Goniometric Image Analysis of Observed Color Change in Dyed Trilobal Cross-section Polyester Monofilament Fabrics

Lee, Jung-Min · Kim, Jong-Jun* · Jeon, Dong-Won*
Ahn, Byung-Tae** · Choi, Jung-Im***
Doctor candidate, Dept. of Clothing and Textiles, Ewha Womans University
Prof., Dept. of Clothing and Textiles, Ewha Womans University*
Prof., Dept. of Chemistry, Ewha Womans University**
Lecturer, Dept. of Clothing and Textiles, Ewha Womans University***

Abstract

The cross-section of the polyester filament yarn has been modified to have a variety of shape for aesthetic, added functions and sensitivities, and other purposes. Transparent polyester filament of trilobal cross-section has unique optical properties with high anisotropic reflectivity and transmissivity. The monofilament yarns may be utilized to impart to the fabrics lustrous appearance along with unique color change in case differently dyed yarns are woven together. The color changes of the fabric specimens according to the changes in observation and lighting conditions were analyzed using a CCD camera and an image analysis software. The changes of color/luster of the fabric specimens were measured and analyzed based on RGB, L’ab’, L’C’h’, and the color distribution within a three-dimensional color space.

Key Words: polyester, monofilament, trilobal, reflectivity, color distribution.

I. Introduction

The recent trend of employing glittering or metallic sheen textiles has become an important part of fashion trends. Along with these materials, there have been color-changing fabrics based on the color differences in warp and filling yarns comprising the fabrics.

Since fabrics are highly deformable, leading to very subtle mechanical variations into large draping and motion variations that modify completely the visual appearance of garment models. Therefore, the motion variations and deformation of the fabrics, in the case of the color-changing fabrics, may conspicuously alter the visual appearance of the apparel.

The cross-section modification in polyester filament manufacture was introduced to mimic the appearance of silk, including its luster, bulkiness, and crispness. The cross-section shape of the polyester filament yarn may be modified

Corresponding author: Kim, Jong-Jun, Tel: +82-2-3277-3102, Fax: +82-2-363-3078
E-mail: jjkim@ewha.ac.kr
to have a variety of trilobal, rectangular, L-type, or U-type cross-sections, according to the design of orifice shape and/or polymer and melt-flow modification. Engineers have found the potential of non-circular cross-section to achieve a variety of hands and other fabric characteristics different from those of existing fabrics.  

It engages the viewer and it creates an inner sense of order, a balance in the visual experience. Color harmony delivers visual interest and a sense of order.  

In color changing fabrics, the selection of colors are of prime importance. Complementary colors, any two colors which are directly opposite each other, are often employed in the manufacture of the color changing fabrics to effectively exhibit the color change or iridescence.  

Gunji et al. measured the optical color of iridescent fabrics using a goniophotometric colorimeter at 45 and 60 degree illuminating angles and 0 and 75 degree viewing angles, and reported that the change of color in iridescent fabric depends on the fabric color value in each viewing angle.  

Takeshi et al. proposed a method to predict the surface color of union fabric from individual color of yarns and weave. They employed Kubelka Munk's law and Lambert–Beer's law for predicting surface color as theory of subtractive color mixing, together with isomeric matching method for making spectral reflection factor in prediction.  

In case of fabrics comprising modified cross-section monofilament warp yarns, especially for satin weaves, the luster effect or occlusion effect due to the shape factor and/or the warp density factor may be conspicuous resulting in more evident iridescent appearance. In order to enhance iridescence, Kobsa et al. used, in their invention, polymers, forming the sheath and core, with substantial differences in receptivities for dyeing, e.g., acid, basic, or disperse dyes. The weave of the fabrics comprising the invented sheath and core filaments is satin which has long floats of straight and parallel yarn sections on the fabric to show the iridescent two-color effect.  

