PROGRESS
IN COLOR, COLORANTS AND COATINGS

available online @ www.pccc.icrc.ac.ir

*Prog. Color Colorants Coat. 11 (2018), 113-122*

Ministry of Science, Research and Technology
Institute for Color Science and Technology

# The Dependency of Colorimetric Characteristics of Black Fabrics to the Whiteness Attribute of Substrate

**R. Jafari**
Department of Color Physics, Institute for Color Science and Technology, P. O. Box: 16765-654, Tehran, Iran.

ARTICLE INFO

Article history:
Received: 25 Apr 2018
Final Revised: 11 Jun 2018
Accepted: 12 Jun 2018
Available online: 18 Jun 2018

Keywords:
Textile printing
Black coated fabrics
Tint attribute
White substrate

## ABSTRACT

*In this paper, the effect of whiteness attribute of white substrates on blackness property of black coated fabrics is investigated. To this aim, four cotton fabrics with different whiteness and tint attributes are used as white substrates. To prepare a set of black samples, various concentrations of four color pigments, i.e., red, green, blue and yellow, were mixed with the black one and applied on white fabrics via the conventional textile printing method. Then, the colorimetric attributes of black coated fabrics prepared by applying the same recipes on different white substrates were investigated. The results indicated the effect of substrate's whiteness index and tint factor on colorimetric characteristics of achieved blacks where by decreasing of the whiteness attribute of white substrates, the black coated fabrics became darker and more saturated. Besides, the tint attributes of black coated fabrics differ dramatically depending on the colorimetric attributes of the white substrate. As a summary, the general imagination of dominant effect of blackness rather than the whiteness attribute of employed white substrate is not approved. Prog. Color Colorants Coat. 11 (2018), 113-122© Institute for Color Science and Technology.*

## 1. Introduction

Black samples play a vital commercial role in different industries like textile, printing, paints, automotive, plastics, cosmetics, and so on [1, 2]. Since blacks are culturally percept in different meanings and concepts, various nations symbolize and apply blacks differently. For example, in western cultures, black is the symbol of death and used for funerals while in Egypt, this achromatic color represents the productivity and fertile attribute of the earth [3]. Irrespective of the unique role of black color in printing, the application of black color in luxury goods and vehicles could not be ignored [1]. Besides, wearing of the black clothes for the formal and/or religious ceremonies in different cultures in addition to its fashion applications for slimming appearance, make this achromatic color too important for systematic study [3, 4]. In color physics point of view, ideal blacks obey from chroma and lightness values equal to zero. So, it is expected that blacks could be described as a one dimensional samples in direction of lightness axis. While, real blacks deviate from the unidirectional distribution because of having various tint effects [5, 6]. On the other hand, the benefit of different tint attributes of blacks leads to their impressive commercial applications, especially for cosmetic and clothes.

Limited studies have investigated the spectral and colorimetric behaviors of black samples [4-16]. Jafari and her coworkers proved that a one dimensional subspace is not enough to describe blacks, spectrally and colorimetrically. They compressed and recovered three spectral domains of different black papers and fabrics, i.e., reflectance, absorbance (K/S) as well as the reverse reflectance (1/R) spectra, by applying the

*Corresponding author: jafari-ra@icrc.ac.ir

principal component analysis technique (PCA). Results showed that, depending on the type of samples and the applied spectral domains, at least a 2-3D subspace is needed to suitably describe blacks [6]. To determine the pure blackness of fabrics, Kihara *et al.* investigated the visual impression of blackness in women's formal dresses. They showed that the perceived blackness could not be described by optical attributes, while the physical thickness of fabrics strongly affects their blackness perception [4]. Later, Asano *et al.* investigated some visual impression of black fabrics, i.e. blackness, formality and warmth, to introduce a novel method for classification and evaluation of black fabrics [7]. In another work, Asano *et al.* proposed a method to objectively assess the human impression of black fabrics based on the logistic discrimination analysis. Results showed the capability of their method to objectively compare the image features for expressing the human visual impression [8]. On the other hand, there are some studies on the colorimetric attributes of blacks to propose an index for evaluation of blackness based on the visual assessment experiments [2, 9, 10, 13]. The outcomes indicated the vital role of tint attribute of black samples on blackness perception and preference [9, 10, 12-16].

Ideal blacks and whites are defined in the direction of lightness axis, reversely. In fact, ideal achromatic colors (blacks, whites and grays) just differ in their lightness attribute. So, the ideal black would behave as the dominant color and could cover the colorimetric effects of both ideal whites and grays. While, in the real world, blacks, whites and grays have different tint attributes [5, 6, 11, 17]. So, the dominant effect of real blacks rather than the colorimetric attributes of neutral substrate is in doubt.

