Color Reproduction Capability on 100% Cotton Fabrics Using Dye-Sublimation Heat Transfer Printing

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Abstract

It is well known that dye sublimation inks are designed to bond with polymers. In the textile industry, however, the most common printed textiles are made of cotton and cotton blends. 100% cotton accounts for approximately 45% of the textile market. Recent developments in heat transfer paper carrier made it possible to use heat transfer printing on 100% cotton fabrics. Color reproduction capability of a heat thermal print is highly related to the amount of dye transferred. To achieve high dye transfer efficiency and obtain the best color reproduction capability, three primary parameters, heat transfer temperature, dwell time in the heat zone, and pressure, need to be taken into account. The main purposes of this experimental study are: first, to identify the most important factors that influence color reproduction on 100% cotton fabrics using heat transfer printing; second, to establish optimum process operating conditions so that the maximum yield of color gamut and optical density could be obtained. The experiment was conducted using a randomized 2^3 *factorial design in which every factor was run at two specified levels (1 = high level, -1 = low level). The factorial levels were determined based upon the practical operating conditions of the heat transfer press. Three independent factors in this study are: dwell time in the heat zone* (X_1)*, transfer temperature* (X_2)*, and pressure* (X_3)*. Color reproduction capability was evaluated in terms of optical density and gamut volume. It was found that pressure* (X_3) *is the dominant factor affecting color reproduction on 100% cotton fabrics.*

Introduction

The most common and well-known use of cotton fabrics is in textiles and clothing apparel. Some of the best properties of cotton fabric include high absorbency, resistance to heat, resistance to static, and strength and stability. Many times, cotton is combined with other fabrics in order to obtain better properties and to cut down on the cost of cotton fabric[1]. While clothing is the most common use of cotton, it is also being used in carpeting and rugs because it is easy to dye and wears better than some other fabrics commonly used for carpeting[2].

Dye sublimation heat transfer printing technology has been developed for textile printing for many years[3]. In the heat transfer printing process, the required image is first printed onto a paper carrier (can be done by either screen printing or ink-jet printing) using dye inks, which comprise sublimable dyes. Then the paper carrier is brought into intimate contact with textile fabrics, through a heated press. The paper carrier releases a color dye when heated, and the dyes sublime and diffuse into the fabric, permanently coloring it. Although digitally printed textile technology draws a lot of attention recently, this simple, flexible process still offers many advantages, such as quietness, low price, ease of color reproduction, reduced post processing, and low maintenance requirement. The textile thermal transfer printing method has been expanding into an increasing number of applications with its dry process and quick output digital image data[4, 5].

With heat transfers, the printed ink film must be brought up to a “gel” state in order to transfer to the textile and bond well with the textile fabric. To achieve high dye transfer efficiency, an intimate and sufficient contact is required between the heat transfer press and the paper carrier, and between the paper carrier and the textile, to ensure efficient heat transfer across the interfaces and high activity of dye diffusion from the dye layer of the paper carrier to the dye-receiving layer of the textile fabric. Paper carrier is coated in order to help the paper withstand the high temperatures and high pressures used in heat transfer printing. The coated paper carrier used for heat transfer is found to have better ink holdout, improved ink tone/gloss reproduction, and ink absorption that is more uniform than uncoated paper. This type of paper is made to release as much of ink as possible onto the object that is being printed on using heat transfer. The most important properties of coated paper carrier are a smooth surface, high opacity, high brightness, sufficient mechanical strength to withstand the stresses of printing, and a pore structure that interacts effectively with printing ink. All of these properties of coated paper help to enhance the transfer process and can also contribute to better color reproduction.

Three primary parameters for controlling heat transfer are the heat transfer temperature, the dwell time in the heat zone, and the pressure. Any unexpected variations in these three variables can adversely affect the quality of the finished product. In order to get good adhesion and a durable applied print, these three parameters need to be taken into account and need to be well defined. Depending on the type of textile being used, the optimum parameters for a specific textile material need to be established. For example, a fine dress fabric would be printed using the highest temperature compatible with the fiber, with a relatively short dwell time in the heat zone to give a well-defined print on the surface of the fabric. Conversely, a needle punch fabric where dye penetration is important, the temperature would be below optimum, and the time dwell increased to hold the dyes in the vapor form longer to assist penetration[4, 5, 7]. Previous study shows that heat transfer temperature and dwell time are the two dominant key factors affecting color reproduction on polyester fabrics[8]. Recent developments in heat transfer paper carrier made it possible to use heat transfer printing on 100% cotton fabrics. The purpose of this study is to identify the most important factors that influence color reproduction on 100% cotton fabrics using heat transfer printing and to establish optimum process operating conditions. Establishing the optimum parameters will help predict and control color reproduction for heat transfer printing on 100% cotton fabrics.

