TEXTILHÖGSKOLAN
HÖGSKOLAN I BORÅS

How to get changing patterns on a textile surface by using pearl luster and color travel pigments.

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Master thesis

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Abstract

The color is the one of the most important factor at textile and it is also an important factor at the point of purchasing a garment. Effect pigments provide extra color effects; they give angular color dependence such as iridescence, color travel, and luster. These special pigments can be found in a variety of industrial products and end-user applications for instance in automotive, fashion, cosmetic and decorative texture which make special effect like angle-dependent color. In this work, we studied six different kinds of effect pigments and applied them on polyamide fabrics. Then the CIExy and CIEL*a*b* diagrams of all samples plotted in five different angles; and the color of fabrics, printed by these pigments, studied base on CIE diagrams. On the other hand, the color of samples asked from randomly chosen people and compared with color which predicted from CIE diagram. In addition ΔE values between fabrics, printed by effect pigments, and unprinted fabrics calculated and compared. Finally the reproducibility property in the printing process has been considered.

The results of this thesis work show that the color which we expected from fabric, printed by effect pigments, are different with human visualization.

Keywords: effect pigment, Pearlescent and color travel pigments, computational color physics.

Preface

This final thesis work has been done at Swedish School of Textile, University College of Borås, Sweden, during course 2009/2010.
Nils Krister Persson & Maria Åkerfeldt have been the supervisors of this thesis work.

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CHAPTER 1:

Introduction

1. Introduction

The color is the one of the most important deciding factor at the point of purchasing a garment, and it comes before other factors (such as texture, drape, design or handle). Color is also an important part of human expression, there is not any particular definition of 'color' that is scientifically precise in all cases. Color can have different meanings. From the physical point of view, color is a very small range of electromagnetic waves and from chemical point of view; it is a result of a series resonant electron which is agitation. But what color physics than rely on it refers to the psychological response of the eye-brain combination to light waves falling upon the light-sensitive retina which makes up the inner surface of the eye. A general and comprehensive definition of color is the reflection, absorption, and emission spectra of an object. The only features of the composition of light, and thus color, which can be interpreted by the human brain, are when the curtain retina eye is stimulated by electromagnetic radiation wavelength spectrum from 380 nm to 740 nm. It appears that an average that human eye can distinguish about 10 million different colors but there are no vocabulary within the human language to describe each color precisely [1, 2].

1.1. Pigment

Pigment is a material that is basically insoluble in the application medium and changes the color of reflected or transmitted light as the result of wavelength-selective absorption.

Pigments have special properties that make them ideal for coloring other materials. A pigment must have a high tinting strength and also must be stable in solid form at ambient temperatures [3].

Even though, providing color is the most common use of pigments, pigments can afford magnetic, corrosion inhibiting, electrical or electromagnetic properties as well. They can be used in wide range of media includes coloring paint, ink, coatings, plastic, fabric, glass, enamel, cosmetics, food and other materials [3].

Pigments can be classified in four categories: white pigments, colored pigments, black pigments, and effect pigments. The particles of first type of pigments (white pigment) scatter the incident light equally in all directions (diffuse direction). In this category, effect pigments are classified as metal effect pigments or pearl luster pigments [3].

1.2. Effect pigment

In application medium, effect pigments provide extra color effects; for example, they give angular color dependence such as iridescence, color travel, and luster [3]. Driven by trends in automotive, fashion and other consumer markets, pigments which make special effect like angle-dependent color or decorative texture can be found in a variety of industrial products and end-user applications, for instance they are used for functional purposes, such as security printing or optical filters, and for decorative purposes, such as printed products, cosmetics, industrial coatings, plastics, or car paints. Consequently, many countries use pearlescent and optical multilayer pigments on banknotes. In addition, the effect pigments can acts as functional optical system. In this application, parallel oriented effect pigments and optical multilayer polymer films designed and can reflect a certain portion of the visible light. For example they can use in greenhouses, the special effect pigments can take an influence on the transmitted and reflected part of the light and, hence, take an influence on the plant growth [4].

There are several types of effect pigments such as color travel pigments, pearlescent pigments, sparkle performance pigments, transparency pigments, and Pyrisma pigments. In this project, we studied three different kinds of effect pigments; pearlescent pigment, pyrisma pigment, and color travel pigment which have prepared from Merck Company.

1.2.1 Pearlescent pigments

Pearlescent or nacreous pigments are new inorganic pigments which have ability to show the elegant luster and they have become very popular in the creation of luster effects in coatings.

Pearlescent or nacreous pigments are flaked shape. Pearlescent pigments consist of flakes of mica which are coated with a highly refractive layer of titanium dioxide (TiO_2) and iron oxide. White light imposing on pearlescent pigment is partly reflected at TiO_2 layer and the reminder is refracted through TiO_2 surface (figure (1.1)) [4, 5, and 6].

