Journal of Imaging Science and Technology® 67(2): 020410-1–020410-14, 2023.

Analysis of Color Measurement Methods for Single-sided and Double-sided Digital Printing with Silk Fabrics

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Abstract. *Digital printing is a new technology that combines innovative design with cutting-edge technology, and it represents a breakthrough in the field of dyeing and finishing. Silk is the most widely used medium among double-sided digital printing industry. Owing to the gaps caused by different weaving methods, silk products are generally translucent and loose in structure, therefore, the color measurement of textile fabrics also has the same problem as that of translucent materials. The final color visualization is the result of combining the fabric yarn color with the voids in the area, which make it difficult to directly measure the colors of the printed fabrics with traditional spectrophotometer. The color measurement method of double-sided digital printing was always vague, and the difficulty of measuring the color of double-sided digital printing is increased for silk, a translucent material. In this paper, sixty colors of different hues, chroma and lightness are printed on four different types of silk fabrics in order to solve this industry problem. The L* (Lightness), a* (Red/Green) and b* (Blue/Yellow)values of each color layer were measured after stacking the four types of fabrics from one to multiple layers respectively and placing them on top of a standard white board and a standard black board as a backing, respectively, to calculate the color difference between the actual color and the design color of the silk fabric, as well as the color difference before and after stacking. The fabric properties and color properties that influence fabric color measurement are then investigated. The results show that thickness is the most important factor influencing fabric color measurement, and during measuring thin fabrics, multiple layers need to be overlaid. The effect of gloss on the number of layers in fabric color measurement is inversely proportional. The b* value is not significantly correlated with color measurement, whereas L* and a* are positively correlated with the number of layers when measuring color. Moreover, based on the fabric thickness, gloss, L*, a* and b* value, the regression model was proposed, and a color measurement method suitable for silk fabrics with different fabric properties and color properties is proposed.*
[DOI: 10.2352/J.ImagingSci.Technol.2023.67.2.020410]

Received June 20, 2022; accepted for publication Sept. 29, 2022; published online Oct. 28, 2022. Associate Editor: Min Xu.

1062-3701/2023/67(2)/020410/14/$25.00

1. INTRODUCTION

Double-sided digital printing technology is evolving, particularly in the silk sector, with Hermes and other worldwide high-end fashion companies launching double-sided digital printing of silk scarf items. Direct spraying is now used in silk double-sided digital printing. The surface properties of a silk product are dictated by their fabric properties (thickness, feel, gloss, etc.) as well as their color attributes.

Most silk products in the market are light and delicate, the design that enhances the fabric structural qualities and printing colors can increase the competitiveness of silk products [1]. Silk textiles' physical properties are dictated by its interweaving regulations. The fabric is made of colored warp and weft yarns interwoven in a specific law, and the structure of the textile can be highly diverse depending on the interweaving laws, resulting in weaves that lead to different properties in the printing and subsequent color measurement of the fabric [2]. When using a spectrophotometer to measure color, the transmission of light due to the pores between the yarns resulting from the interweaving of the fabric, the reflected light collected by the integrating sphere will not be entirely provided by the object itself, but will be mixed with the reflected light from the incident light passing through the gaps and hitting the backing materials [3]. As a result, this issue occurs for color measurement of textiles as it does for transparent materials. When combined with the complex color schemes and patterns of silk printed textiles, sometimes, even a dozen proofs are necessary to generate a product that achieves the intended color effect [4].

In weaving practice, the final result is frequently appraised aesthetically rather than statistically. For example, the coloring result in the woven structure is compared to the original result by a distant observation, resulting in an optical mixing of light reflected by different colored threads [5].

Textile color quantification measurement technologies are still in their infancy. The majority of current textile color measurement instruments employ spectrophotometers, which detect information about the spectral energy distribution on the surface of an object by irradiating the sample with incident light at a specific angle and collecting the reflected light from the sample's surface via a sensor. In reality, the structure of the fabric properties (e.g., fabric yarn material, fabric weaves, warp and weft density, etc.), color properties (lightness, etc.), and backing material all have a significant impact on the measurement [6].

As a result, the process of color measurement after each proof being printed on silk is very difficult. The current method is to measure the color by layering the material in numerous layers until it is light impermeable and then measuring the color [7]. In reality, the influence of different fabric characteristics on color measurement before and after overlay measurement varies significantly and the reflectivity of the backing material utilized has a considerable impact on the color measurement. When creating a silk product, having a set of color measurement solutions for its fabric qualities and color properties available during the proofing stage can assist the designer in swiftly determining the difference between the proof color and the design color and making design revisions. As a result, it is critical to have a tried-and-true design solution for all types of silk textiles.

Current color measurement methods consider thickness as a factor in color measurement, as two to four layers are required for knits or woven materials in order to prevent the undesired reflection of light on the background. An opaque material layer will lead to an accurately measured value, but thin or light textiles could require more layers. In some cases, a single layer on top of a white tile could be used for comparison purposes, as the reflectance component can be ignored.

But in addition to thickness, fabric structure and texture also has a strong influence on the measurement performance. The crimp and gloss owing to the weaving of yarns have an important influence to transmission property of fabrics, and textile materials have an important directional feature, due to positions of yarns.

In this research, four distinct textiles with varying hues, chromas, and gray scales are chosen for single-sided and double-sided printing to investigate the color measuring technique for various fabric properties and colors.

2. EXPERIMENTAL DESIGN

2.1 *Printing Color Design*

In this research, both single-sided and double-sided heterochromatic printing colors were designed to explore the influence of color characteristics on the color measurement of silk fabrics. Single-sided printing: Following incorporating the printing machine's ICC color profile provided by Hangzhou Honghua Digital Technology Co., Ltd after color calibration [8], six hue variations of R, G, B, C, M, Y, six gray scale gradient variants, and three chroma variations of cyan, yellow, and magenta were chosen within the printing machine's color gamut. The L*a*b* values of the selected colors are shown in Table I.

In the changes of gray scale, the maximum lightness is 90, the minimum lightness is 15, and the chroma value is 0. The six colors' gradient lightness change is 15, The chroma changes of cyan, yellow, and magenta is the maximum saturated color of that hue in the printer's color gamut and colors at 75%, 50%, and 25% of that chroma. Each hue (C, M, and Y) has four chroma levels.

The double-sided printing colors are composed of six different hues (R, G, B, C, M, Y), which are paired in groups respectively, as the front and back side of the print; the serial number 1–6 in Table I are choose as the hue color.

Considering the influence of the reactive dye properties and sizing agent on the printing coloring [9], the printing colors were selected from the ICC color gamut of the same printing machine. The fabrics were sized, printed and finishing in the same batch with the technical supports of Hangzhou Honghua Digital Technology Co., Ltd.

2.2 *Printing Fabric Selection*

In this experiment, four different thicknesses and fabric tissues of silk textiles were chosen for digital printing. Table II displays the fabric structure.

