Effect of Padding Parameters on Shade Depth and Dye Penetration of Digitally Printed Cotton Fabrics

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Abstract

This study determined padding process parameters that influence the shade depth (K/S, color strength) of the inkjet printed fabrics. Three roller speeds (20, 40, and 60 rpm) and six roller pressures (5, 15, 20, 40, 60, and 70 psi) were studied. The fabric samples were padded through liquor (formula: 0.8% alginate, 4% sodium hydroxide, 10% urea, and 85.2% water, all concentrations in w/w) in a one-dip-one-nip procedure with wet pickup ranging from 84.9% to 99.0%. Padded samples were printed with a piezo-technique based Mimaki TX-2 printer, post-treated, and evaluated for their color. Optimum shade depth was obtained at a combination of 20-psi roller pressure and 40-rpm speed.

Introduction

Color shade depth is an important factor in determining acceptability of textile fabrics. Digital textile printing is a relatively new technology in the textile and apparel industry that allows for computerized designs to be instantly printed onto fabric in the needed amounts [1]. To achieve desirable color characteristics in digital textile printing, processing parameters have to be carefully determined. Digital textile printing cannot be achieved on any fabric because printing directly onto a substrate requires the fabric be chemically pre-treated to ensure optimum dye penetration and color vibrancy. The chemical pre-treatment is best applied using a padder consisting of rollers [2].

Rollers have been used in conjunction with textile printing for years. Roller printing was once a major method for commercial printed fabric production but its use has decreased greatly with the development of more modern printing technology. In roller printing, the final result depends on the efficiency of machine operation and control and the accuracy of the roll preparation [3]. These practices also are relevant when padding fabric for digital textile printing. Fabric preparation is critical to the appearance and colorfastness of the final printed product.

Fabric preparation for digital printing includes the padding solution and the fabric pre-treatment process for printing. The padding solution or chemical pre-treatment varies according to fiber chemistry and end-use requirements. The proper padding solution is applied to clean scoured fabric, which is free of impurities and must be applied evenly and be completely absorbed by the substrate. Using a padder to apply the chemical pre-treatment produces the best results, although other techniques can be employed such as briefly soaking the fabric in the solution [2] or coating the fabric with solution through light spraying. Exposure to the chemical treatment will produce a colorfast fabric.

The quality of print in inkjet printing is greatly dependent on the interaction between the ink and the media (substrate) [4]. Reactive ink is one of the most widely used dyes for digital printing on cellulosic fibers, such as cotton. These inks react with cellulose in the presence of alkali (NaOH) and electrolyte (NaCl) to form cross-linked compounds that are insoluble in water. It is important to remove the residual dyes that have not penetrated into the fiber. Because of the cross-linking, reactive ink printed fabrics tend to have good colorfastness characteristics [5]. Therefore, a quality print would then be one with optimal color consistency and colorfastness throughout the entire design, which is the goal of digital textile printing. Occurrences of poor quality or color inconsistency in printing have been linked to printing at different times, on different machines, and printing on large dimensions of the fabric [6]. Although color inconsistency may be attributed to matters related to certain printing parameters, it may possibly be associated with pre-treatment of the fabric. More research is needed to determine the dye penetration during digital printing process which ultimately affects shade depth or color strength of the final print. The overall goal of this study is to determine optimum padding process parameters such as padding roller speed and pressure to achieve higher shade depths with good colorfastness properties in digitally printed cotton fabrics.

Experimental

Materials

Cotton (100%) double-knit fabric was used for this study. Pre-treatment chemicals: Sodium Alginate – high viscosity type, Urea, and Sodium Carbonate were used in this study. Reactive inks: Cyan, Light Cyan, Magenta, Light Magenta, Yellow, Orange, Grey, and Black were used. AATCC 1993 Standard Reference Detergent WOB (without optical brightener) was used to wash the steamed fabrics.

Equipment

A 36” wide padder with variable speed and pressure was used to apply the pre-treatment to the fabric. Mimaki TX-2 printer (a piezo technique based printer) with eight refillable ink cartridges (cyan, light cyan, magenta, light magenta, yellow, orange, grey, and black) was used for printing the fabric. Jacquard bullet type steamer with atmospheric pressure set-up steamer was used for steaming the fabrics. Kenmore 80 series washing machine and Kenmore Elite model dryer were used to wash and dry the samples respectively. Color evaluations were performed by X-Rite Color i5 spectrophotometer.

Padding

The padding formulation was adapted from North Carolina State University. The concentrations of the chemicals are given in Table 1. The ingredients were weighed and blended to produce a smooth consistent, lump-free padding pretreatment solution which was then poured into reservoir. The fabric was submerged in the solution, and then passed through the squeeze to remove the excess solution. The samples were air dried by laying them flat over night.