Iridescent fabrics exhibit various color changes together with glittering looks. Futuristic trends in the textile materials often employ the following characteristic fabrics. A variety of metallic sheen fabrics having gold-like or silver-like reflections are fabricated through the use of slitted thin-film yarns having deposition of aluminum layers or other thin metal layers. Some of the textile fabrics are coated using polyurethane emulsions containing metal flakes or flakes for similar effect.  

Other effects are manifested by the use of metal chains or spangles which reflect incoming lights in full splendor, including hologram printing or attachments on the fabric surface. These are often visually creative, providing exclusive, unique and fashionable look. They deliver modern and contemporary look by design.  

In this study, the color change of the fabric due to the differences between warp and weft yarn color, and the sheen change due to the cross-section shape of the filament yarn, under various illumination and observation conditions, were examined and analyzed.  

II. Experiments  

Commercially available fabrics, exhibiting color-changing characteristics when viewed from different observation conditions, were selected.
The four fabric specimens were of the same greige fabric specifications of warp and filling materials, except for the color of the yarns. The cross-section shape of polyester monofilament, comprising the specimen fabrics, was trilobal. Specifications of the fabric specimens are given in Table 1.

1. Colorimetry

A tristimulus color analyzer, Minolta Chroma-meter Model CR200b (Minolta, Japan)\(^9\) was used for measuring \(L^*, a^*, b^*\) values of the fabric specimens. It uses an 8mm measuring area, diffuse illumination, and a zero degree viewing angle. A pulsed xenon arc lamp is employed in the illumination mechanism. Only the light reflected perpendicular to the specimen surface is collected by the optical cable for color analysis. \(L^* a^* b^*\) stands for luminance, or lightness, and \(a^*\) and \(b^*\), which are chromatic components. According to this model \(a^*\) ranges from green to red, and \(b^*\) ranges from blue to yellow. This model was designed to be device independent. With this model it is possible to handle colors regardless of specific devices, such as monitors, printers, or computers.\(^9\) \(L^* a^* b^*\) allows the specification of color perceptions in terms of a three-dimensional space. Samples for which \(a^* = b^* = 0\) are achromatic.

The quantities \(L^*, a^*, b^*\) are obtained from the tristimulus values according to the following transformations: <Eqns. 1-3>

\[
L^* = 116(Y/Y_0)^{1/3} - 16, \quad \text{<Eqn. 1>}
\]
\[
a^* = 500[(X/X_0)^{1/3} - (Y/Y_0)^{1/3}], \quad \text{<Eqn. 2>}
\]
\[
b^* = 200[(Y/Y_0)^{1/3} - (Z/Z_0)^{1/3}], \quad \text{<Eqn. 3>}
\]

where \(X_0, Y_0, Z_0\) are the values of \(X, Y, Z\) for the illuminant that was used for the calculation of \(X, Y, Z\) of the sample. For the above equations to yield valid results, \(X/X_0, Y/Y_0, Z/Z_0\) should all be greater than 0.008856.

From the measured RGB values using the color CCD camera, conversion to \(L^* a^* b^*\) and \(L^* C^* h^*\) were performed based on the Java-based program supplied by the Colorpro.com.\(^1\) The conversion from \(L^* a^* b^*\) to \(L^* C^* h^*\) are based on the following calculations.<Eqns. 4 and 5>

\[
C' = (a'^2 + b'^2)^{1/2} \quad \text{<Eqn. 4>}
\]
\[
h = \tan^{-1}(b'/a') \quad \text{<Eqn. 5>}
\]

2. CCD Camera, illumination, specimen rotation, and image analysis

Jenoptik Progres-C10 plus color camera was used for measuring the fabric images under various observation conditions, which may help interpret the color-changing behavior of the specimen fabrics. An illuminating device with goose-neck fiber optic light guides was used for the illumination at various angles. Fabric specimen for observation under the CCD camera was mounted on a rotating platform (Namil Optical Component Co., Korea) to examine the