The two different thicknesses represent the fabric's yarn fineness and warp and weft density; the higher the fabric thread density per unit area, the more fiber roots, and the smaller the gap space between the yarns; and the pore space of the fabric has the most direct effect on its light transmission. The three fabric weaves generated by the varied interweaving laws of yarn are variables in this research. Different fabric weaves will cause the curvature between yarn bending, different undulation height, which controls the flatness of the fabric yarn and surface gloss. When light strikes a fabric, it is reflected, refracted, and transmitted several times between and inside the fibers. When the undulation between fibers varies, it affects the angle and direction of the fibers with respect to the incident light, as well as the interference of light created between fibers, resulting in variable final reflected light patterns [10]. The variation in glossiness reflects the distribution of reflected light and light intensity on the fabric's surface [11]. Various elements are investigated in terms of control variables in this research in order to develop parameters impacting fabric color measurement accuracy and specialized color measurement methods for different silk textiles.

2.3 *Experimental Procedure*

Color measuring instrument: KONICA MINOLTA CM-700d portable spectrophotometer.

Experimental lighting condition: standard D65 light source.

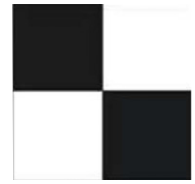
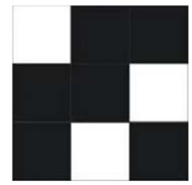
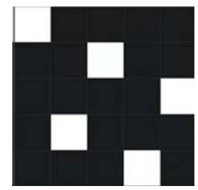
The standard white board used for the color measurement meets the following conditions: (1) Strong chemical and mechanical stability, and its spectrum reflectance stated during usage stays stable. (2) High level of diffuse reflectance. (3) The spectrum reflectance is higher than

Table I. L*a*b* values of the selected colors.

	Serial number	Color	L*	a*	b*
Hue variations	1		50	69	54
	2		50	−52	26
	3		32	16	−47
	4		60	−39	−43
	5		50	69	−3
	6		85	−5	86
Gray scale	1		15	0	0
	2		30	0	0
	3		45	0	0
	4		60	0	0
	5		75	0	0
	6		90	0	0
Chroma variations	1		66	−30	−35
	2		67	−22	−27
	3		74	−15	−19
	4		84	−8	−10
	5		57	62	−3
	6		65	49	−4
	7		74	35	−8
	8		84	19	−2
	9		88	−5	78
	10		88	−5	58
	11		88	−4	36
	12		88	−2	15

90% at all wavelengths, with a similar spectral reflectance at 360–780 nm. The following requirements are met by a standard black board: (1) Strong chemical and mechanical stability, and its spectral reflectance remains constant during

Table II. Fabric structure.

Serial number	Fabric thicknesses/mm (momme)	Weave	Weave structure
1	8	Plain weave	
2	16	Plain weave	
3	16	Twill	
4	16	Stain	

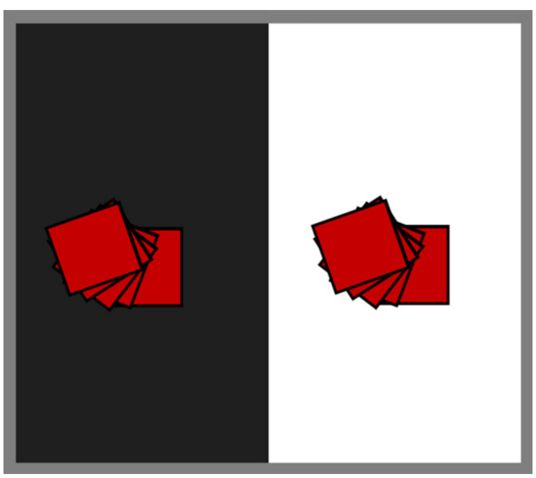


Figure 1. Schematic diagram of measurement method.

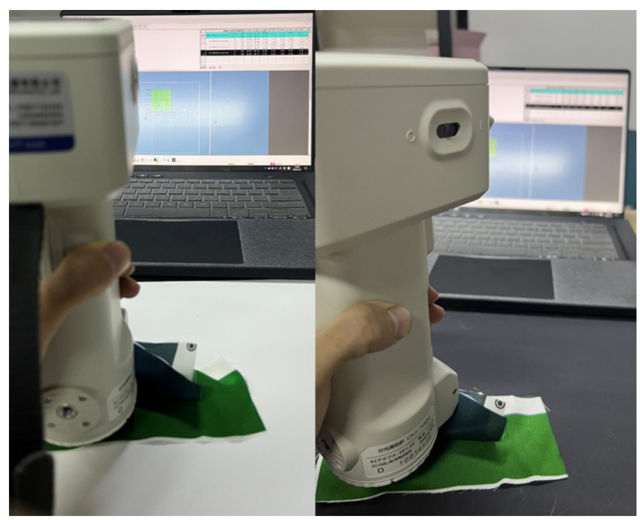


Figure 2. Fabric color measurement process (when stacked with one layer).

usage. (2) High diffuse reflectance performance. (3) The spectrum reflectance is lower than 5% at all wavelengths, with a similar spectral reflectance at 360–780 nm. The fabric is stacked successively with one to multiple layers (five to six layers), placed on a black board and a white board respectively, and the L*a*b* values on both sides are measured using a spectrophotometer for different layers. Figure 1 depicts the measuring procedure schematically, and Figure 2 depicts the real cloth color measurement process. When measuring the color, it is ensured that the fabric measurement area is as flat as possible.

The L*a*b* values of different stacked layers are recorded during the color measurement when the fabric is measured on the standard white board (liner total reflection) and the standard black board (liner total absorption), and the number of stacked layers is recorded when the fabric is measured on the same color on the two liners. Following the completion of the color measurement, the actual color of the fabric and the design color difference, black board and white board circumstances before and after the fabric overlay color difference are calculated using ΔE_{00} (CIE2000) color difference formula. The factors influencing fabric color measurement are examined under actual color measurement

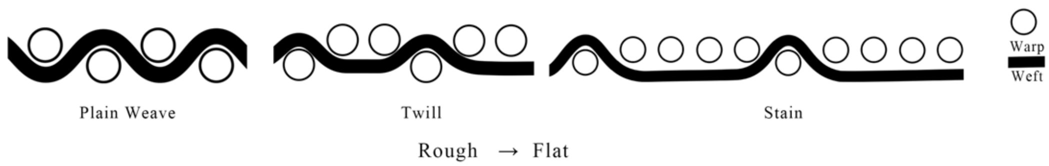


Figure 3. Structure of the cross-sectional view of three different weaves.

Table III. Thickness and glossiness of the fabric.

Serial number	Weave	Fabric thicknesses/mm (momme)	Gloss (60°)/Gu
1	Plain	8	2.97
2	Plain	16	2.57
3	Twill	16	4.35
4	Satin	16	3.74

settings, and a regression model for estimating the number of overlapping layers in fabric color measurement is presented.

3. EXPERIMENTAL RESULTS AND ANALYSIS

The flatness between the threads and the glossiness of the surface are fabric characteristic that are impacted by fabric weave. The flexure and undulation of the interweaving between the yarns dictate the flatness of the fabric, and Figure 3 depicts the cut surface structure of three distinct tissues. The cross-sectional view shows that the continuous floating length between the yarns of the plain tissue is less and the undulation is greater, resulting in the most uneven fabric, whereas the continuous floating length between the yarns of the satin tissue is greater and the undulation is less, resulting in the flattest fabric.