This research tries to investigate the effect of whiteness and tint attributes of white substrate on colorimetric properties of black coated fabrics. So, if the colorimetric attributes of the achieved blacks remain constant, the dominant property of black color will be proved. Otherwise, the dependency of colorimetric characteristics of black coated fabrics to the whiteness attribute of white substrate will be confirmed.

## 2. Materials and Methods

### 2.1. Sample preparation

The conventional textile printing method was applied to prepare black samples. Four white cotton fabrics with different whiteness and tint attributes were employed as substrates to investigate the effect of whiteness attribute of substrate on colorimetric properties of black coated fabrics. To prepare real black fabrics (blacks with different tint attributes), the printing pastes were prepared by combining of various concentrations of four color pigments, i.e., yellow, red, blue and green, with the black one in different mixtures, i.e., binary, ternary and quaternary. Besides, the (oil/water) emulsion as well as ammonium sulfate and acrylic binder were used in the printing recipe to balance the printing paste and fix the coated fabrics. Finally, 48 original printing pastes were prepared and applied on four white cotton fabrics benefited from different whiteness and tint attributes. Therefore, 192 black fabrics were totally coated by manual silk screen printing method. Table 1, shows the commercial and generic names of applied pigments.

**Table 1:** The commercial and generic names of pigments employed for coating of white fabrics.

| Commercial name | Supplier | Generic name |
|---|---|---|
| Imperon Black FBB | Dystar | Pigment Black 7 |
| Imperon Blue K-RR | Dystar | Pigment Blue 15 |
| Imperon Yellow K-2G | Dystar | Pigment Yellow 14 |
| Imperon Red K-GC | Dystar | _ |
| Imperon Green K-G | Dystar | Pigment Green 7 |

Table 2 shows various concentrations of four color pigments were mixed as binary, ternary and quaternary mixtures with the black one based on the gram of applied pigments per 1 kilogram of printing paste.

### 2.2. Sample Measurement

The reflectance spectra of 192 black coated fabrics as well as the total radiance factors (TRFs) of four white substrates were measured by Color Eye 7000 A spectrophotometer from Gretag Macbeth over the visible wavelengths from 400 to 700 nm. The measurement geometry was d/8 and the specular component as well as the UV content of the standard illuminant was considered. Then, the CIEXYZ tristimulus values of black samples and substrates as well as their chromaticity coordinates (x, y), CIELAB and CIELCH parameters were calculated based on the measured reflectance spectra under D65 standard illuminant and CIE1964 standard observer.

## 3. Results and Discussion

The four white cotton fabrics applied as substrates had been treated differently. Substrate #1 treated with optical brightening agent and substrate #2 was chemically bleached. The two other white fabrics (substrates #3 and #4) were just normally cured and no whitening treatment was applied on them. The spectral behaviors of four white cotton fabrics applied as substrates over the visible wavelengths are shown in Figure 1. The figure clearly shows that regarding different scouring and bleaching treatments had been done on substrates, white fabrics have various reflectance spectra that result in different whiteness attributes.

To compare the whiteness characteristics of employed white substrates, their whiteness index as well as their tint factor were calculated by using the common CIE whiteness formula [17-21]:

$$WI=Y+800(x_n-x)+1700(y_n-y) \quad (1)$$

$$T_w=900(x_n-x)-650(y_n-y) \quad (2)$$

**Table 2:** Various concentrations of color pigments as well as the black one applied in different printing recipes.

| Black (g/1 kg of printing paste) | Yellow (g/1 kg of printing paste) | Red (g/1 kg of printing paste) | Blue (g/1 kg of printing paste) | Green (g/1 kg of printing paste) |
|---|---|---|---|---|
| 30,40, 50, 60 | 5,8,10,12,15,20, 25,30,40,50,60 | 2,4,5,8,12,15,20,2 5,30,40,45,50 | 2,4,5,10,20,30,40,45,50 | 2,20,30 |

