogging of the print head.

Screen Ink

The recipe for the pigmented screen ink is formulated as follows: Pigment dispersion 10 wt% (cyan, magenta, yellow, and black from Mikuni Color Works, Himeji, Hyogo, Japan), BR-700 acrylic binder (Mikuni Color Works Himeji, Hyogo, Japan) with a binder-to-pigment ratio fixed at 2 to 1, fume silica (Degussa, Frankfurt, Germany), and NK-faster-MEG catalyst (acrylic emulsion, Shin-Nakamura Chemical Co. Wakayama, Japan) were each added into a glass beaker with vigorous stirring to become homogeneous.

Inkjet Printing

Cyan, magenta, yellow, and black inks were printed on the padded cotton fabric using a modified Stylus 3000 inkjet printer from Seiko Epson. The printer was calibrated according to the manufacture instruction. The test forms were applied and printed with Adobe Photoshop program without any color matching function and resolution of 1,440 dpi. To obtain a saturated optical density of the prints, triple-pass printing at the same area was carried out. After printing, they were dried in an oven at 100-120°C for 10 min.

Screen Printing

The non-treated cotton fabric was printed by screen printer. The pigmented inks of cyan, magenta, yellow, and black inks were sequentially printed. After printing, they were heated to dry and to fix the ink film at 100-120°C for 10 min.

Characteristics of Binder and Inks

Viscosity, surface tension, particle size, glass transition temperature and young modulus of the binder were characterized by the conventional techniques, mentioned elsewhere.

Characterization of Printed Cotton Fabric

Absorption of inks on cotton fabrics, its stiffness, crock fastness of the printed cotton fabric, and air permeability were characterized by standard test methods. Surface morphology of cotton fabric was sighted and photographed by scanning electron microscopic technique.

Color Measurement

Color values of the printed cotton fabric: cyan, magenta, yellow, green, blue, red, and black were measured by a spectrophotometer.

Results and Discussion

Characterization of Binders and Inks

Both binders, S-711 and BR-700 have T_g values of 13.9 and 4.2 °C with corresponding moduli of 246 and 222 MPa at 25 °C, respectively. This implies that both binders are elastic and exhibit viscous deformation. BR-700 has a low T_g value and low modulus indicating that it is more flexible, which is ideal for screen printing in which the highly viscous ink is used. Surface tension of the cyan, magenta, yellow and black inkjet inks was 40.8, 40.3, 41.3, and 41.3 mN m^{-1}, respectively. Inkjet ink used is quite stable. The initial particle sizes of pigment dispersion of cyan, magenta, yellow, and black and S-711 were 98, 177, 200, 132, and 161 nm, respectively. The average particle size in the range of 80 to 300 nm is acceptable for inkjet ink nozzle printing. The ejections of these inks with S-711 were very good, because no discontinuous streaks were observed indicating best ink ejection and printability. At the initial three weeks, little increase in viscosity was observed because changes in particle size were rarely detected. A steady state could be resulted from the non-interaction environment because S-711 binder is non-ionic polymer dispersion, whereas the pigment dispersion is ionized. Any interaction between the binder and the pigment dispersion in the ink system could not be possible. The flocculated state might be build up in ink at rest. Soft settlement could be easily reincorporated into solution by simple shaking. The pigment particles can then be effectively dispersed by the dispersant so that there is no irreversible agglomeration to increase pigment particle size. Screen ink is of high viscose so that particle size is easy to stabilize.

Rheology of Inkjet Ink

The viscosity of inkjet inks determined at the temperature of 25°C is 5.1, 4.9, 6.3, and 4.6, mP s, respectively. The inkjet ink is characterized as somewhat Newtonian fluid due to a relatively constant viscosity at various shear rates. The flow curves show slightly decreased in apparent viscosity with increasing rates of shear indicating a characteristics of shear thinning. The particle aggregation occurred in a colloidal system, an increase in shear rate will tend to break down the aggregates, which will result, among other things, in reduction of amount of solvent immobilized by the particles, thus lowering the apparent viscosity of the system. However, the ink is still of the Newtonian fluid, because their viscosity is converted a little. The inkjet ink is thus the Newtonian fluid, which preserves a constant viscosity negligent of shear rate.

Rheology of Screen Ink

The fume silica was added in the preparation of screen inks to obtain the ink viscosity in the range of 4.2 to 5.3 Pa s. The increasing viscosity gives the non-linear viscosity behavior, since surface of fume silica is fully hydroxylated. When mixed with a hydrophilic polymeric binder, a particle-molecule interaction occurred. This will lead to bonds creating a three-dimensional network structure. This structure ruptures easily, when the dispersion is subjected to shear over an extended time.[1] The decrements of viscosity of the screen ink were observed with increasing shear rate indicating characteristics of pseudo plastic behavior with a yield value. Besides, the yield value depends on the presence of forces between the particles, either second valence forces or electrostatic forces. The phenomenon has been linked with the assumption of a degree of structure in the fluid[1] in which fumes silica induces a particle-molecule interaction, thus initial curve represented high viscosity. Then, increment of shear rate will tend to break down of a three-dimensional network structure and of molecular orientation, which result in drop of viscosity.