Table 1. Padding formulation (per one yard of fabric)

Ingredient	*Quantity (gms)*	*Concentration (w/w%)*
Alginate	4	0.8
Urea	50	10
Soda ash	20	4
Water	426	85.2

Six roller pressures (5, 15, 20, 40, 60, and 70 psi) and three roller speeds (20, 40, and 60 rpm) were studied to find out an optimum combination of these two parameters to achieve higher shade depth values and an optimum dye penetration. It is important to control the dye penetration into the fibers during printing as it affects over all shade depth of the printed goods. Wet pick-up for all the roller pressure and speed combinations was also measured to determine the optimum quantity of the chemicals to add during padding process in order to achieve the required shade depth and dye penetration.

Printing

The pre-treated fabrics were loaded onto Mimaki TX-2 digital textile printer. Four sets of color bands cyan, magenta, yellow, and black (Table 2) were printed and air dried. The print options selected were: resolution 720 x 720 dpi, bi-directional with 4 passes.

Table 2. Color details

Color	*Values*
Cyan	C=100%, M=Y=K=0%
Magenta	M=100%, C=Y=K=0%
Yellow	Y=100%, C=M=K=0%
Black	C=Y=M=K=100%

Post-printing

The printed samples were steamed using atmospheric pressure type bullet steamer. The samples were steamed for 30 minutes, which was determined for optimum colorfastness through our previous study. Steamed samples were 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.

Color Measurement

Color strength values of the printed fabrics were measured instrumentally according to AATCC Evaluation Procedure 6:2001 [7] using the X-Rite Color i5 spectrophotometer. Each sample was evaluated at three different areas (warp, filling and bias direction) and average value was taken as the final reading. As samples were single layered, two additional layers of the same shade (which were cut from the same printed fabric) were backed up to avoid any dispersion through the fabric sample during measurement. Dye penetration can be quantified by measuring color strength values on reverse side of printed fabrics. Samples were evaluated for their shade depth (K/S value), given at the wavelength of the maximum absorption. The Kubelka-Monk equation is roughly linear with respect to colorant concentration (dye content).

$$K/S = [1-R]^2 / 2R \quad (1)$$

where, R is spectral reflectance, expressed in %, K & S are sample's absorbance and scattering characteristics respectively.

Statistics

Three replicas were used for each of the conditions and an average was reported. Each of these replicas was sampled from different warp and filling yarns according to standard fabric sampling.

Results and Discussion

The wet pick-up values ranged from 84.6% to 99.8%. Figure 1 shows the trend in wet pick-up percentage which decreased as the roller pressure increases. The values got saturated beyond 40 psi indicating that higher roller pressures (60 and 70 psi) is not required as they do not affect wet pick-up values. The high pressure region (including 40, 60, and 70 psi) has more variations among all the roller speeds (20, 40, and 60 rpm) in terms of their wet pick-up (Refer Figure 1) which indicates that roller pressures (40 psi and above) may not be ideal for achieving consistent wet pick-up which ultimately reflect in final shade depth of the prints.

Shade depth (K/S) values measured on face or printed side represents actual color strength of the printed fabrics. Shade depth on back or reverse side represents a rough approximation of dye penetration onto the other side of the print.

Effect of roller pressure

It is important to add an optimum amount of pre-treatment liquor to achieve prints with higher shade depth values. Lower roller pressures reflected in higher wet pick-up values (Refer Figure 1) which are not favorable to produce bright shades. These conditions add higher amounts of alginate (acts as dye migration preventer during printing) and urea (absorbs water/moisture during printing or post-printing) which interferes with dye diffusion into the fibers and causes dye hydrolysis respectively producing lighter shades of the prints.

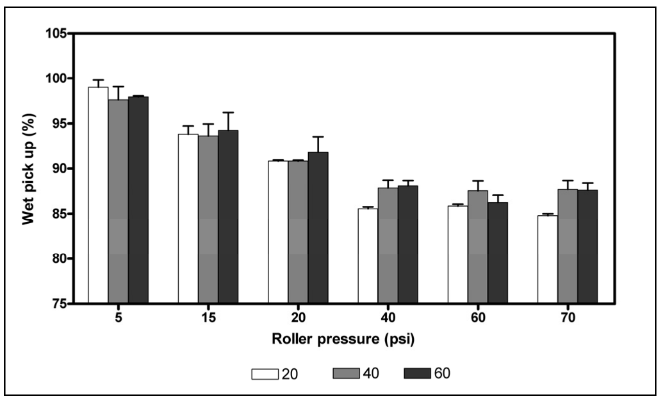

Figure 1. *Wet pick-up data (average of two specimens)*

Higher roller pressures (40, 60, and 70 psi) are not recommended as they had consistency problems in terms of percent add-on (wet pick-up) of the pre-treatment liquor. Among the studied roller pressures, 20 psi was observed to be an optimum pressure to achieve maximum shade depth values in all the four colors (Refer Figures 2, 4, 6, & 8). This phenomenon is related to the optimum wet pick-up of pre-treatment solution during padding process.