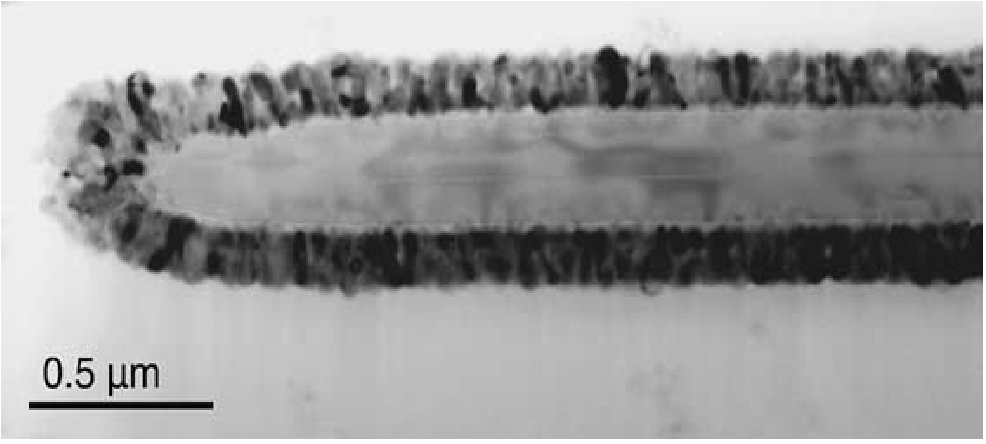


Figure 1.1: Transmission electron micrograph photo of the cross section through an pearlescent pigments of the mica platelet and the closed TiO2 layer with its typical grain structure which covering the mica [4].

The specular reflection of light from the many surfaces of the platelets with parallel orientation at various depths within the coating film can engender the pearlescent effect of pigments. When light reaches the platelets it will be partially transmitted and partially reflected through the platelets. Dependence of the reflection on viewing angle creates pearly luster effect and the reflection from different layers produces the sense of depth [4, 5, and 7].

Pearlescent pigments can basically be classified into two groups, platelets which contain of only one homogeneous material and platelets that consist of two or more optically different layer materials. Some features of pearlescent pigments are acid and alkali resistance, excellent chemical stability, safety and non toxicity, high temperature resistance, good weatherability, good dispersibility and compatibility and so on [3, 7, and 8].

Pearlescent pigments can be used alone or in combination with other transparent color pigments and coloring agents. In this way, the three-dimensional satin effects which are ranging from a pearlescent sheen right up to glittery sparkle effects will be create. Furthermore, by incorporating the color of the background, or pre-print, the effect for pearl luster pigments can be created [9].

In addition, adding small amounts of any transparent color pigments (up to 20 wt-percent related to pearlescent pigment) will effect on the color shade in textile printing and Soft, lustrous, silver, gold, bronze, and interference effect results can be obtained.

Pigmenting the metallic or mica flake makes some special effects and shifts hue at different angles of view. The color or appearance of the color completely depends on the angle of reflection or the viewing angle of the observer.

Through major market for pearl luster pigments, textile printing inks containing pearl luster pigments can be used for marvelous color and pattern effects on substrates ranging from small decorative objects to a wide verity of textile materials. The use of pearl luster pigments for printing onto textile is because of their excellent resistance to thermo fixation, solvents, washing, perspiration and chemical cleaning agent; and when pearl luster pigments are used, there is no negative influence to the application caused by high chemical resistance. The principal printing processes used for pearl luster pigments are screen printing and flatbed screen printing for roll to roll printing, and carousel flatbed screen printing [9].

A pearlescent or iridescent pigment which is based on thin platelets of low refractive index material, coated with a high refractive index material. The light can be reflect or refract by the layer. The figure (1.2) shows how the light works [9, 10].

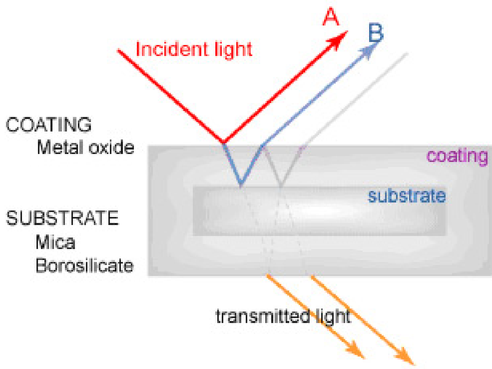


Figure 1.2: Reflection and refraction of light on substrate which coated by pearlescent pigment [20].

