IMPROVING UV PROTECTION OF COTTON FABRICS THROUGH DIGITAL TEXTILE PRINTING

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Abstract

Protection of the skin from harmful UV rays is an important consideration in the selection of fabrics for outerwear because of the rise in cases of skin cancer. Fiber composition, fabric porosity and color can significantly affect UV blocking properties. Digital textile printing is a unique method of coloration of textiles whereby fabric preparation parameters can be manipulated to improve the application of ink to maximize the coating effect of the inks. Ultraviolet Protection Factor (UPF) of a fabric provides a quantitative assessment for the amount of UV radiation blocked. Our study aimed to improve UPF of cotton fabrics by application of colorants via inkjet printing process and manipulation of structural change of the fabric to reduce fabric porosity and hence increase their UV blocking properties. Two major colorants were investigated to compare the performance of the printed goods in terms of their UV blocking property. Cotton fabrics were printed with piezo technique based ink jet printers: Mimaki GP 604 (pigment based inks) and Mimaki TX-2 (dye based inks). Four process colors Cyan, Magenta, Yellow and Black (CMYK) were selected to investigate individual color performance. UPF values of the printed goods and control fabric were measured by a spectrophotometer according to the AATCC test method 183-1999. All the printed and control fabrics were examined for their structures changes in the fabric porosity during printing process. This study provided valuable information on UV blocking property of digitally printed cotton fabrics to textiles professionals, designers and, customers.

Introduction

Exposure to UV radiation causes melanoma (a serious type of skin cancer), and inflammation of skin with consequences like erythema or sunburn. UV protection can be achieved by sunscreen lotions and sun-protective clothing which are designed to block UVA (320 – 400nm) and UVB (290 – 320 nm) radiations [5, 10]. Consumers generally consider light weight non-synthetic fabrics (such as cotton and linen) for summer wear because of their comfort properties. Bleached cotton fabrics were proved to be very transparent to UV radiation providing relatively low UV protection (approximately 23.7% UV transmission) whereas the same unbleached fabric had UV transmission of 14.4% due to the presence of natural pigments, pectin, and waxes which absorb UV light [2, 7, 9, 10]. Each colorant is unique in terms of its UV blocking ability. Variety of factors such as colorant type, molecular structure and their absorption characteristics, shade depth, and the uniformity influence the UV protection of textiles. Generally, the darker shades (such as black, navy, and dark green/red) significantly improve UPFs when compared to lighter pastel shades [6, 8, 11]. UV protection factor (UPF) describes the level of sun protection provided by fabrics, and it indicates the level that a fabric can block UV rays from reaching the skin. UPF has a scale ranging from 0 (worst) to 50 or 50+ (best).

The UPF of the specimen is calculated as follows:

$$\text{UPF} = \frac{\sum_{290}^{400} E_\lambda \times S_\lambda \times \Delta\lambda}{\sum_{290}^{400} E_\lambda \times S_\lambda \times T_\lambda \times \Delta\lambda}$$

where

E_λ : Relative Erythermal Spectral Effectiveness
S_λ : Solar Spectral Irradiance ($W.m^{-2}.nm^{-1}$)
T_λ : Spectral Transmittance of the Item
$\Delta\lambda$: Wavelength (nm)
λ : Wavelength (nm)

These UPF values must be determined by the AATCC Test Method 183 [1]. UV protective textiles, according to ASTM D 6544 [3] and ASTM D 6603 [4] will be labeled with a UPF. A label UPF value is equivalent to mean UPF calculated for a set of sample observations less the standard error for that sample set. The calculated value is then rounded down to the nearest 5 to produce a UPF label for a textile product (See Table 1) [5]. Digital printing technology is new in the textile industry and there is not much research done in terms of UV radiation blocking property of the printed fabrics. The objectives of this study are to explore the possibilities of improving UPF of cotton fabrics thru digital printing process and to investigate the effect of pre-treatment chemicals and colorants on UV blocking property of the cotton fabrics.

Table 1. UPF Classification System (AS/NZS 4339: 1996)

UPF Range	UVR protection category	Effective UVR transmission, %	UPF Ratings
15 - 24	Good	6.7 to 4.2	15,20
25 - 39	Very Good	4.1 to 2.6	25, 30, 35
40 - 50, 50+	Excellent	≤ 2.5	40, 45, 50, 50+

Materials & Methods

100% cotton broadcloth (bleached, mercerized, combed - style # 419 from Test Fabrics Inc.) was used for this study. Pre-treatment chemicals: Sodium Alginate – high viscosity type, Urea, and Soda ash (from Dharma Trading Co.) were used in this study. Reactive inks: Cyan, Light Cyan, Magenta, Light Magenta, Yellow, Orange, Grey, and Black and pigment inks: Cyan, Magenta, Yellow and Black (from Mimaki Inc.) were used in this study. AATCC 1993 Standard Reference Detergent WOB (without optical brightener) was used to wash the steamed fabrics.