Experimental

This study utilizes a randomized 2^3 factorial design which contains eight treatment combinations (Table 1). The run order for the eight treatment combinations was randomly generated by computer (randomized design) to reduce bias introduced by unplanned changes in the experiment. Five observations were systematically recorded for each of the eight treatment combinations for a total sample size of 40.

Table 1: 2^3 Factorial design

	Long Dwell Time		Short Dwell Time	
	Low Temperature	High Temperature	Low Temperature	High Temperature
Low Pressure				
High Pressure				

Factors	Factor Level	
	-1	1
Dwell Time (X_1):	25 seconds	35 seconds
Temperature (X_2):	380°F	400°F
Pressure (X_3):	60 psi	100 psi

A digital four-color test chart was designed for this study. The test chart included a TC 2.83 RGB test target designed for X-Rite i1iO Spectrophotometer and photographic images. The list of the equipment and materials used in this work is presented as follows.

- Textile media: 100% cotton fabrics.
- Heat transfer paper: i-Trans™ Paper from LRi/Laser Reproductions Inc.
- Ink-jet printer: Epson Stylus Pro 4880 printer with dye sublimation inks.
- Heat transfer press: DC16AP press from Geo Knight & Co Inc.

The designed test target was first printed onto i-Trans™ transfer paper by using Epson Stylus Pro 4880 ink-jet printer. The printed transfer paper was brought into contact with 100% cotton fabrics through the DC16AP heat transfer press using eight different treatment combinations.

Color measurements were taken using an X-rite i1iO Spectrophotometer with illuminant D65 and a 10-degree observer for textile prints. The measurement files were used to generate ICC profiles with ProfileMaker Pro 5.0.8. The color gamut was then determined by using CHROMiX ColorThink Pro 3 software. The color reproduction capability of 100% cotton fabrics was evaluated in terms of optical density and color gamut. The software package employed to analyze the data was Minitab 14.0.

ANOVA and Regression Analysis

ANOVA and Regression statistical procedures were employed to determine the main effects of the independent variables and their interaction effects on the color reproduction capability. The significant level was set to be .05 for all the analyses, i.e., $\alpha = 0.05$. The full model derived from 2^3 the factorial design is:

$$\hat{Y} = \alpha+\beta_1X_1+\beta_2X_2+\beta_3X_3+\beta_4X_1X_2+\beta_5X_1X_3+\beta_6X_2X_3+\beta_7X_1X_2X_3+\varepsilon,$$

where X_1 = dwell time, X_2 = temperature, and X_3 = pressure.

Figures 1 to 5 illustrate the main effects plots for the optical density and color gamut. It shows the dominant factor for color reproduction on 100% cotton fabrics is pressure (X_3), because its significance is ranked at the top on the optical density and color gamut attributes.