In addition to flatness, gloss is also influenced by the fabric weave. This research also measured the gloss of four textiles used in the experiment. Table III displays the gloss value at a light angle of 60°. From the table it can be seen that all four fabrics are low gloss materials. The luster of the 8 momme (mm) plain fabric is higher than that of the 16 momme plain fabric. In the same thickness of the three textiles, gloss of twill fabric is highest, gloss of satin is second highest, and the gloss of plain fabric is the lowest, but the difference between the three glosses is not prominent.

3.1 *Analysis of Single-sided Printing Results*

In the single-sided printing section, the "color difference with designed color", the before-and-after-stacking color difference", and the "number of layers" are calculated after completing the color measurement of four fabrics. The color difference formula used for calculating the color difference is ΔE_{2000} color difference formula. The calculation results are shown in Table IV.

Mean color difference value of all measured colors with designed color is shown in Figure 4. The standard white board is used as a backing to simulate the conditions where total light transmitted through the fabric is reflected during color measurement. Conversely, the standard black board was used as a backing to simulate the conditions where total light transmitted through the fabric is absorbed during color measurement. When measured with a standard white board as the backing, the average color difference between the four single-sided printed fabric and the target design color was lower than when measured with a standard black board as the backing material. However, it does not demonstrate that the standard white board as a color measurement backing material is more capable of measuring the real color of the fabric. Because the fabrics' own inter-yarn structure is loose and impermeable lightness is poor, the reactive dye quantity inked by the printing machine in the design color will not all fall onto the fabrics, resulting in the actual color chroma of the fabric being lower than the design color chroma. When combined with the subtractive mixing technique of inkjet printing and dyeing [12], the fabric is colored with less dye, resulting in an increase in overall lightness. In contrast, when the color is measured on a standard white board, the increase in reflected light collected by the integrating sphere leads to an increase in measured color lightness, which reduces the color difference between the measured color and the design color due to the nature of the total reflection of the standard white board. The color difference of all measured colors with designed color as shown in Fig. 4 is 11.00 when the color is measured on the black board and 7.68 when the color is measured on the white board, which is due to the fact that the 8 mm plain fabric has the smallest fabric thickness, low warp and weft yarn density, and loose fabric structure compared to the other three fabrics. When the color was measured on the white board, the backed white board provided more reflected light compared to the other three fabrics, making the overall lightness of the 8 mm plain fabric closer to the lightness of the design color.

3.1.1 *Effect of Fabric Thickness on Single-sided Printed Fabric's Color Measurement*

If the measured color after multi-layer stacking is essentially the same as the preceding layer ($\Delta E < 1$) [5], the measured color can be deemed independent of the fabric backing material. Figure 5 shows a comparison of (a): the average value of the color difference of layers after layer-by-layer stacking with the color of the previous layer and (b): the number of layers (average value) when the color measurement results are stable for two different fabric thicknesses single-sided printing color measurement. The following are the figure's common points: (1) In the standard black board color measurement, the color difference before

Table IV. Calculation results of single-sided printing color difference.

	Fabric thicknesses/mm (momme)	Weave	Color difference with designed color	Before-and-after-stacking color difference	Number of layers
Standard white board	8	Plain	7.68	3.30	4
	16	Plain	7.44	1.81	3
	16	Twill	6.27	1.25	2
	16	Satin	6.50	1.55	3
Standard black board	8	Plain	11.00	2.37	3
	16	Plain	9.29	1.50	3
	16	Twill	7.19	1.09	2
	16	Satin	7.83	1.52	2

* Note: The color difference with designed color refers to the average color difference value of all measured colors with expected printed color; before-and-after-stacking color difference refers to, after measuring all colors of the fabric from one layer to multiple layers, the average value of the color difference between each layer's measured color and the color of the previous layer. The number of layers refers to the number of layers stacked when the fabric is measured to be approximately the same color on both the standard white board and the standard black board, and the numbers are rounded to an integer.

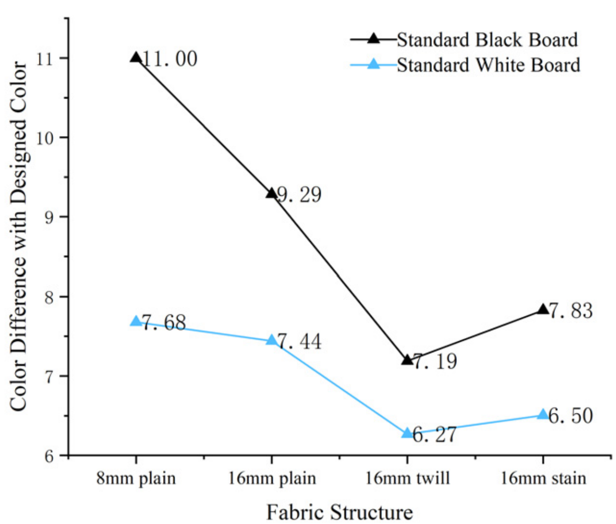


Figure 4. Color difference compared with the design color on two conditions of backing materials.

and after stacking is less, and the number of layers required to stack to provide consistent color measurement findings is also reduced. (2) Color measurement of two types of fabric with different thicknesses; 8 mm plain fabric, before and after stacking, has a higher average value of color difference than 16 mm plain fabric, and the number of layers required to accomplish stable color measurement is also more than 16 mm plain fabric. The fabric property that is dominated by the thickness of the fabric is opacity; 8 mm fabric has finer yarns and low density of warp and weft yarns, which lead to strong light transmission and low opacity. Therefore, more layers are needed to be overlaid when the actual color is measured for thinner fabric.

In Fig. 5(a) the color difference between 8 mm plain fabric before and after stacking is the highest in standard white board circumstances: 3.30. The color difference is about 1.49 compared to the standard white board condition of 16 mm fabric. Because the actual product is still a single layer of fabric, the color difference before and after stacking represents the fabric color measurement influenced by the liner material, but it also reflects the actual production of silk surface's color visual effect, so in the actual production, it is suggested to choose the fabric with less color difference before and after stacking. Fig. 5(b) shows two fabrics on the standard white board's color measurement; the 8 mm fabric requires about 1 more layer of overlap than the 16 mm fabric color measurement to obtain a stable color. When the color is measured on a standard black board, there are about 0.75 more layers. The conventional measuring procedure is to stack four layers and then measure the color [13], but the experimental findings show that 8 mm plain fabric requires more than 4 layers to measure the true color, but 16 mm plain fabric only requires about 3 layers. The number of layers stacked when the stable color is measured on the white board is about 0.5 layers more than the color measured on the black board for the 8 mm fabric, and the number of layers stacked when the stable color is measured on the white board for the 16 mm fabric is about 0.21 layers more than the number of layers stacked when the color is measured on the black board.