\(<\text{Table 1}>\) Specification of fabric specimen

<table>
<thead>
<tr>
<th>warp/</th>
<th>Fabric Count</th>
<th>Denier</th>
<th>Number of Filaments</th>
<th>Material</th>
<th>Luster</th>
<th>Air permeability</th>
</tr>
</thead>
<tbody>
<tr>
<td>filling (threads/5cm)</td>
<td>(d)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(cm(^3)/cm(^2)/s)</td>
</tr>
<tr>
<td>Warp</td>
<td>420</td>
<td>23.4</td>
<td>1</td>
<td>PET</td>
<td>Bright</td>
<td>98.5</td>
</tr>
<tr>
<td>Filling</td>
<td>180</td>
<td>170.3</td>
<td>160</td>
<td>Rayon</td>
<td>Bright</td>
<td></td>
</tr>
</tbody>
</table>
color/luster change under specific observation condition. A lens with relatively long working distance was mounted to the C-mount of the CCD camera in order to allow enough working space for the specimen rotation and illuminator positioning. Image analysis program used in this study was ImageJ (NIH, USA).

After image acquisition, ROI (Region of Interest), excluding blurry regions due to the inclination of the fabric specimen, was selected from the image. Histogram and relevant data were acquired using color histogram function of the software. Average RGB values were calculated and the ratios of red to green or red to blue were subsequently calculated. Color Inspector plug-in for the ImageJ was utilized for visual representation of the color/luster changes according to the observation condition changes.

3. Air–permeability

Air–permeability Tester Model FX3300 (Textest AG, Switzerland) was used for the air–permeability measurement of the fabric.

4. SEM image of yarn cross–section

A scanning electron microscope (JEOL, Japan) was used for the cross–section image examination.

III. Results and Discussion

1. Colorimeter measurement

The measurement results of $L^ab^*$ values of the specimen fabrics are listed in <Table 2>.

The $\Delta E$ values of color differences between the face and back of the satin fabric specimens range from 9.9 to 16.3 depending on the warp and filling yarn colors. The back colors of the fabrics mostly come from the rayon filling yarn colors.

Due to the facts that the measurement using the colorimeter is based on the fixed illumination and measurement conditions and that the resulting value is based on the average of the specified area of the specimen, the goniometric measurements are needed to interpret the color–changing behavior of the fabric specimens.

2. Monofilament measurement

<Fig. 1> shows a SEM image of cross–section of the trilobal polyester monofilament of a fabric specimen.

In order to examine the luster change according to illumination angle change, a single monofilament was extracted from the fabric specimen. Under a microscope with CCD, the image of monofilament specimen was captured first at an illumination angle not inducing strong sheen, and then another image was captured at an illumination angle for strong sheen as shown in <Fig. 2>.

<Table 2> Measurement Results of Thickness, Weight, and $L^ab^*$

| Fabric | Thickness, mm | Weight, g/m² | Face | | Back | | $\Delta E$ (F–B) |
|--------|---------------|--------------|------|----------------|----------------|-----------------|
| A      | 0.192         | 93.7         | 30.8 | 17.1           | -23.0          | 28.7            | 26.4            | -20.6          | 9.9            |
| B      | 0.192         | 94.3         | 53.5 | 33.3           | 2.2            | 50.0            | 43.1            | -3.5           | 11.9           |
| C      | 0.185         | 93.4         | 56.0 | -0.8           | 9.9            | 60.6            | 5.4             | 24.3           | 16.3           |
| D      | 0.180         | 94.1         | 53.2 | 29.5           | 22.7           | 49.5            | 41.1            | 22.9           | 12.2           |

118
<Fig. 1> SEM image of cross-section of trilobal polyester monofilament.

<Fig. 2> Captured images of trilobal monofilament.
(Left: incidence angle 8 degrees for low luster,
Right: incidence angle 45 degrees for high luster)

<Fig. 3> shows the drastic change of the reflection intensity pattern of the triangular cross-section monofilament specimen with the change of incidence angle of illumination. This is attributed to the relatively flat sides of the triangular cross-section as shown in <Fig.1>. The reason for the multiple peaks seems to be related to the multiple reflections and refractions inside the almost transparent trilobal monofilament specimen.
<Fig. 3> Intensity plot profile across the trilobal monofilament surface (incidence angle: 45 degree for high luster, 8 degree for low luster).