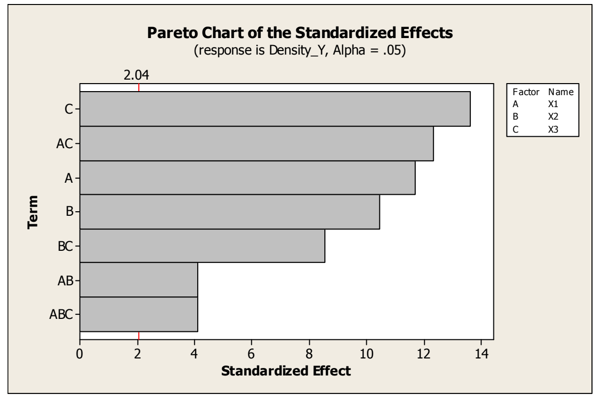

Figure 2: *Main effects plot for the optical density of yellow.*

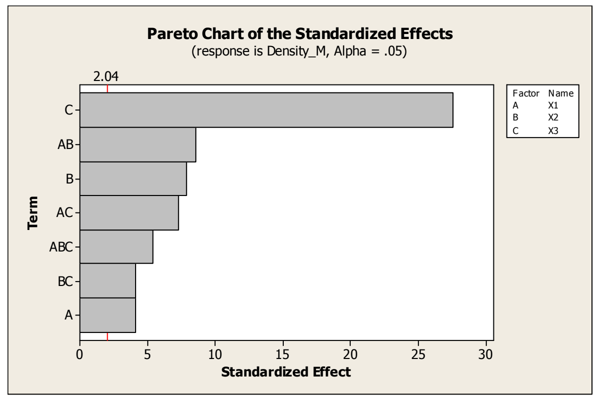

Figure 3: *Main effects plot for the optical density of magenta.*

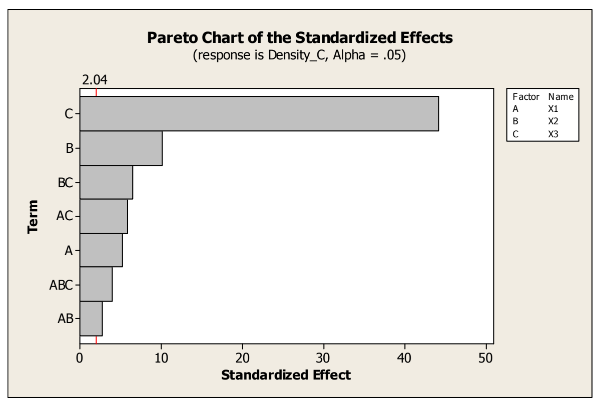

Figure 4: *Main effects plot for the optical density of cyan.*

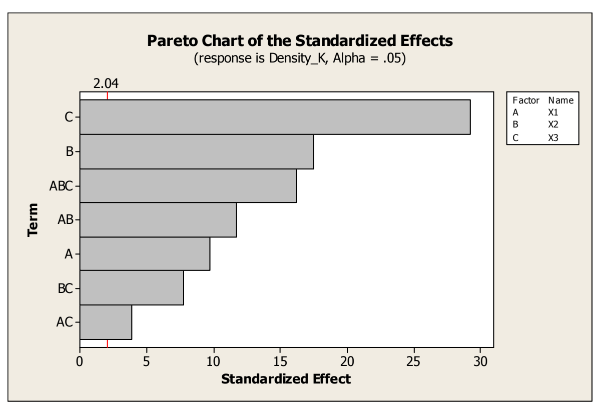

Figure 5: *Main effects plot for the optical density of black.*

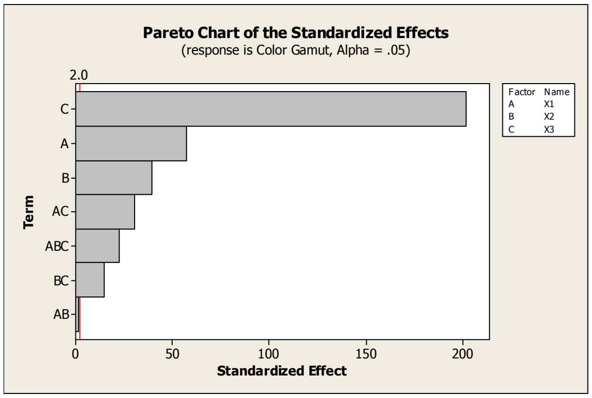

***Figure 6:** Main effects plot for the color gamut.*

Table 2 shows the ANOVA and Stepwise Regression summary for the main and interaction effects on the optical density and color gamut. The treatment combination of $(X_1, X_2, X_3) = (1, 1, 1)$ is suggested to achieve the maximum yield of optical densities of yellow, magenta, and cyan. In other words, the highest dye transfer efficiency was achieved when the dwell time was 35 seconds ($X_1 = 1$), heat transfer temperature was 400°F ($X_2 = 1$), and the pressure was 100 psi ($X_3 = 1$) on the DC16AP heat transfer press. The treatment combination of $(X_1, X_2, X_3) = (-1, 1, 1)$ is suggested to achieve the maximum yield of color gamut, while the treatment combination of $(X_1, X_2, X_3) = (-1, -1, 1)$ is suggested to achieve the maximum yield of optical density for the black. The R^2 values in Table 2 indicate that the prediction model explains approximately 94% to 99% of the total variability in optical densities and color gamut.