3.1.2 *Effect of Fabric Weaves on Single-sided Printed Fabric Color Measurement*

Different fabric weaves affect the dyeing in the printing process, and the weaves will have a demonstrable effect on color output in inkjet printing, whether assessed through instruments or perception [14]. Figure 6 shows the mean value of (a): the color difference from the preceding color layer after layer-by-layer stacking to (b): the number of layers stacked until the color measurement result is stable for single-sided printing color measurement of three types of distinct-weave fabrics. The common points of the folding graph shows: (1) Among the three materials, twill fabric has the lowest average value of color difference before and after stacking, as well as the fewest layers required to get reliable

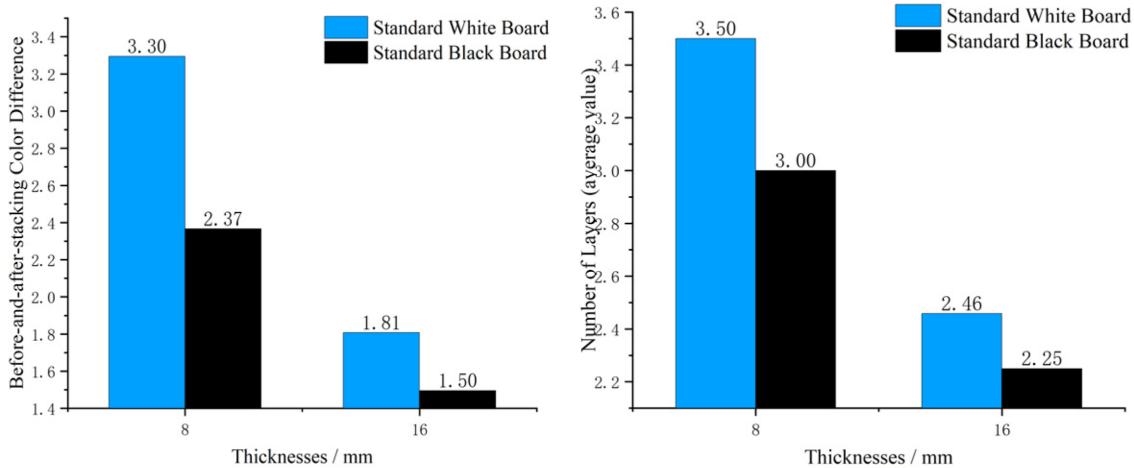


Figure 5. Color measurement results of single-sided printed fabrics with different thicknesses.

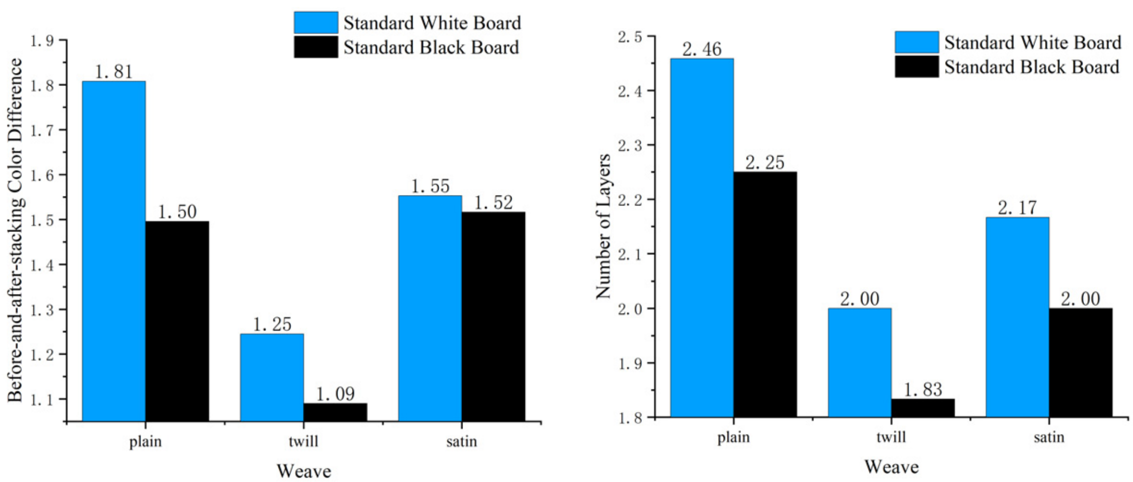


Figure 6. Color measurement results with different weaves.

color measurement results, followed by satin fabric, and lastly plain fabric. (2) As for color measurement of the three fabrics on the white board before and after multi-layer stacking, the average value of the color difference is greater than the color difference before and after the stacking on the black board.

Among the three types of weaves, twill fabric yarn has moderate flatness and the highest gloss, satin fabric has flat and consecutive yarn interwoven, with the gloss level lower than twill fabric, and plain fabric's gloss is the lowest and its yarn interwoven is the roughest. The results demonstrate that the stronger glossy fabric measured before and after the stacking color difference change is less, and the true color is measured when the number of layers required for stacking is reduced. When fabric was not overlapped, twill fabrics were closer to the true color than satin and plain fabrics.

3.1.3 *Influence of Fabric Properties and Color Properties on Single-sided Printed Fabric's Color Measurement*

The analysis of the graphical results above shows that thickness and fabric weave have an effect on the color measurement of the fabric, and this effect is consistent whether the backing is white board (total reflection) or black board (total absorption). Moreover, the same fabric printed with different colors in the experiment needs to be overlaid with different layers when measuring the color. It shows that the fabric color measurement is impacted not only by fabric characteristic (thickness, opacity, flatness, and so on), but also to a considerable extent by printing color characteristic (L*a*b* values). When measuring the different colors being printed, the different spectral reflectance of different colors, combined with the inconsistent amount of dye mixing when printing in different colors, results in different conditions for measuring the actual color (number of layers, backing material used) even for the same fabric. In their study, Alexander Colsmann and his colleagues, for example, noted that visible light passed through transparent materials produces distinct color rendering effects [14]. In this research the L*, a*, b* values of the fabric actual color in the CIELAB space are used as variables to analyze the influence of different printing colors during the color measurement.

Table V. Pearson correlation between the number of layers of color measurement's overlay, fabric properties and color properties of single-sided printed fabrics.

	Thickness	Gloss	L*	a*	b*
Pearson correlation	−0.687	−0.364	0.352	0.287	0.076
Sig.	0.000	0.000	0.000	0.005	0.462

When the fabric is placed on a standard white board and a standard black board to measure the same L*a*b* value, it can be assumed that the reflected light collected in the integrating sphere of the spectrophotometer is provided by the fabric, independent of the backing material, the number of layers when the consistent color is measured as the dependent variable; the fabric thickness, gloss, and the L*, a*, b* value of the fabric as independent variables for Pearson correlation analysis. The Pearson correlation between the five variables and the number of superimposed layers is shown in Table V. During color assessment, the largest and most negative association was found between fabric thickness and the number of overlapping layers. the fabric with thinner yarns has low density, resulting in wider gaps between the yarns, when measuring these fabrics, we need overlaid more layers. Gloss is inversely proportional to the number of stacked layers. High gloss samples tend to have more chroma and deeper color than lower gloss or enhanced surface texture pigmented samples [13]. The higher gloss the fabric, the fewer layers must be layered. The number of layers overlaid is strongly connected with lightness, thus materials with higher L* values require more layers to be overlaid to acquire the real color from color measurement. Because of the subtractive color mixing concept of inkjet printing, producing high lightness colors results in a smaller overall inkjet volume than printing lower lightness colors. The number of overlapping layers required to overlap the actual color of the fabric measured when the printed color is red-oriented is positively connected with the a* value. The b* value is less associated with the number of overlapping layers, as is its significance.