<Fig. 4> Photomicrograph of fabric surface (specimen A).

Since the monofilaments are floating on the fabric surface of the satin weave, they cast shadows on the fabric when the illumination source is positioned near the fabric surface, with strong glitter from some monofilaments in case the reflection angle is appropriate for the sheen development.<Fig. 4>
The strong reflection from the sides of the trilobal monofilament laid on the dark shadow of the fabric base made good contrast scene, which would change the color/luster drastically with possible movement of the fabric specimen.

3. Image acquisition and analysis

(Table 3) shows the change of the ratios of R, G, B values of ROI (Region of Interest) of the acquired images according to the angle change of the specimens under CCD camera. Even if exact control of the illumination condition was difficult, it was needed to simulate wearing conditions to interpret color/luster changes in actual environment.

In the case of A, the r/b values gradually decreased, while g/b values gradually increased with the increase of angle of specimen inclination. This indicates that the specimen color, apparent to the CCD camera, changes toward bluish and greenish color when viewed from skewed position. The other specimens with differently colored warps and fillings showed similar trends.

(Table 4) shows the change of \( L' \), \( a' \), \( b' \), \( C' \), and \( h \) measured with incidence angles of \( \Theta_i=0 \) and \( \Theta_i=45 \) degrees, when the angle of camera lens axis was normal to the specimen table. Lower values of \( L' \) compared to those \( L' \) values shown in (Table 2) are ascribed to the deliberately lowered intensity of illumination for avoiding saturation of some CCD pixel sites, which would receive photons from the glittering side sections of trilobal monofilaments.

<table>
<thead>
<tr>
<th>Fabric</th>
<th>angle</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>r/b</td>
<td>g/b</td>
<td>r/g</td>
<td>r/b</td>
<td>b/g</td>
</tr>
<tr>
<td>0</td>
<td>1.08</td>
<td>1.75</td>
<td>1.89</td>
<td>2.05</td>
<td>1.36</td>
</tr>
<tr>
<td>20</td>
<td>1.07</td>
<td>1.79</td>
<td>1.91</td>
<td>2.01</td>
<td>1.35</td>
</tr>
<tr>
<td>30</td>
<td>1.00</td>
<td>1.89</td>
<td>1.89</td>
<td>1.97</td>
<td>1.34</td>
</tr>
<tr>
<td>40</td>
<td>0.94</td>
<td>1.86</td>
<td>1.75</td>
<td>1.98</td>
<td>1.23</td>
</tr>
<tr>
<td>50</td>
<td>0.94</td>
<td>1.87</td>
<td>1.77</td>
<td>1.96</td>
<td>1.17</td>
</tr>
<tr>
<td>60</td>
<td>0.91</td>
<td>1.92</td>
<td>1.75</td>
<td>1.91</td>
<td>1.09</td>
</tr>
<tr>
<td>70</td>
<td>0.97</td>
<td>1.98</td>
<td>1.91</td>
<td>1.88</td>
<td>1.11</td>
</tr>
</tbody>
</table>

(Table 4) Change of \( L' \), \( a' \), \( b' \), \( C' \), and \( h \) measured with incidence angle variation.\(^1\)

<table>
<thead>
<tr>
<th>Incid.</th>
<th>( \Theta_i=0 )</th>
<th>( \Theta_i=45 )</th>
<th>( \Delta E )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fabric</td>
<td>( L' )</td>
<td>( a' )</td>
<td>( b' )</td>
</tr>
<tr>
<td>A</td>
<td>16.9</td>
<td>18.0</td>
<td>-9.6</td>
</tr>
<tr>
<td>B</td>
<td>31.5</td>
<td>34.2</td>
<td>6.7</td>
</tr>
<tr>
<td>C</td>
<td>38.4</td>
<td>6.7</td>
<td>22.8</td>
</tr>
<tr>
<td>D</td>
<td>31.2</td>
<td>33.5</td>
<td>18.1</td>
</tr>
</tbody>
</table>