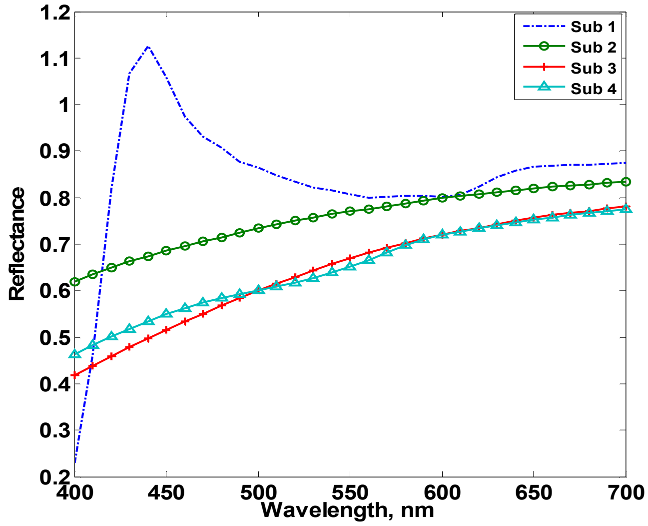



**Figure 1:** The spectral behavior of employed white substrates.

where, *Y* indicates the lightness attribute of white substrates and (*x, y*) and (*xn, yn*) show the chromaticity coordinates of white substrate and light source under CIE1964 standard observer, respectively. Based on the CIE whiteness formula, samples are defined as whites if their whiteness index (*WI*) and tint factor (*Tw*) obey from limitations determined by Equations (3) and (4):

$$40<WI<(5Y-280) \quad (3)$$

$$-4<Tw<+2 \quad (4)$$

where, samples with *Tw=0* are defined as bluish whites and those with positive (*Tw>0*) and negative (*Tw<0*) tint factors represent the greenish and reddish whites, respectively [22, 23].

Table 3 shows the specifications of white cotton fabrics applied as substrates in this research. According to Table 3, four cotton fabrics have different whiteness and tint attributes. In addition, based on limitations determined by equations (3) and (4), substrates #1, #2 and #4 are defined as white. While, the whiteness index (*WI*) and tint factor (*Tw*) of substrate #3 are out of boundaries determined by CIE whiteness formula.

On the other hand, based on Table 3, all the four white substrates have negative value of tint factor. Meanwhile, substrate #1 with the highest whiteness index (*WI*=129.4) and lowest tint factor (*Tw*=-0.25) could be defined as the whitest substrate among the four white fabrics. Clearly, the special whitening treatment of substrate #1 with optical brightener leads to its superior whiteness attribute in comparison with other white substrates.

The chromaticity coordinates of employed white substrates and the D65 standard illuminant are shown in Figure 2.

**Table 3:** Colorimetric specifications of four cotton fabrics applied as white substrates.

| White Cotton fabric | Treatment | x | y | Y | WI | Tw |
|---|---|---|---|---|---|---|
| Substrate 1 | Scoured & optically brightened | 0.299 | 0.309 | 83.01 | 129.40 | -0.25 |
| Substrate 2 | kier boiled & Chemically bleached | 0.326 | 0.342 | 76.73 | 45.42 | -3.09 |
| Substrate 3 | Scoured | 0.327 | 0.340 | 67.01 | 38.30 | -5.29 |
| Substrate 4 | Scoured | 0.325 | 0.340 | 68.90 | 41.79 | -3.50 |

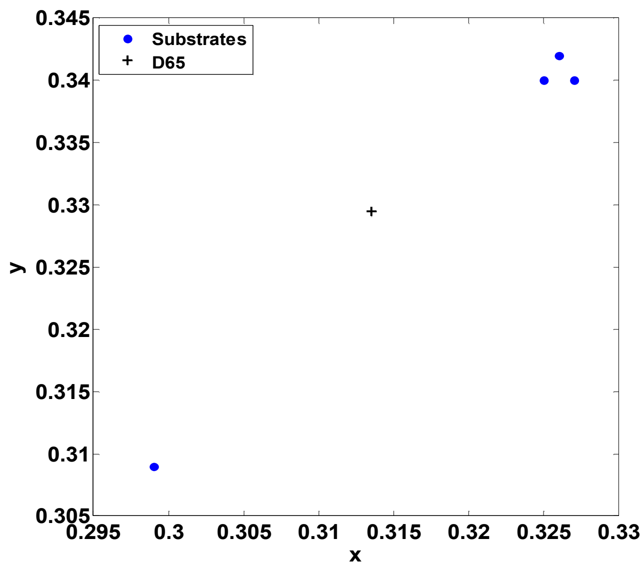



**Figure 2:** The chromaticity coordinates of four white substrates and the D65 standard illuminant.

The reflectance spectra of 192 black coated fabrics prepared by applying 48 original printing pastes on four white substrates are shown in Figure 3. According to Figure 3, various reflectance behaviors are obtained for black coated fabrics over the visible wavelengths.