A linear regression analysis with standardized coefficients of the four factors with strong Pearson correlation leads to the model of Eq. (1) (standardized coefficients). The adjusted R2 of the model is 0.77, indicating a satisfactory goodness-of-fit. The b* value was not included in the regression model since the correlation between it and the number of stacked layers was weak and the significance in the model was low ($0.069 > 0.05$). Silk contains yellowing properties, and when combined with preliminary treatment before printing and finishing like soaping and steaming after printing [15], the high b* value of the measured color of the fabric is heavily impacted by the fabric parameters. Fabric qualities, as the main component, influence b* value across textiles, resulting in a reduced correlation and significance of b* in the regression when assessing color. Fabric thickness, L* value and a* value's significance $0.000 < 0.05$, which is the main factor that affects the number of layers need to be stacked when measuring the color of the fabricgloss significance $0.002 < 0.05$, is the secondary factor that affects the number of layers need to be stacked when measuring the color of the fabric. The change of thickness has the greatest influence on the number of stacked layers when measuring color, and the change of luminance has the second largest influence on the number of stacked layers when measuring color, and the change of a* value and the change of glossiness value are relatively weaker than the influence of thickness and L*.

The regression model for the amount of colorimetric overlays impacted by fabric and color parameters (standardized coefficients):

$$\text{layers} = -0.64\ \text{thickness} - 0.17\ \text{gloss} + 0.51\text{L}^* + 0.38\text{a}^* \quad (R^2 = 0.77). \tag{1}$$

In practice, regression models with unstandardized coefficients are available Eq. (2).

Regression model (unstandardized coefficients) for the number of colorimetric overlay layers as influenced by fabric properties and color properties:

$$\text{layers} = 5.29 - 0.21\ \text{thickness} - 0.31\ \text{gloss} + 0.04\text{L}^* + 0.02\text{a}^* \quad (R^2 = 0.77). \tag{2}$$

3.2 *Analysis of Double-sided Printing Color Measurement Results*

The average value of color difference before and after stacking, as well as the number of layers when many layers are layered until the color remains intact, are determined in the double-sided printing part. Tables VI show the outcomes of the calculations.

3.2.1 *Effect of Thickness on Double-sided Printing Fabric's Color Measurement*

Figure 7 shows a comparison of the average value of the color difference of layers after layer-by-layer stacking with the color of the previous layer (a) and the number when the color measurement results are stable for two different fabric thicknesses double-sided printing color measurement (b). (a) measured color difference before and after stacking of 8 mm fabric on the standard white board and standard black board are extremely different, while color difference before and after stacking of 16 mm fabric on the standard white board and standard black board are modest.

Fig. 7(b) shows the number of layers that must be stacked when the thickness of the paper changes and the single-sided printing trend is similar. 8 mm double-sided printing fabric requires more than 3 layers to measure the real color, whereas

Table VI. Calculation results of double-sided printing color difference.

	Fabric thicknesses/mm (momme)	Weave	Color difference with designed color	The number of layers
Standard white board	8	Plain	4.10	4
	16	Plain	1.03	2
	16	Twill	0.82	2
	16	Satin	0.93	2
Standard black board	8	Plain	1.32	3
	16	Plain	0.76	2
	16	Twill	0.82	2
	16	Satin	0.69	2

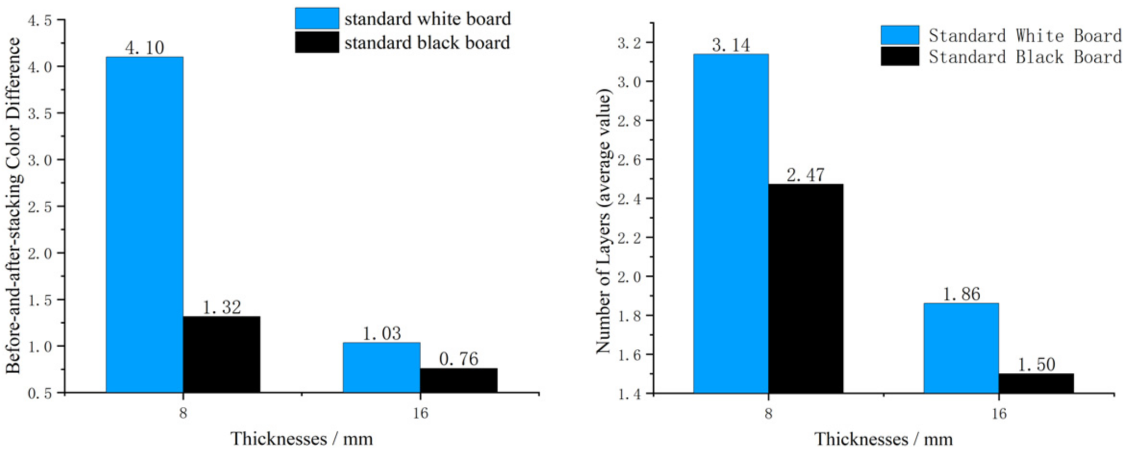


Figure 7. Color measurement results comparison of different thickness double-sided printing fabric.

16 mm fabric is generally around 2 layers. Stable color can be measured of 16 mm fabric when the stacked layers are less than 8 mm fabric.

3.2.2 *Effect of Fabric Weaves on Double-sided Printed Fabric Color Measurement*

Figure 8 compares the average value of the color difference between double-sided printing and the preceding layer after layer stacking (a) and the number of layers until the color measurement result is steady (b). When the three fabrics in the two figures were measured on a standard white board, the color difference before and after stacking, as well as the number of stacked layers, were identical to single-sided printed fabrics, however the color measurement findings on a black board were not. Fig. 8(a): among the three types of fabrics, twill fabric's color difference before and after stacking is the highest on a standard black board, plain fabric is second, and satin fabric is lowest; the color difference before and after layer stacking was very close for twill fabrics on both backing materials. The color difference and layers stacked of double-sided printing twill fabric before and after layer stacking are quite similar under standard white board and standard black board. This suggests that when measuring color, double-sided printing twill fabric is less impacted by the backing material, and the parameters influencing color measurement are more connected to the physical properties of the fabric material.

3.2.3 *Effect of Fabric Properties and Color Properties on Color Measurement of Double-sided Printing Fabrics*

Pearson correlation analysis was performed with the number of layers of double-sided printing fabric as the dependent variable when consistent color was measured on standard white board and standard black board conditions, and the fabric thickness, gloss, and L^*, a^*, and b^* values as the independent variables. Table VII shows the Pearson correlations of the five variables with the number of stacked layers when stable layers were assessed. The Pearson correlation coefficient −0.685 between the number of stacked layers and thickness when printing color measurement is extremely similar to the Pearson correlation coefficient −0.687 for single-sided printing. It demonstrates that the impact of fabric thickness on single-double-sided color measurement is almost the same. The connection of gloss during color measurement on double-sided printing is larger than that of single-sided printing, but the influence of color characteristics (L^* values, a^*, b^* values) is lower than that of single-sided printing.