Lab Pad 36" wide (Poterala Mfg. Co.) was used to pad the pre-treatment chemicals onto the fabric. The digital printers used in this study were Mimaki GP-604 and Mimaki TX2- 1600 which are pigment ink based and reactive ink based respectively. Jacquard bullet type steamer with atmospheric pressure set-up steamer was used in this study. Geo Knight Co Inc. (model K20S) heat press was used to cure the pigment printed fabrics. Kenmore 80 series washing machine and Kenmore Elite model dryer were used to wash and dry the samples respectively. Labsphere UV-1000 series UV Transmittance analyzer was used to measure UPF values and all the color evaluations were performed by X-Rite Color i5 spectrophotometer. Fabric structures were examined using Zeiss microscope (model AxioCam HRc).

Pre-treatment for reactive printing

The concentrations of the pre-treatment chemicals were: alginate (0.8%), urea (10%), soda ash (4%) and water (85.2%). The quantity of the pre-treatment liquor needed for 1 yard of fabric was 500 grams and all the ingredients were blended thoroughly to produce lump-free solution, which was then padded onto the fabric. The optimum padding process parameters (roller pressure and roller speed) used in this study were 20 psi and 40 rpm respectively. These conditions were determined based on our previous study, which was aimed to determine the optimum padding process parameters to achieve higher shade depths in digitally printed cotton fabrics.

Printing and post-treatment

Four basic colors: cyan, magenta, yellow and black were printed using both pigment and reactive based printers. The color values were Cyan (C=100%, M=Y=K=0%), Magenta (M=100%, C=Y=K=0%), Yellow (Y=100%, C=M=K=0%), Black (C=M=Y=K=100%). The print options set were bi-directional with 4 passes and 720 x 720 dpi resolution and maintained consistently for both the printers. Pigment printed samples were cured at 220F for 1 minute. Reactive printed samples were steamed at 212F for 30 minutes. Steamed samples were then washed through two 6-minute cold wash/drain cycles followed by two 6-minute hot wash/drain cycles. Then the samples were dried in a commercial dryer. The samples were then equilibrated in a conditioning chamber at 21°C and 65% relative humidity for 24 hours before they were evaluated for their color values.

UPF and Color Measurement

UPF values were determined according to AATCC test method 183-1999. Each sample was measured at 10 different areas and the mean UPF value along with UV transmission values in UVA and UVB regions were obtained. UPF rating is then calculated by the software according to AS/NZS 4399:1996. Color measurements were performed instrumentally according to AATCC Evaluation Procedure 6:2001 using X-Rite Color i5 spectrophotometer with D65 illuminant and 10° observer settings. The readings (L*, a*, b*) were taken in 3 different areas (warp, filling, and biased directions) and averaged. Shade depth (K/S), given at wavelength of the maximum absorption, was measured using Kubelka-Monk equation ($K/S = [1-R]^2 / 2R$), where R is spectral reflectance (%), K & S are sample's absorbance and scattering characteristics.

Fabric Porosity

Test specimens were examined with transmitted light microscope at 5x magnification for their structural changes during the pre and post printing processes.

Results and Discussion

Table 2. Test results - UV related and Color related

Sample ID	Mean UPF	UPF rating	Category	Transmission, %		Mean COV, %	K/S
				UVA	UVB		
Control	5.36	0	Non-ratable	26.39	15.46	3.16	0.18
Control Treated	7.21	5	Non-ratable	21.97	11.77	5.05	0.24
Control Washed	4.67	0	Non-ratable	28.35	17.77	2.04	0.18
Pigment Cyan	13.95	10	Non-ratable	9.36	6.67	5.64	2.31
Pigment Magenta	17.46	15	Good	9.03	4.94	3.90	4.14
Pigment Yellow	15.02	10	Non-ratable	7.31	6.03	2.33	4.77
Pigment Black	19.17	15	Good	6.64	4.75	3.75	3.33
Reactive Cyan	40.12	40	Excellent	2.87	2.39	3.71	15.39
Reactive Magenta	42.37	40	Excellent	3.14	2.21	4.54	18.17
Reactive Yellow	31.36	30	Very Good	4.30	2.72	6.83	17.22
Reactive Black	52.13	50+	Excellent	2.31	1.81	1.72	20.56
Reactive Cyan Washed	41.73	40	Excellent	2.74	2.32	1.38	18.45
Reactive Magenta Washed	39.75	40	Excellent	3.46	2.34	2.30	16.75
Reactive Yellow Washed	28.15	25	Very Good	5.20	2.87	6.30	15.25
Reactive Black Washed	42.43	45	Excellent	2.83	2.20	7.84	18.17

Control fabrics (unwashed and washed) have 'non-ratable' UPF rating which indicates their sheer transparency towards UV radiation. Pre-treated control fabric showed improvement in UPF rating (still non-ratable) but not significant enough to fall under UV protection classification. The chemicals, alginates and urea, added during padding process absorb UV radiation and thus decreasing UVR transmission through the fabric. Post-treatment in reactive printing removes loose surface dyes as well as pre-treatment chemicals which in turn lowers the UPF value of the printed fabric.