Figures 4 and 5 show the a*b* and C*L* scatter plots of black coated fabrics over the CIELAB and CIELCH color spaces, respectively. According to Figures 4 and 5, black fabrics have different colorimetric attributes (lightness, chroma and hue angle). It means that irrespective of the applied white substrate, each group of black coated fabrics are scattered in four quarters of hue area with different lightness and chroma values. On the other hand, Figures 4 and 5 show the dependency of colorimetric attributes of black coated fabrics on the employed white substrates. It means that application of equal printing recipes for four white substrates does not lead to the identical colorimetric properties of the achieved blacks. In fact, the distribution of black coated fabrics over the a*b* and C*L* diagrams varies depending on the applied white substrate. In Figure 4, it seems that the tint attribute of black coated fabrics shifts from the third and fourth quarters of hue area to the first and second quarters by changing the white substrate from #1 to #4. It means that the tint effect of black coated fabrics changes from cyanish-bluish to the reddish, greenish and yellowish by changing the whiteness and tint attributes of white substrate. Besides, Figure 5 indicates the presence of darker and more saturated black coated fabrics as the employed white substrate changes from the whitest substrate (substrate #1) to another white substrate.

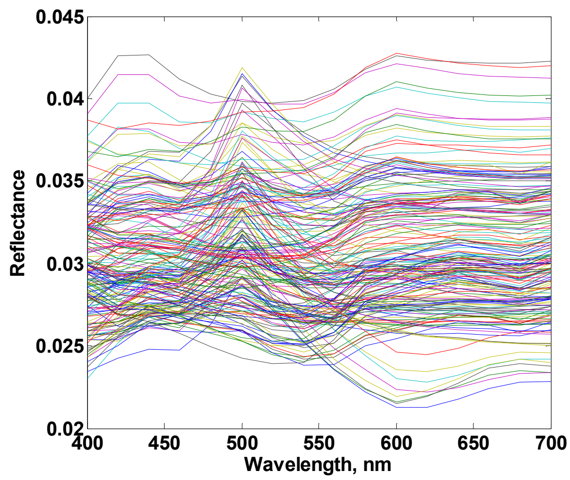



**Figure 3:** The reflectance spectra of 192 black coated fabrics.

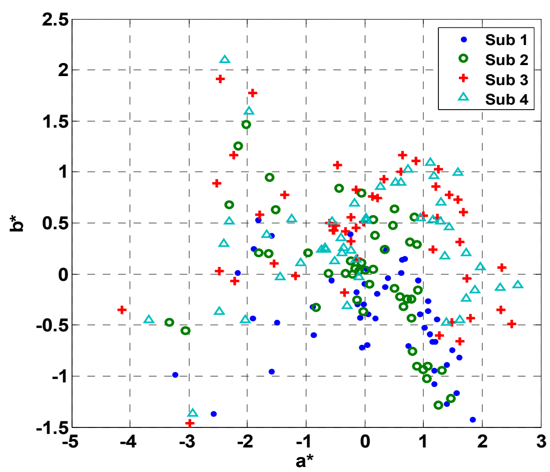



**Figure 4:** The a*b* scatter plot of 192 black coated fabrics over the CIELAB color space.

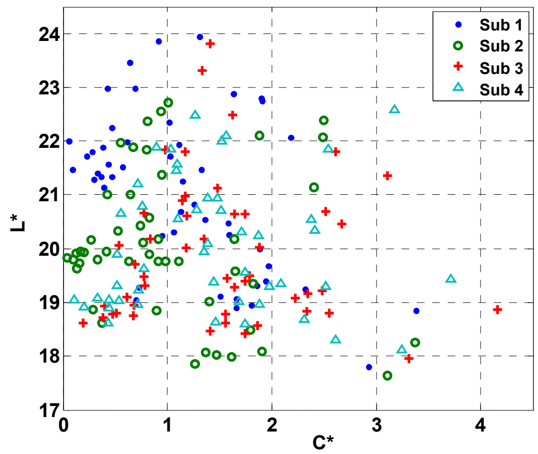


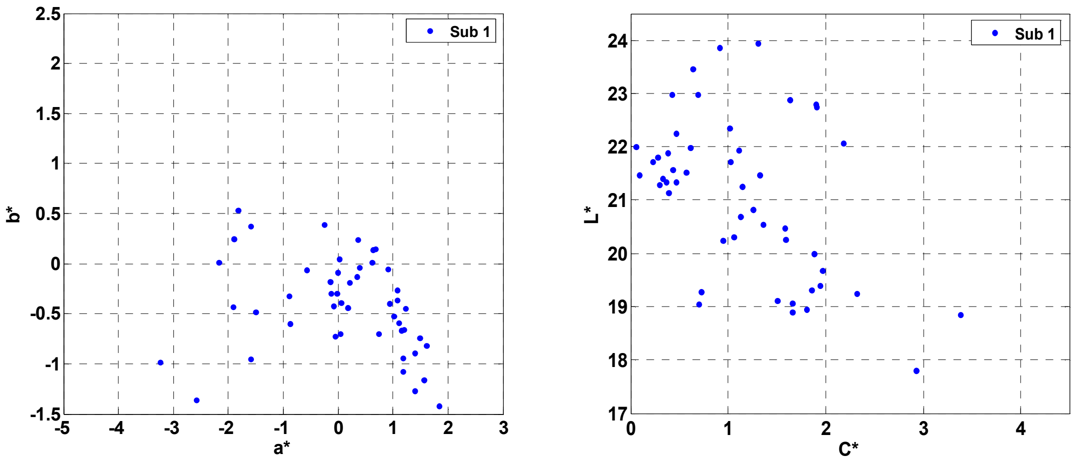

**Figure 5:** The C*L* scatter plot of 192 black coated fabrics over the CIELCH color space.

To clarify the variation of colorimetric attributes of black coated fabrics, the a*b* and C*L* scatter plots of blacks are shown in Figures 6 to 9 based on the employed white substrates.