The model of Eq. (3) is obtained through regression analysis of the number of layers of double-sided printing

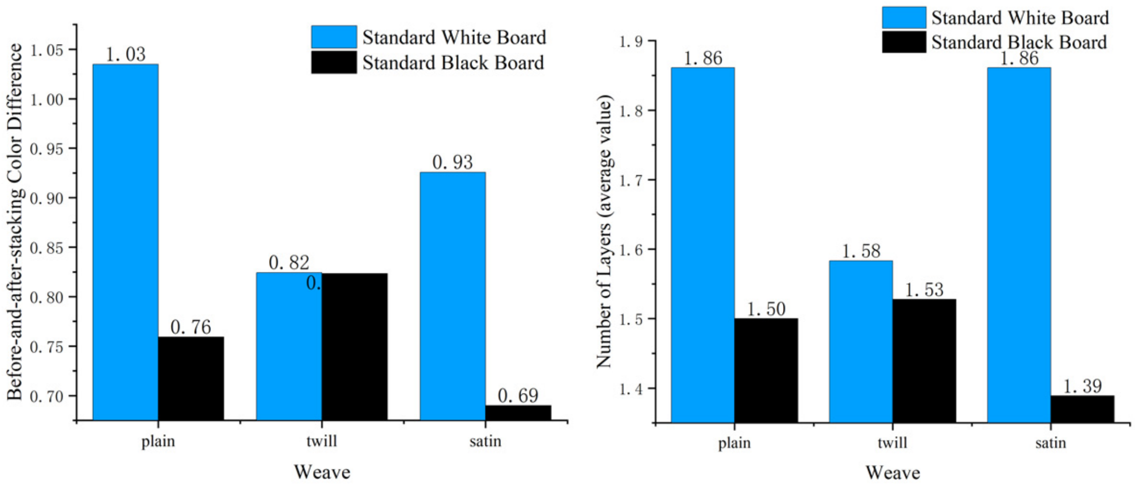


Figure 8. Color measurement results with different weaves in double-sided printing fabric.

Table VII. Pearson correlation between the number of layers of color measurement's overlay, fabric properties and color properties of double-sided printed fabrics.

	Thickness	Gloss	L*	a*	b*
Pearson Correlation	−0.685	−0.436	0.027	0.111	0.124
Sig.	0.000	0.000	0.147	0.005	−0.139

fabric when consistent color is measured on standard white board and standard black board conditions as the dependent variable and the thickness of the fabric, gloss, and L* and a* values of the fabric as independent variables (unstandardized coefficient). Because of the low correlation and the significance of 0.905 in the regression model, b* is considerably more significant than 0.05 and is thus not included in the regression model. The model was tweaked to have an R2 of 0.55. Thickness and gloss were significant at $0.000 < 0.05$ and were the most significant factors influencing the number of layers of color measurement overlay on double-sided printed fabrics. The a* significance of $0.001 < 0.05$ is the secondary factor affecting the number of stacked layers in double-sided printing color measurement. the L* property has significance of $0.008 < 0.05$ and correlation in the regression model with b excluded. Therefore, we retained the L* values in the final regression model. After standardizing the coefficients, it can be seen that single-sided printing and double-sided printing thickness variation have basically the same effect on the number of stacked layers when measuring color, and is the main factor affecting color measurement, and the coefficients are basically the same, gloss variation has a greater effect on single-sided printing than double-sided printing when measuring color. The effect of changes in color properties such as luminance L* and a* values on the color measurement of single-sided printing is greater.

The regression model for the amounts of colorimetric overlays impacted by fabric and color parameters (standardized coefficients):

$$\text{layers} = -0.62\ \text{thickness} - 0.28\ \text{gloss} + 0.21\text{L}^* + 0.21\text{a}^* \quad (R^2 = 0.55). \tag{3}$$

In practice, regression models with unstandardized coefficients are available Eq. (4).

Regression model (unstandardized coefficients) for the number of colorimetric overlay layers as influenced by fabric properties and color properties:

$$\text{layers} = 5.72 - 0.20\ \text{thickness} - 0.47\ \text{gloss} + 0.02\text{L}^* + 0.01\text{a}^* \quad (R^2 = 0.55). \tag{4}$$

3.3 *Color Measurement Law Comparison of Single-sided Printing and Double-sided Printing*

The results of stacking layers of single double-sided printing when the average value of color difference before and after layer stacking and color measurement results are stable are shown in Table VIII. The average value of color difference of 8 mm fabric measured on standard white board is greater by 0.93 than the average value of color difference measured on standard black board in the results of single-sided printing, and in the results of double-sided printing, the average value of color difference of before and after layer stacking is greater by 0.93 than the average value of color difference measured on standard black board. The color difference between the standard white board before and after layer stacking is greater by 2.38 than that of the standard black board. The color variation created by the liner material is greater in

Table VIII. Comparison of color measurement results of single-double-sided printing.

Printing method	Backing material	Fabric thicknesses/mm (momme)	Weave	Color difference with designed color	Before-and-after-stacking color difference
Single-sided printing	Standard white board	8	Plain	3.30	3.50
		16	Plain	1.81	2.46
		16	Twill	1.25	2.00
		16	Satin	1.55	2.17
	Standard black board	8	Plain	2.37	3.00
		16	Plain	1.50	2.25
		16	Twill	1.09	1.83
		16	Satin	1.52	2.00
Double-sided printing	Standard white board	8	Plain	4.10	3.14
		16	Plain	1.03	1.86
		16	Twill	0.82	1.58
		16	Satin	0.93	1.86
Double-sided printing	Standard black board	8	Plain	1.32	2.47
		16	Plain	0.76	1.50
		16	Twill	0.82	1.53
		16	Satin	0.69	1.39

single-sided printed fabrics than in double-sided printed fabric. The number of layers that must be stacked for color measurement of double-sided printing fabrics of the same thickness is smaller than that of single-sided printed fabrics. When measured on a standard black board, single-sided printing twill fabrics have less color difference and fewer stable layers to stack for color measurement before and after layer stacking than plain and satin fabrics. The color difference value on the white board and black board before and after layer stacking of double-sided printing's twill cloth is virtually the same, as is the number of stacking layer. The backing material impact on twill fabric color measurement in double-sided printing is smaller than the other two fabrics.

The layers of the same color measured for each fabric stacked on two backing materials is shown in Table IX, The number is the average value for each fabric under various printing color conditions, while the numbers in parentheses are rounded up to the nearest whole number. Figure 9 shows the same color's average layer line graph measured for four different fabrics put on two backing materials. The thickness is an important factor for both single-sided and double-sided printing fabrics, multiple layers are required for fabrics in order to prevent the undesired reflection of light on the background. In the three fabrics with the same fabric thickness, twill fabric's color measurement requires the least number of overlapping layers, satin fabric is the second, plain fabric requires the most overlapping layers to measure its consistent color. Under the same fabric specifications, double-sided printing fabric in two conditions need less layers to measure the same color than single-sided printing; for each type of fabric, double-sided printing's color measurement needs averagely one layer less than single-sided

Table IX. Layers of the same color measured for each fabric.