UV blocking properties of pigments and reactive ink printed fabrics are better than control fabrics. Magenta and black colors in pigments produced 15 UPF rating, which falls under 'GOOD' UVR protection category. Both the unwashed and washed reactive printed cotton fabrics performed better than control and pigment printed fabrics. Cyan, Magenta, and Black produced excellent UV protection with UPFs ≥ 40 (See Table 2). There is a significant difference between pigment based inks and reactive inks in terms of their UV blocking performance. Pigments have better lightfastness properties when compared to reactive dyes because of their large molecular size, however, proper binders should be selected to boost their UV blocking ability. On the other hand, reactive dyes are smaller in size and number of dye molecules per specific area is higher compared to pigments which reflect in their higher UPF values.

Microscopic examination of control fabrics (original, pre-treated, washed) did not show any considerable difference in fabric porosity (Refer Figures 1 thru 3). This reflected in almost no change in their UPF values. From the remaining sets of fabrics, cyan colored samples were selected for comparison and further analysis. Pigment printed cyan fabric surface revealed its dull shade and the surface coloration process where as reactive ink printed samples had bright, saturated shades with higher K/S values (Refer Figures 4 thru 6, and Table 2). It was also observed that the dye penetration is deeper in case of reactive prints compared to pigment prints which influence their UVR transmission values.

Figure 1. Photomicrograph of control fabric at 5x magnification

Figure 2. Photomicrograph of control treated fabric at 5x magnification

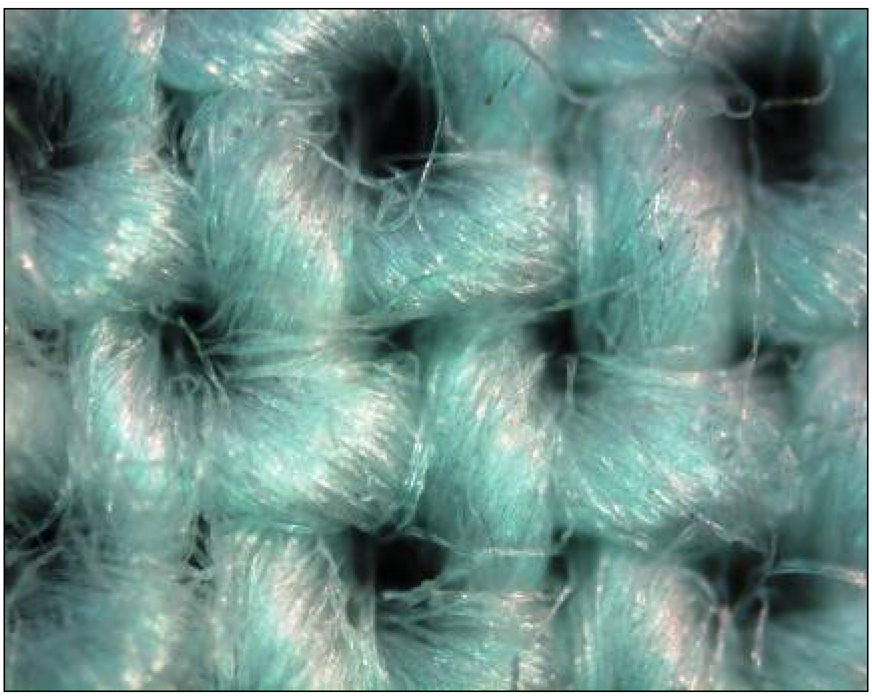

Figure 3. Photomicrograph of control washed fabric at 5x magnification

Figure 4. Photomicrograph of pigment based cyan printed fabric, at 5x magnification

Figure 5. Photomicrograph of reactive based cyan printed fabric, at 5x magnification

Figure 6. Photomicrograph of reactive based cyan printed and washed fabric, at 5x magnification

Summary

Digital printing of cotton fabrics and its effect on UV blocking property is studied and discussed. Reactive printed fabrics showed excellent UV protection when compared to control and pigment printed fabrics. Selection of binders is critical to improve UPF values of pigment printed fabrics.

Pre-treatment chemicals in case of reactive printing absorb UV radiation improving UPF values of the fabrics but not significant enough to qualify under UV protection classification. Multipurpose pre-treatment chemicals which can act as thickeners in padding liquor as well as UV absorbers would be ideal combination to improve UV protection of cotton fabrics.

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