Figure 6 (a) shows the a*b* scatter plot of 48 black coated fabrics prepared by applying 48 original printing pastes on substrate #1. According to Figure 6(a), black fabrics are mainly distributed in the fourth quarter of hue area. Besides, there are some blacks scattered approximately around the zero point of a* and b* axes. It means that, in addition to these near neutral blacks, the majority of black coated fabrics have reddish to bluish tints after applying printing pastes on substrate #1. The C*L* scatter plot of black samples are also shown in Figure 6(b) where their lightness attribute varies from 17.80 to 23.95 with the chroma values between 0.05 to 3.38.

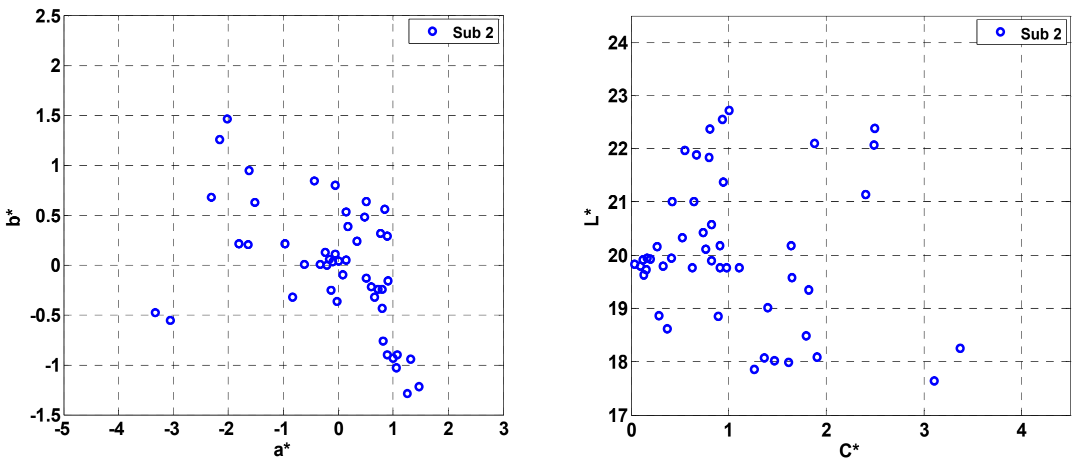
Figure 7 shows the a*b* and C*L* scatter plots of 48 black fabrics prepared by applying 48 original printing pastes on the second white cotton fabric, i.e. substrate #2. Comparison of Figures 6 and 7 indicates different colorimetric distribution of black coated fabrics prepared by applying the same printing pastes on white substrates #1 and #2. Regarding the whiteness and tint attributes of employed substrates (Table 3), it is clear that the differences between colorimetric attributes of achieved blacks arise from the differences between the whiteness properties of substrates #1 and #2. Figure 7(a) indicates the distribution of black coated fabrics around the first, second and the fourth quarters of the hue area. Besides, according to Figure 7(b), the lightness attribute of black coated fabrics vary from 17.64 to 22.72 where their chroma values vary from 0.04 to 3.37. Meanwhile, in comparison to Figure 6, it is found that the number of near neutral blacks increases in Figure 7 while the corresponding lightness values of black coated fabrics decrease. It means that replacing substrate #1 by substrate #2 results in producing darker and more neutral blacks.