	8 mm Plain	16 mm Plain	16 mm Twill	16 mm Satin
Single-sided printing	4.97 (5)	3.29 (4)	2.69 (3)	2.79 (3)
Double-sided printing	3.64 (4)	2.14 (3)	1.53 (2)	1.89 (1)

printing. This is because double-sided printing fabric's inking quantity is higher than single-sided printing, and the overall L* of fabric color will be reduced after mixing. According to the preceding regression models (1) and (3), the lightness of the fabric and the layers needed for measuring the actual color have a positive correlation, so the overall lightness of the lower double-sided printing color measurement needs fewer superimposed layers. More dye-colored the fabric surface is, the more difficult it is for light to pass through the fabric surface into the yarn. Because of the dye, the thickness of the yarn and the thickness of the fabric are increased to some extent, the pores between the yarn become smaller, and the total reflected light on the incident fabric's surface increases, the total transmitted light decreases, and it is easier to measure the actual color.

The regression model coefficients after normalizing coefficients for single-sided and double-sided printing color measurement are shown in Table X. The thickness coefficients in the two models are quite similar, and the Pearson correlation coefficient test shows that the association between thickness and single-sided printing and double-sided printing fabrics is essentially the same. The gloss coefficient (absolute value) is significantly higher in the double-sided

Table X. Regression model coefficients for single-sided and double-sided printing.

	Fabric	Thicknesses	Gloss	L*	a*
Coefficient	Single-sided printing	−0.640	−0.166	0.476	0.374
	Double-sided printing	−0.620	−0.281	0.210	0.206

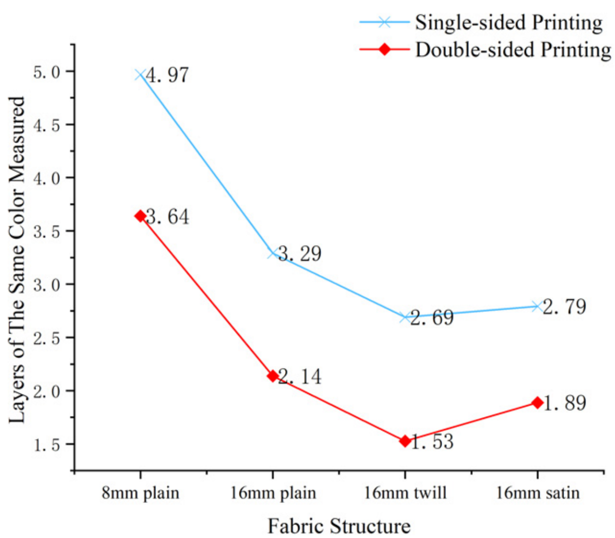


Figure 9. Layers of the same color measured for four different fabrics put on two backing materials.

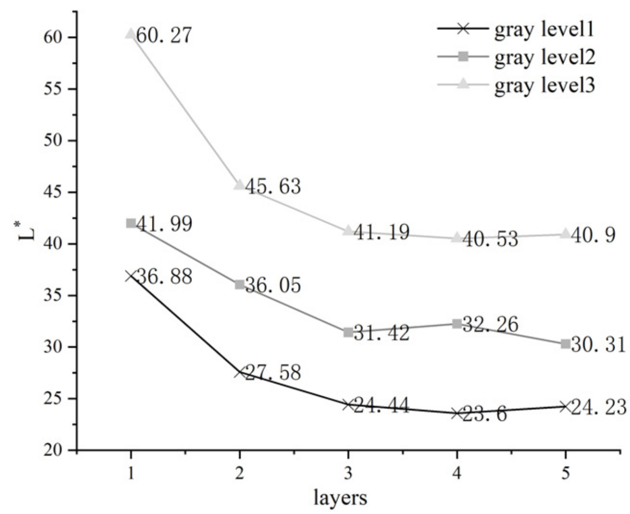


Figure 10. Variation of the three gray levels in L*.

printing model, thus the impact of gloss on double-sided printing fabrics is slightly greater than on single-sided printed fabrics. The coefficients of L* and a* values are somewhat greater in the single-sided printing model. Color characteristic (L* and a*) have a poorer association with double-sided printing textiles than with single-sided printed fabrics.

Furthermore, when the number of overlapping layers increases, single-sided and double-sided printing might differ from the true color. When measuring the color of 8 mm fabric on a standard white board, this phenomenon is more visible. As an example, Figure 10 shows the L* variation of the three gray levels of single-sided printing on 8 mm fabric, and Figure 11 illustrates the a*b* value variation of the six hues of single-sided printing on 8 mm fabric. The trend of a* change is more visible when compared to the change in brightness L*. The a* values of red, blue, magenta, and yellow increase first and subsequently decrease, with the change occurring after two layers of stacking. The a* of these colors are all more than zero, indicating that the hue that prefers red somewhat more than green. Green and cyan a* values decrease and subsequently increase, and the trend change inflection point is likewise after two layers of the stack. Both hues have a* values smaller than 0, indicating that they are biased toward green. After stacking two layers, the a* value shifts toward the trend of convergence to 0 (‖a*‖ drops). This implies that after the stacking measurement, the color tends to shift toward lower chroma. Figure 12 depicts how the color chroma of the six colors varies with the number of stacked layers. The figure demonstrates that when the color is measured after stacking from one layer to two layers, the chroma increases in an upward trend, but when the stacking continues beyond two layers, the chroma changes to a downward trend.

4. CONCLUSION

This research investigated the factors influencing the color measurement of fabrics by regulating the variables of various fabric qualities and color properties of fabrics in order to determine the color measurement technique for silk fabrics appropriate for single-sided and double-sided digital printing. The color measuring technique is also designed based on the fabric qualities and color attributes. In terms of fabric properties, silk fabrics of various thicknesses and weaves were chosen for the investigation. The influence of color on measurement using hue, saturation, and gray scale as variables are chosen for fabric color properties. This study focuses on the influence of superposition between distinct colors on color measurement in the double-sided printing section. Finally, a regression model is developed to determine the influence of fabric thickness, gloss, L* value, and a* value on color measurement. The single-sided printing regression model is represented by Eq. (5), while the double-sided printing regression model is represented by Eq. (6). Both equations are models with normalized coefficients.

$$\text{layers} = -0.64\,\text{thickness} - 0.17\,\text{gloss} + 0.51L^* + 0.38a^* \quad (R^2 = 0.77) \tag{5}$$