Effect of roller speed

Among the roller speeds studied, 20 and 60 rpm produced lower shade depth values when compared to 40 rpm. Lower speed (20 rpm) condition applies relatively higher pre-treatment liquor which hinders the dyes to penetrate into the fabric. Also, slower speeds are not productive in the industrial set-up.

On the other hand higher roller speed (60 rpm) had deeper dye penetration values (higher K/S values on reverse side of the prints, Figures 3, 5, 7 & 9), which should be avoided to achieve brighter shades. Therefore it is very important to set-up the roller speed at an optimum value (which is 40 rpm in this study) to achieve higher shade depth values.

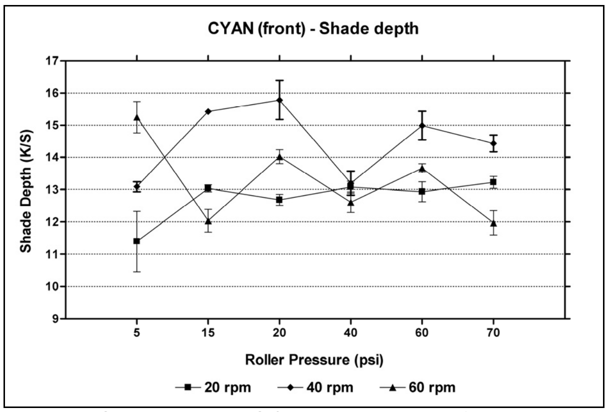

Figure 2. *Shade depth (K/S face side) values in 'cyan'*

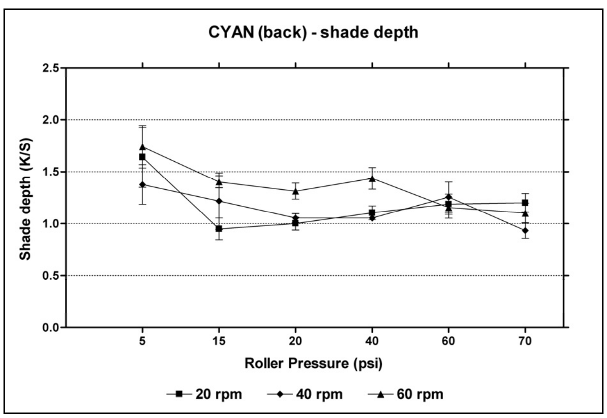

Figure 3. *Dye penetration (K/S back side) in 'cyan'*

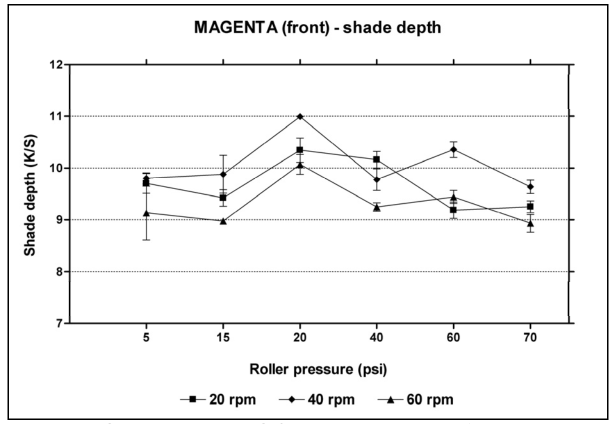

Figure 4. *Shade depth (K/S face side) values in 'magenta'*

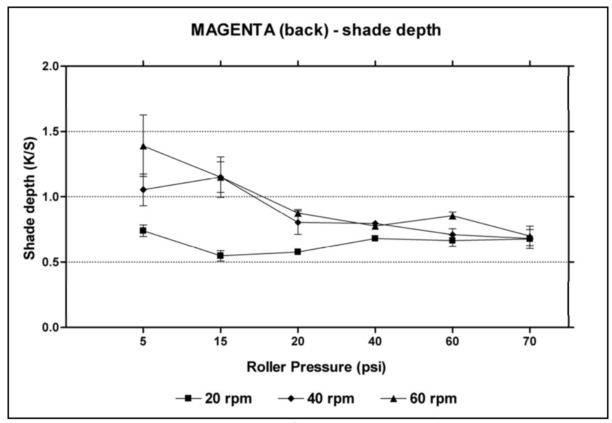

Figure 5. *Dye penetration (K/S back side) in 'magenta'*

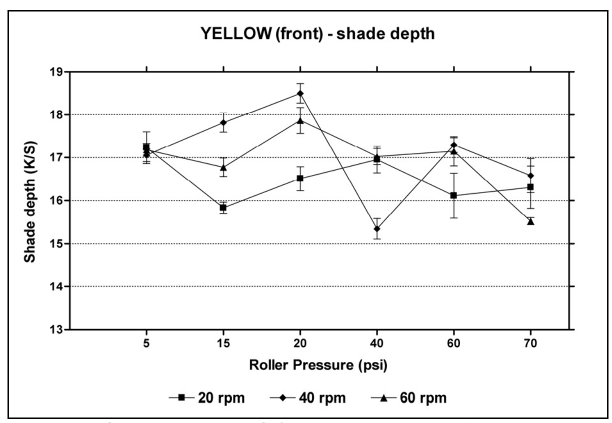

Figure 6. *Shade depth (K/S face side) values in 'yellow'*

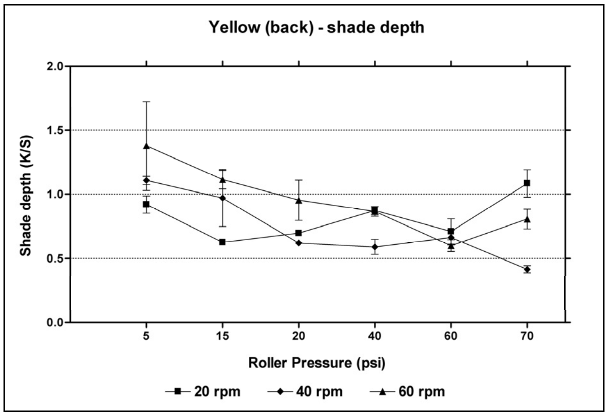