Print Quality

After a preliminary test printing, we found that inkjet ink needs to print three passes repeatedly on the same area to obtain the same density of screen ink. The color gamut volume of these two inks is shown in Table 1 in which the gamut volume of the treated fabric is much higher than those of non-treated and screen printed fabrics. PEO receiving polymer can fix the ink color on its surface otherwise the ink can penetrate into the cotton fabric by capillary flow, which is expressed by Lucas-Washburn equation.[2]

Table 1. Color Gamut Volume of Inkjet Ink and Screen Ink

Type	*Color gamut volume*
Inkjet, Non-treated	
One-pass printing	5193
Inkjet, Treated	
One-pass printing	5667
Three-pass printing	6330
Screen, Non-treated	5498

Color

Ink color saturation S_{uv} of the inkjet inks was almost equivalent to those of screen ink as shown in Table 2. The pre-treated fabrics as expected gave the higher color saturation because it prevents excessive ink spreading owing to deposition of the treating agent on the fiber surfaces to reduce porosity between inter-fiber voids. Usually, penetration of ink causes hue shift, smaller color gamut and saturation reduction.

As mentioned above, inkjet inks have very low viscosity and thus they penetrate much deeper into the fabrics, therefore the amount of pigment of inkjet inks deposited on the fabric surface was much lower than those of screen ink. The amount of pigment on the fabric surface reveals spectral power reflectance of the fabric. This led to the lower color saturation and narrower color gamut of inkjet inks. Only the green boundary of the screen ink was narrower. However, the color gamut volume of screen ink has a lower value than that of inkjet inks as shown in Figure 1 (a, b and c for color gamut in xy chromaticity, CIE a*b* coordinates and chroma and lightness relationship). The viscous screen ink often blocks the screen mesh, which cause non-smooth ink flow during printing and poor color reproduction.

Tone Reproduction and Density

Tone reproduction of the both cotton fabric printed by inkjet and screen ink, are nearly similar. Densities of the print at 80 to 100 % original of the screen ink were higher than those of the inkjet ink, since the inkjet ink has the lower ink viscosity than screen ink. As described earlier, the inkjet ink penetrates better into the fabric fiber, while the screen ink penetrates much less. This fluidity and penetration produce different ink film thickness on the fabric surface. Consequently, the more the ink holdout, the higher the ink density and saturation. The yellow color inkjet ink has a higher ink viscosity, thus the ink produces smaller-sized droplets to give less ink on the fabric surface. The optical density of the yellow color inkjet ink is therefore lower.

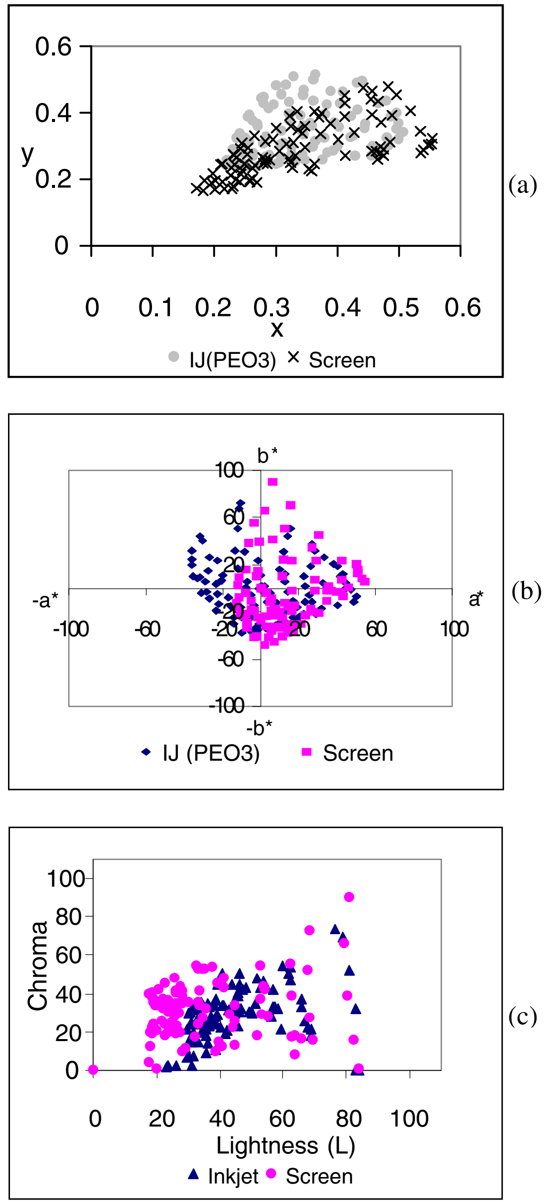

*Figure 1. Color gamut in (a) xy chromaticity coordinate, (b) CIE a*b* coordinate, and (c) chroma and lightness.*