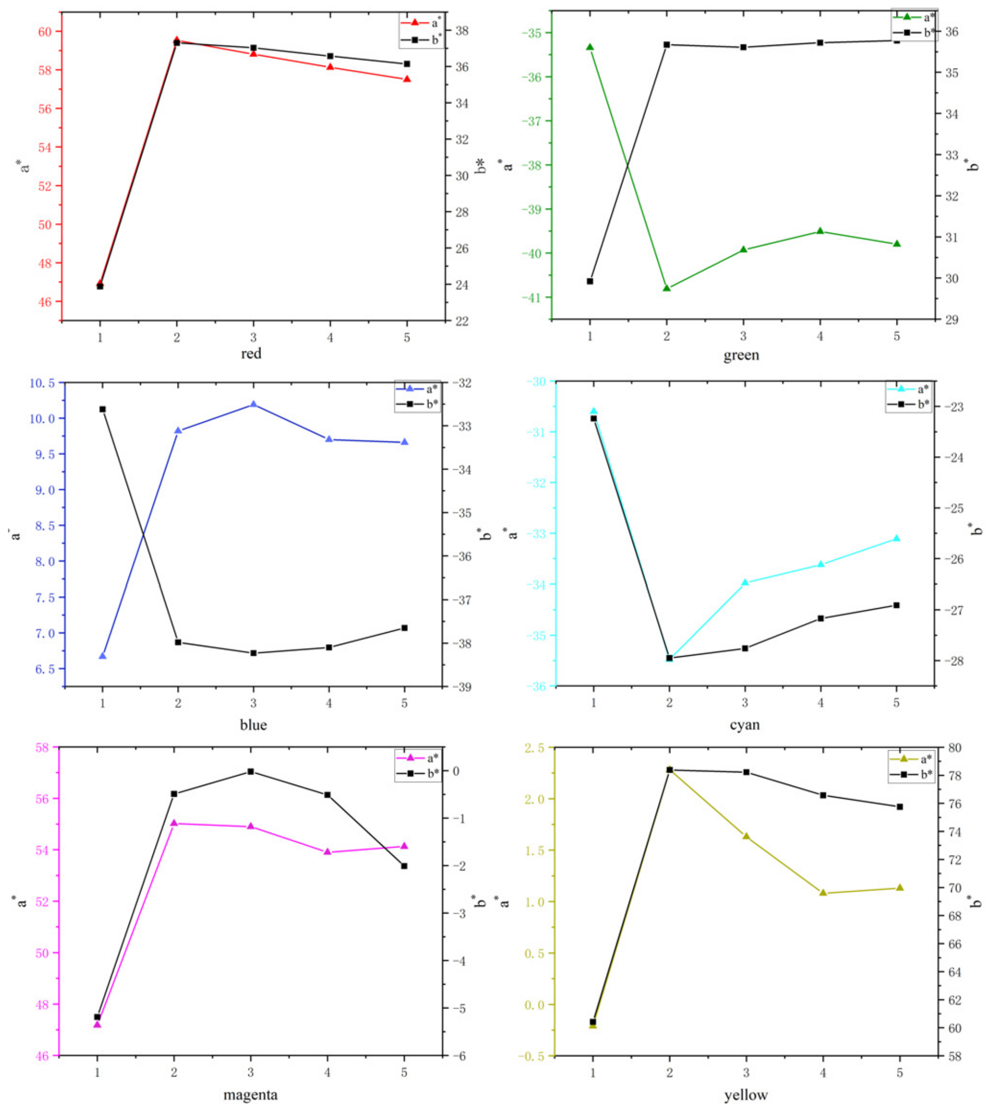


Figure 11. Variation of the six hues in a*b*.

$$\text{layers} = -0.62\ \text{thickness} - 0.28\ \text{gloss} + 0.21\text{L}^* + 0.21\text{a}^* \quad (R^2 = 0.55). \tag{6}$$

The influence of thickness on color measurement in single-sided and double-sided printing is the strongest and almost the same. Gloss has a somewhat greater influence on double-sided printing fabric than it does on single-sided printed fabric. The effect of L* and a* values on single-sided printing color measurement is greater than the effect on double-sided printing color measurement. For the actual color measurement, the model with unstandardized coefficients of model (7) and (8) can be used.

$$\text{layers} = 5.29 - 0.21\ \text{thickness} - 0.31\ \text{gloss} + 0.04\text{L}^* + 0.02\text{a}^* \quad (R^2 = 0.77) \tag{7}$$

$$\text{layers} = 5.72 - 0.20\ \text{thickness} - 0.47\ \text{gloss} + 0.02\text{L}^* + 0.01\text{a}^* \quad (R^2 = 0.55). \tag{8}$$

When measuring the color of silk fabrics, the features of various textiles and environmental circumstances should be integrated to establish an appropriate color measurement method in order to estimate the true color of the fabric. In this research, the color measurement methods for silk fabrics are summarized as follows:

(1) The biggest intrinsic element influencing fabric color measurement is the fabric thickness. When the thickness is the same, the fabric demonstrates that the gloss is the component that influences color measurement.
(2) Compared to the standard white board, the standard black board has less effect on the actual color of the fabric during color measurement. In sufficient color measurement conditions and equipment conditions, the consistent color measured on the standard white board and standard black board can be considered as the actual color of the fabric, but if the test fabric is light and easy to crease chiffon, it is suggested to choose a standard black

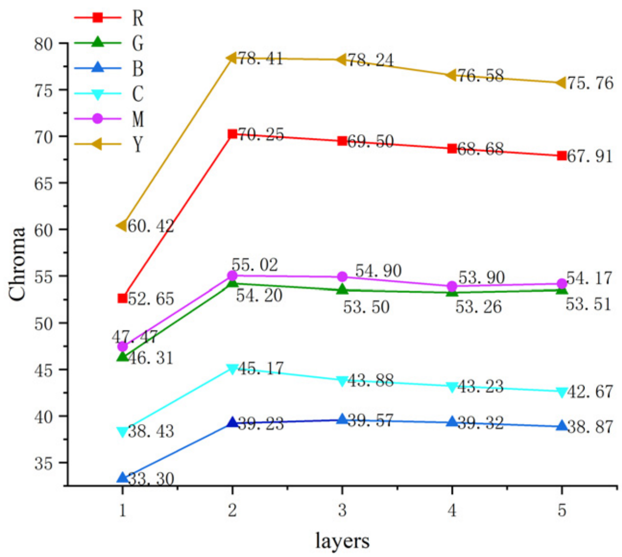


Figure 12. Chroma of the six colors varies with stacked layers.

board for color measurement, overlaid with fewer layers, thereby, the measured results will be closer to the actual color.

(3) When the fabric specification and the color are the same, the number of layers stacking for measurement for double-sided printing is less than that required for single-sided printing.

(4) More layers are frequently required to measure the true color, when the printed color is red or brighter. The effect of color properties on single-sided printing color measurement is greater than the effect on double-sided printing color measurement.

(5) After stacking too many layers, the measured color of textile will deviate from the actual color, for example, with the increase of stacking layers, the measured color saturation will gradually decrease.

5. FUTURE PLAN

Due to the choice of reactive dye material and printing equipment used for printing, the materials selected in this research are all silk fabrics, and are analyzed in terms of the elements impacting at fabric level; thickness of the fabric, fabric weave structure, and so on. There is still a lot of room for discussion when it comes to raw material and yarn structure related considerations.

The color difference of layers after layer-by-layer stacking with the color of the previous layer and the number of layers when the color measurement results are stable represents whether the color of the designed silk product is vulnerable to external effects, as well as the difference between the apparent color and the real color when worn as a single layer product. The ultimate imaging effect of the fabric is a thorough color mixing effect of reflected and transmitted light from the fabric surface. In the product design and proofing stages, in addition to considering the real color of the fabric adjustment, designers can better resolve the issue of color measurement of the fabric, the silk product design, fabric qualities, and color properties. It solves the problem of color measurement of fabrics, and also helps to match fabric properties and color properties in the process of silk product design.

ACKNOWLEDGMENT

This work was supported by Youth Project of Zhejiang Provincial Natural Science Foundation (No. LQ19C090009); and Research Fund of Zhejiang Sci-Tech University (Grant number: 19012201-Y, 18012108-Y, XMJWCb20200029). This work was also supported by Hangzhou Atexco Digital Technology Co Ltd for Dr. Yiting Duan's postdoc research project.

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