Figure 7. *Dye penetration (K/S back side) in 'yellow'*

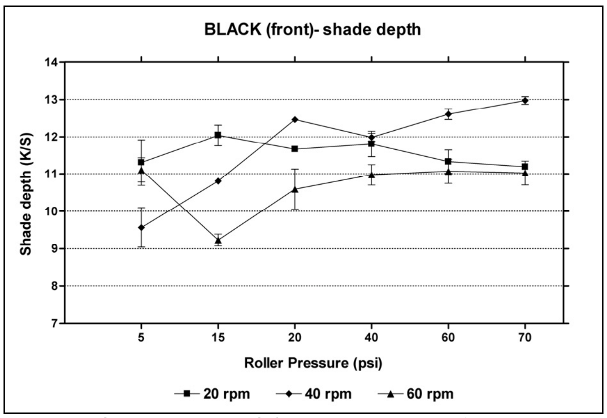

Figure 8. *Shade depth (K/S face side) values in 'black'*

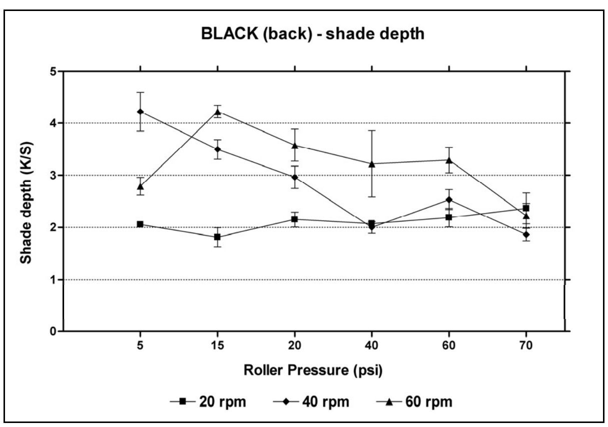

Figure 9. *Dye penetration (K/S back side) in 'black'*

Conclusions

Padding process parameters including roller pressure and roller speed play an important role in achieving brighter shades in digitally printed cotton fabrics. Among the studied roller pressures, 20 psi was found to be an optimum condition which produced not only higher shade depth values but also consistent results in terms of wet pick-up during pre-treatment process.

Also, 40 rpm was observed to be an optimum roller speed which avoids deeper dye penetration as well as surface application of colorants to obtain dark and bright prints. Observing the shade depth values of cyan, magenta, yellow and black colors, it is evident that the combination of roller pressure of 20 psi and roller speed of 40 rpm is the optimum padding process parameters to achieve higher shade depths with minimal consistency problems.

Acknowledgements

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Author Biography

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