\(^1\) \( \Theta_i = \) Incidence angle of illumination: Fabric specimen was laid horizontally on the horizontal specimen table: Angle of camera lens was normal to the specimen table (\( \Theta_i=0 \))
In the case of specimen A, as the incidence angle, θ, increased to 45 degrees, the sheen from the trilobal monofilament became significant leading to the increase of L' value and decrease of b' value. Compared to the 0 degree measurement, 45 degrees measurement gave ΔE value of 20.6, which is a significant increase. Overall, it became more bluish and brighter. This is also evident from the fact that the hue, h, value changed from 331.9 to 292.8 degrees. This overall tendency is presented in terms of 3-dimensional axes of L'a'b' as shown in <Fig. 5>, which shows the color distribution within the 3-dimensional color space for fabric specimen A.

In the case of specimen B, the incidence angle increase induced the increase of L' value and b' value. Compared to the 0 degree measurement, 45 degrees measurement gave ΔE value of 23.8, which is the second most significant increase of the four fabric specimens. Overall, it became yellower and brighter. <Fig. 6> shows the overall change within the 3-dimensional color space of L'a'b'.

In the case of specimen C, as the incidence angle, θ, increased to 45 degrees, the shine from the monofilament became significant leading to the increase of L' value and decrease of a' and b' value. Compared to the 0 degree measurement, 45 degrees measurement gave ΔE value of 16.4, which is a notable increase. The hue, h, value changed from 73.6 to 78.7 degrees. This overall tendency is presented in terms of 3-dimensional axes of L'a'b' as shown in <Fig. 7>.

In the case of specimen D, the increase of incidence angle caused the increase of L' value and b' value. Compared to the 0 degree measurement, 45 degrees measurement resulted in ΔE value of 24.0, which is the most significant increase among the four fabric specimens. Overall, it became yellower and brighter. The hue, h, value increased from 28.4 to 40.0 degrees. <Fig. 8> shows the overall change within the 3-dimensional color space of L'a'b'.

IV. Conclusions

Transparent polyester filament of trilobal cross-section has unique optical properties with high anisotropic reflectivity and transmissivity. The monofilament yarns may be utilized to impart to the fabrics lustrous appearance along with unique color change in case differently dyed yarns are woven together. The color changes of the fabric specimens according to the changes in observation and lighting conditions were analyzed using a CCD camera and an image analysis software. Color/luster change of the trilobal polyester monofilament specimen was examined.

When the specimens were rotated, in the case of A, the r/b values gradually decreased, while g/b values gradually increased with the increase of angle of specimen inclination. This indicates that the specimen color, apparent to the CCD camera, changes toward bluish and greenish color when viewed from skewed position. The other specimens with differently colored warps and fillings showed similar trends.

When incidence angles were changed from θ =0 to θ=45 degrees, L' values of all the four specimens significantly increased, together with conspicuous increase of ΔE ranging from 16.4 to 24.0.

With further controlled investigation, it might be possible to predict reliably the actual color/luster changes of fabrics based on the analysis results of warp yarns and fillings.
<Fig. 5> Color distribution within the 3-D color space of L’a’b’:
(specimen A): Left θi = 0, Right θi=45, vertical axis L’

<Fig. 6> Color distribution within the 3-D color space of L’a’b’:
(specimen B): Left θi = 0, Right θi=45, vertical axis L’

<Fig. 7> Color distribution within the 3-D color space of L’a’b’:
(specimen C): Left θi = 0, Right θi=45, vertical axis L’

<Fig. 8> Color distribution within the 3-D color space of L’a’b’:
(specimen D): Left θi = 0, Right θi=45, vertical axis References
References


3) http://www.colormatters.com/colortheory.html


10) http://www.colorpro.com/info/tools/convert.htm

Received 30 August 2007, Accepted 16 October 2007.