Figure 8 shows the a*b* and C*L* scatter plots of 48 black fabrics prepared by applying 48 original printing pastes on white substrate #3. According to Figure 8(a), the majority of black coated fabrics are distributed in the first and second quarters of the hue area. Besides, based on Figure 8(b), the lightness values of black coated fabrics vary from 17.96 to 23.81 while their chroma values vary in the range of 0.20 to 4.16. Meanwhile, comparing Figure 7(b) with 8(b) shows that replacing substrate #2 by substrate #3 results in production of darker and more saturated blacks. According to Table 3 and the whiteness and tint attributes of the employed white substrates, it is evident that substrate #3 is less white and more tinted than substrate #2. So, the enhancement of chroma and darkness of black coated fabrics shown in Figure 8(b) and Figure 7(b) may be due to the whiteness differences between employed substrates (substrates #2 and #3).



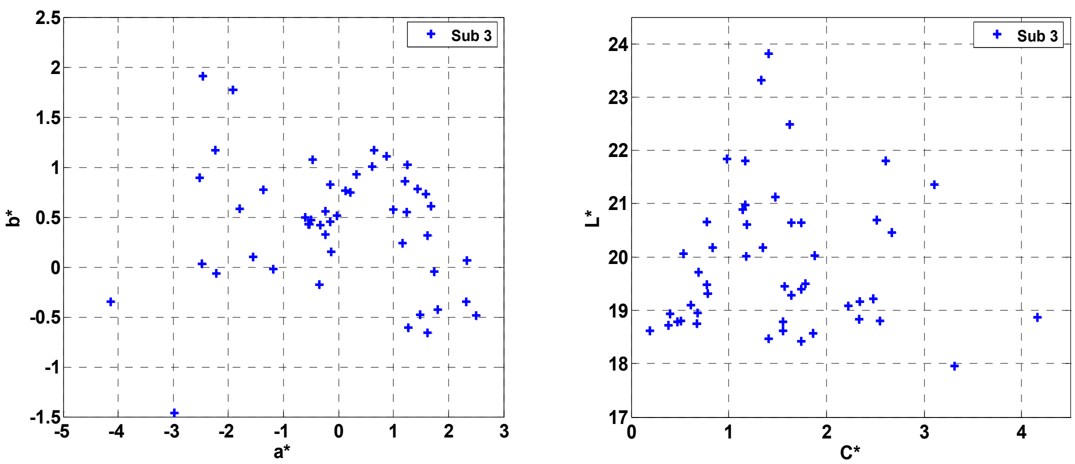

(a) (b)

**Figure 6**: The (a) a*b* and (b) C*L* scatter plots of 48 black fabrics prepared by coating of white substrate #1.



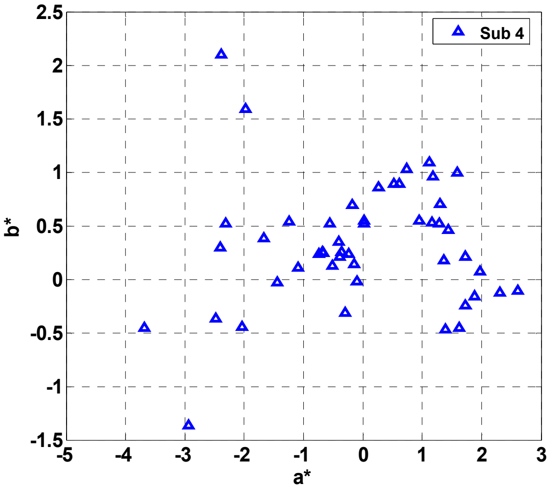

(a) (b)

**Figure 7:** The (a) a*b* and (b) C*L* scatter plots of 48 black fabrics prepared by coating of white substrate #2.

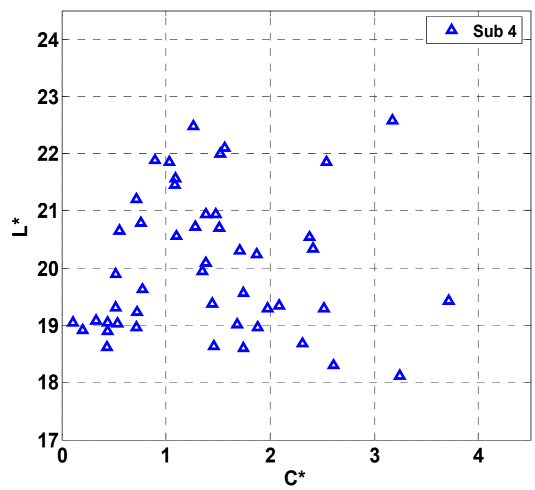



(a) (b)