Table 2: Summary of ANOVA and regression analyses

	Optical Density				Color Gamut
	Yellow	Magenta	Cyan	Black	
Significant Level	α = 0.05	α = 0.05	α = 0.05	α = 0.05	α = 0.05
Significant Effects	$X_3 = 0.0215$ $X_1X_3 = 0.0195$ $X_1 = 0.0185$ $X_2 = 0.0165$ $X_2X_3 = 0.0135$ $X_1X_2 = 0.0065$ $X_1X_2X_3 = -0.0065$	$X_3 = 0.0435$ $X_1X_2 = 0.0135$ $X_2 = 0.0125$ $X_1X_3 = -0.0115$ $X_1X_2X_3 = -0.0085$ $X_2X_3 = 0.0065$ $X_1 = 0.0065$	$X_3 = 0.0715$ $X_2 = 0.0165$ $X_2X_3 = 0.0105$ $X_1X_3 = 0.0095$ $X_1 = -0.0085$ $X_1X_2X_3 = 0.0065$ $X_1X_2 = 0.0045$	$X_3 = 0.045$ $X_2 = -0.027$ $X_1X_2X_3 = 0.025$ $X_1X_2 = -0.018$ $X_1 = -0.015$ $X_2X_3 = 0.012$ $X_1X_3 = 0.006$	$X_3 = 20204$ $X_1 = -5750$ $X_2 = 3963$ $X_1X_3 = 3035$ $X_1X_2X_3 = 2268$ $X_2X_3 = 1453$
Prediction Equation	$0.711 + 0.00925 X_1 + 0.00825 X_2 + 0.0108 X_3 + 0.00325 X_1X_2 + 0.00975 X_1X_3 + 0.00675 X_2X_3 - 0.00325 X_1X_2X_3$	$1.42 + 0.00325 X_1 + 0.00625 X_2 + 0.0218 X_3 + 0.00675 X_1X_2 - 0.00575 X_1X_3 + .00325 X_2X_3 - 0.00425 X_1X_2X_3$	$1.15 - 0.00425 X_1 + 0.00825 X_2 + 0.0358 X_3 + 0.00225 X_1X_2 + 0.00475 X_1X_3 + 0.00525 X_2X_3 + 0.00325 X_1X_2X_3$	$1.43 - 0.0075 X_1 - 0.0135 X_2 + 0.0225 X_3 - 0.009 X_1X_2 + 0.003 X_1X_3 + 0.006 X_2X_3 + 0.0125 X_1X_2X_3$	$230266 - 2875 X_1 + 1982 X_2 + 10102 X_3 + 1518 X_1X_3 + 726 X_2X_3 + 1134 X_1X_2X_3$
Best Treatment Combinations	X_1= 35s X_2= 400°F X_3= 100 psi (1, 1, 1)	X_1= 35 s X_2= 400°F X_3= 100 psi (1, 1, 1)	X_1= 35 s X_2= 400°F X_3= 100 psi (1, 1, 1)	X_1= 25 s X_2= 380°F X_3= 100 psi (-1, -1, 1)	X_1= 25 s X_2= 400°F X_3= 100 psi (-1, 1, 1)
Estimated Max. Value	0.76	1.45	1.21	1.47	243,599
R^2	94.6%	96.2%	98.2%	97.8%	99.9%

Color Reproduction Capability Comparison

Table 3 displays the color reproduction capability comparison for 100% cotton, cotton/polyester blend, and polyester fabrics. It shows that polyester fabrics yield highest gamut volume and tend to have higher density for yellow and cyan. Cotton/polyester blend fabrics, on the other hand, produce higher density for magenta and black. Overall, 100% cotton yields lower optical density and gamut volume, compared to other fabrics using heat transfer printing.

Table 3: Color reproduction capability comparison

		Cotton	Blend	Polyester
Density	Y	0.71	0.82	0.88
	M	1.42	1.45	1.33
	C	1.15	1.32	1.49
	K	1.43	1.46	1.37
Color Gamut		230,265	259,827	291,021

Conclusions

The dye particles used in the dye sublimation inks are designed to bond with polymers, so that the higher the polyester content in the material, the more dye will bond with material, producing a brighter image. Recent developments in heat transfer paper carrier made it possible to use heat transfer printing on 100% cotton fabrics. We found that pressure (X_3) is the dominant key factor affecting color reproduction on 100% cotton fabrics. However, the optimum parameters for observed print attributes are varying. Unlike paper carrier used for polyester fabrics, the heat transfer paper used for 100% cotton fabrics demonstrated variations during the heat transfer printing process. In addition, the optical density levels and gamut volume of heat transfer on 100% cotton are not competitive with polyester or cotton/polyester blend fabrics. To achieve high dye transfer efficiency and obtain better color reproduction capability, effort must be taken to continuously improve the quality of paper carrier.

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