Table 2. Color Saturation of Inkjet Ink and Screen Ink

Type	S_{uv}					
	C	**M**	**Y**	**R**	**G**	**B**
Inkjet						
• Non-treated (One-pass printing)	4.15	5.02	5.51	5.39	5.78	4.12
• Treated						
- One-passing printing	4.17	5.17	6.32	5.78	5.81	4.17
- Two-pass printing	4.27	5.20	6.34	5.88	5.82	4.26
- Three-pass printing	4.98	5.40	6.43	5.91	5.83	4.39
Screen						
• Non-treatd	3.66	6.03	6.51	6.21	4.92	3.65

Table 3. The Bending Length and Stiffness of Printed Cotton Fabric by Inkjet and Screen Inks

Color	Bending Length (cm)			Stiffness (mg cm)		
	IJ 1	IJ 3	Screen	IJ 1	IJ 3	Screen
Cyan	2.52	3.08	3.15	220.5	407.6	507.3
Magenta	2.55	3.10	3.18	223.4	410.5	532.2
Yellow	2.48	2.84	3.68	210.5	320.0	804.9
Black	2.53	3.07	3.47	233.2	427.7	687.3

IJ 1 and IJ 3 are one- and three-pass printing, respectively, on the same area.

Printed Fabric Properties

Stiffness

The increment of bending length of the fabrics indicates the effect of treatment and direction of fiber structure on bending length effect. The stiffness is the ability of a material to resist deformation. The bending length value can indicate the stiffness of fabrics. The high bending length value means the higher stiffness of fabric. In the case of a yarn subjected to a tensile force or pull, stiffness is thus the ability to resist elongation. It is more customary to express the flexural of the printed fabric in terms of stiffness by the following equation:

$$G = W \times c^3 \tag{1}$$

where G = flexural rigidity, mg cm; W = fabric mass per unit area, mg cm^{-2}; c = bending length, cm. Table 3 shows the results of bending length and stiffness. One can find that the higher the bending length, the greater the stiffness.

The pretreatment PEO did not affect the stiffness value; hence, the bending length depends on the ink. Additionally, the result further indicates the increment of bending length on MD of the printed cotton fabric after printing with inkjet and screen inks**.** The stiffness value of printed cotton fabric with inkjet ink was lower the printed cotton fabric by screen ink. The triple-time printing of inkjet gave the higher amount of inkjet ink on the cotton fabric, which was in agreement with the amount of screen ink. Furthermore, the higher amount of inkjet ink gave the high increment of bending length or gave more stiffness to the printed fabric because of the higher modulus of the binder in inkjet inks. Modulus is a fundamental measure of the stiffness of the material. As mentioned previously, the BR-700 binder and S-711 binder gave a modulus range of between 700 ≥ E (MPa) ≥ 70 that is defined as semi-rigid with some elasticity.[3] The two films are similar in stiffness.

Air Permeability

Pigmented inkjet and screen inks were printed on the treated and non-treated cotton fabric, respectively. The pretreatment reagent did not affect air permeability because the aqueous polymer, PEO, the density of the deposits is not high enough but due to the nature of the fabric structure, the deposits contribute to the construction of the inter-fiber spaces. Therefore, the fabric treated with the aqueous PEO polymer gave the better result of the air permeability. The air permeability depends on the characterization of ink deposited on the cotton fabric. The harder the ink film, the lower the air permeability.

Conclusions

Inkjet ink and screen ink with the same pigment dispersion were prepared and characterized. The inkjet ink with acceptable properties are pH of 8-9, viscosity of 4.6–6.3 mPa s, surface tension of 40–41 mN m^{-1}, pigment particle size of 98–200 nm, binder particle size of 111 nm to give the Newtonian flow with good and smooth ejection. No agglomeration or significant increases in particle sizes were observed. For screen ink, non-Newtonian behavior was observed for the short and buttery–like viscosity of 4.2–5.3 Pa s. The number of passes in printing and the pretreatment agent control the color and quality of inkjet printing. At least three-pass printing on the pretreated cotton fabric is needed to produce high color gamut, color gamut volume and color saturation. The pretreatment agent did not affect stiffness value and air permeability due to penetration and deposition into the fibers. The stiffness depends on the amount of ink deposited on the printed areas. Screen ink give the lower air permeability and crock fastness of the fabric than those of inkjet ink because of the thicker ink film deposition on the fabric surface. Toner reproduction of both inks was nearly the same.

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Biography

Suda Kiatkamjornwong received her B.Sc. degree in Chemistry and M.Sc. in Physical Chemistry from Chulalongkorn University, Thailand in 1970 and 1972, respectively; and Ph.D. in Polymer Science and Engineering from Lehigh University, U.S.A. in 1983. She is now the Head Department of Imaging and Printing Technology where she is a full professor in Polymer Science. She is the recipient of many awards such as the outstanding professor of Chulalongkorn University for teaching and research, Outstanding Science Faculty alumnus; Outstanding National Researcher Award in chemical and pharmaceutical sciences. Her research interests are hydrogel, imbiber beads and imaging polymer.