**Figure 8:** The (a) a*b* and (b) C*L* scatter plots of 48 black fabrics prepared by coating of white substrate #3.




(a)




(b)

**Figure 9:** The (a) a*b* and (b) C*L* scatter plots of 48 black fabrics prepared by coating of white substrate #4.

Figure 9 shows the a*b* and C*L* scatter plots of 48 black fabrics prepared by applying 48 original printing pastes on substrate #4. Similar to Figure 8(a), Figure 9(a) shows that the majority of blacks are distributed around the first and second quarters of the hue area. Besides, comparing Figures 8(b) and 9(b) indicates some similarities between the lightness and chroma distribution of blacks prepared by coating of substrates #3 and #4. According to Table 3, it is found that both substrates #3 and #4 approximately have the same whiteness index (*WI*) while substrate #3 is more saturated than substrate #4. So, blacks prepared by coating of substrate #4 are less saturated than those coated on substrate #3. Figure 9(b) shows that the lightness attribute of blacks vary from 18.13 to 22.58 while their chroma values vary from 0.11 to 3.71.

The CIELAB color difference formula (Equation 5) was applied to quantify the colorimetric differences between blacks prepared by printing of the same recipes on four white fabrics with different whiteness attributes. As can be seen in Table 3, the white substrate #1 has the highest whiteness index and lowest tint factor. In this way, the colorimetric attributes of black samples prepared by coating of the whitest substrate (substrate #1) were considered as the reference. Then, the colorimetric differences between all black coated fabrics and the reference blacks were computed under D65 standard illuminant and CIE1964 standard observer by applying Equation 5 [24]:

$$\Delta E^*_{ab} = [(\Delta L^*)^2+(\Delta a^*)^2+(\Delta b^*)^2]^{0.5} \quad (5)$$

where $\Delta L^*$, $\Delta a^*$ and $\Delta b^*$ represent the differences between lightness, reddish-greenish and yellowish-bluish properties of black samples and reference blacks, respectively.

Table 4 shows the computed color differences between black coated fabrics and the reference blacks (those blacks prepared by coating substrate #1 using the same recipes) in terms of minimum, mean and maximum values. According to the mean values of calculated $\Delta E^*_{ab}$ shown in Table 4, it is found that the color differences between samples are visually perceptible. In other words, employing substrates with different whiteness attributes results in perceptible color differences between the final black coated fabrics. In fact, applying the same black recipes on different whites does not lead to the same colorimetric attributes of the achieved black coated fabrics.

**Table 4:** The color differences between black coated fabrics and the reference blacks.

| Blacks with substrate | ΔE*ab | | | |
|---|---|---|---|---|
| | Min | Mean | Max | Sd |
| #1 (Reference blacks) | 0 | 0 | 0 | 0 |
| #2 | 0.54 | 1.21 | 2.12 | 0.41 |
| #3 | 0.39 | 1.60 | 3.10 | 0.69 |
| #4 | 0.48 | 1.51 | 2.85 | 0.65 |

## 4. Conclusion

In order to investigate the dominant effect of blackness, various black recipes were prepared and coated on four cotton fabrics as white substrates. Due to using different whiteness treatments for white cotton fabrics, the whiteness and tint attributes of substrates differed with each other. Results showed that by decreasing the whiteness attribute of employed substrates, the black coated fabrics became darker and more saturated. Besides, the mean values of computed color differences between black coated fabrics and the reference blacks (those blacks with the whitest substrate) showed that the color differences between achieved blacks are significant and visually perceptible. By this way, the outcomes indicated the dependency of colorimetric characteristics of black coated fabrics on the whiteness and tint attributes of employed white substrates. In fact, contrary to the ideal blacks and whites, the dominant effect of blackness of real blacks (blacks with different tints) rather than the whiteness attribute of real whites (whites with various tints) was not approved.

## 5. References


1. R. Jafari, F. Ameri, N. Khalili, Effect of the type of illumination on perceived blackness of automotive finishes, *J. Coat. Technol. Res.,* 13(2016), 133-141.
2. S. Westland, T. L. V. Cheung, O. R. Lozman, A metric for predicting perceptual blackness, in Proceeding of the 14th Color Imaging Conference Final Program and Proceedings, Society for Imaging Science and Technology, Arizona, (2006),14-17.
3. L. Tao, S. Westland, V. Cheung, Black, in Proceeding of the CREATE: Colour in Art, Science, Design, Conservation, Research, Printmaking, Digital Technologies, Textiles Conference, Gjovik, (2010).
4. M. Kihara, I. Yoshizawa, M. Murakami, C. M. Asano, A. Asano, T. Fujimoto, The determination of pure blackness of the fabric in women's formal dresses, in Proceeding of the 6th Asian Textile Conference, Hong Kong, (2001).
5. R. Jafari, S. H. Amirshahi, S. A. Hosseini Ravandi, Determination of spectral dimensions of Munsell neutral samples, in Proceeding of AIC 2011 midterm meeting, Zurich, Switzerland, (2011), 447-450.
6. R. Jafari, S. H. Amirshahi, S. A. Hosseini Ravandi, Spectral analysis of blacks, *J. Color Res. Appl.*, 37(2012), 176-185.
7. C. M. Asano, A. Asano, M. Murakami, M. Mori, T. Fujimoto, A novel evaluation method of visual impression of black fabrics, in Proceeding of the Asian Design International Conference, Chiba, (2003).
8. C. M. Asano, S. Hirakawa, A. Asano, Exploration of image features for describing visual impressions of black fabrics, in Proceeding of the KES 2004, Wellington, (2004).
9. J. R. Clonts, R. Shamey, D. Hinks, Effect of colorimetric attributes on perceived blackness of materials, in Proceeding of the 4th European Conference on Colour in Graphics, Imaging, and Vision, Finland, (2010).
10. J. R. Clonts Haslup, R. Shamey, D. Hinks, The effect of hue on the perception of blackness using Munsell samples, *Color Res Appl.*, 38(2013), 423–428.
11. R. Jafari, S. H. Amirshahi, S .A. Hosseini Ravandi, Blacks colorimetric boundaries based on the perceived blackness, in Proceeding of the 12th Congress of the International Color Association, AIC Color 2013, Newcastle, United Kingdom, (2013), 503-506.
12. R. Jafari, S. H. Amirshahi, S. A. Hosseini Ravandi, Effect of lightness on blackness preference of black fabrics, *Prog. Color Colorants Coat.,* 8(2015), 11-24.
13. R. Jafari, S. H. Amirshahi, S. A. Hosseini Ravandi, Colorimetric analysis of black coated fabrics, *J. Coat.*

*Technol. Res.,* 13(2016), 871-882.
14. L. Tao, S. Westland, V. Cheung, Blackness: Preference and Perception (Hue), in Proceeding of the 19th IS&T/SID Color and Imaging Conference, San Jose, (2011), 270-275.
15. L. Tao, S. Westland, V. Cheung, Blackness:Preference and Perception (Value and Chroma), in Proceeding of the 6th European Conference on Colour in Graphics, Imaging, and Vision, Amsterdam, (2012), 253-258.
16. L. Tao, Impact of blackness preference and perception on product design, PhD thesis, University of Leeds, England, 2013.
17. R. Jafari, S. H. Amirshahi, Variation in the decisions of observers regarding the ordering of white samples, *Society of Dyers Colourists, Color. Technol*., 124(2008), 127–131.
18. S. H. Amirshahi, F. Agahian, Basis function of the total radiance factor of fluorescent whitening agents, *Text. Res. J*., 76(2006), 197-207.
19. R. Jafari, S. H. Amirshahi, A comparison of the CIE and Uchida whiteness formulae as predictor of average visual whiteness evaluation of textiles, *Text. Res. J*., 77(2007), 756-763.
20. R. McDonald, Color physics for industry, 2th Ed, Dyers company publication trust, Bradford, 1997.
21. H. Uchida, A new whiteness formula, *J. Color Res. Appl*., 23(1998), 202-209.
22. J. Lin, R. Shamey, D. Hinks, Factors affecting the whiteness of optically brightened material, *J. Opt. Soc. Am*., 29(2012), 2289-2299.
23. M. Tutak, O. Demiryürek, S. Bulut, D. Haroğlu, Analysis of the CIE whiteness and whiteness tint of optically whitened cellulosic fabrics, *Text. Res. J*., 81(2011), 58-66.
24. M. D. Fairchild, Color Appearance Models, John Wiley & Sons Ltd., Chichester, 2005.

How to cite this article:
R. Jafari, The Dependency of Colorimetric Characteristics of Black Fabrics to the Whiteness Attribute of Substrate. Prog. Color Colorants Coat., 11 (2018), 113-122.