The thickness (nm) of the TiO_2 makes influence on the reflection and transmission colors (figure (1.3)). In other word, the color effect of a flake of mica in various thickness of

TiO_2 reached ranges from silver-white through yellow, red, and blue, to green by increasing thickness. In addition, the effect of pigments depends on the particle size distribution of the platelets. Large particle size distribution lead to a sparkle effect (that it is more transparent), but small particle size distribution leads to a satin effect with excellent hiding power [9, 11].

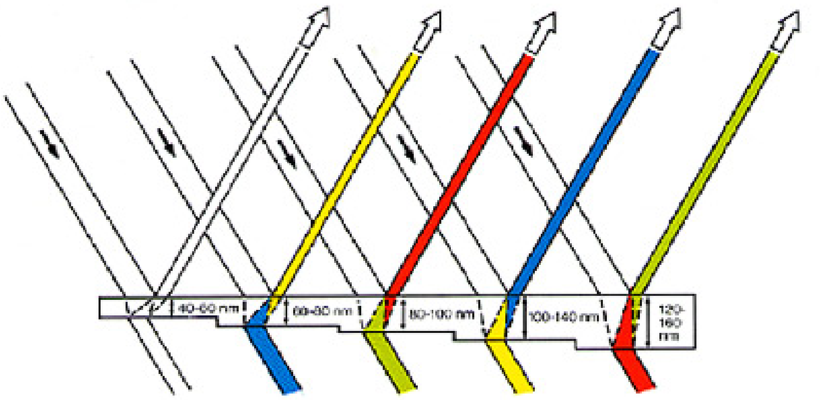


Figure 1.3: The reflection and transmission colors depend on the thickness of the TiO2 [20].

1.2.1.2 Mica

The mica group of sheet silicate minerals consists of materials with having highly basal cleavage which are monoclinic with a leaning to pseudo-hexagonal crystals. The word “mica” is derived from the Latin word micare (meaning “to glitter”) that it refers to the sparkling appearance of this mineral [9].

The natural mica has special characteristics such as being transparent, chemical inert, and temperature stable. The thickness of 100 to 500 nm of mica platelets produces and effect pigment. Therefore, it can be categorized base on its particle size. It means a width of 5-25 m gives a silky gloss effect, 10-50 m is used for brilliant effects and 30-150 m provides glitter effect [9].

1.2.2. Pyrisma pigments

Pyrisma pigment is a new generation of effect pigments for coatings that Merck Company has developed it. It has the maximize Chroma of interference pigments and maximize the performance and then making a new benchmark in Chroma and performance. Pyrisma offers designers new styling possibilities in the fields of color and texture with interference pigments. It also determines its optimal hue angle for the largest possible gamut with a minimum number of pigments and increases the value in use [12, 13].

A common way to discriminate the eight Pyrisma® titanium dioxide interference pigments is done by high color saturation. The Pyrisma® pigments which contains mica particle which has an optimized sized distribution as well as developed titanium oxide interference layer cover the largest possible color space possibly reached with eight pigments. When all eight pigments are mixed together a unique tone appears because they are all perfectly matched. Based on the Merck Color Space Concept, all the pigments display great resistance to environmental influences and have no problem from outdoor applications such as in automotive coatings or architectural facade coatings [13]

1.2.3. Color travel pigments

Color travel pigments are a new pigment which by having thin silica flakes (SiO_2) with uniform and controllable substrate thickness can improved chromatic strength and purity as well as color travel effects. Figure (1.4) shows the scanning electron micrographs of silica flakes and iron oxide coated silica flakes.

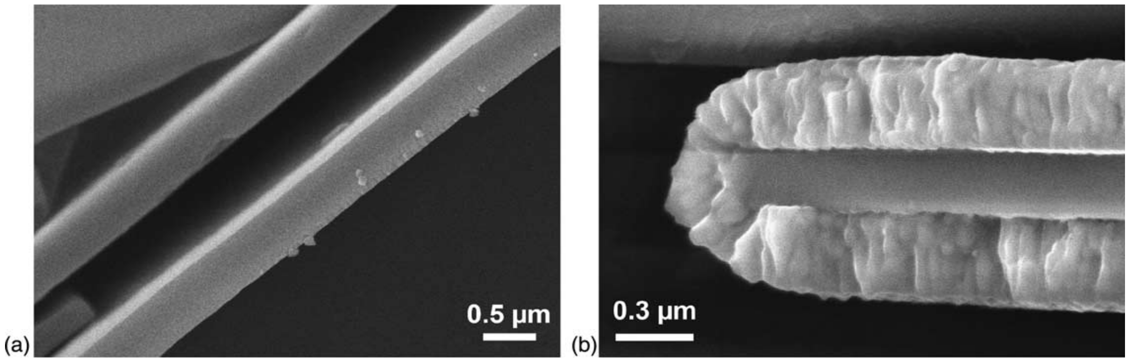


Figure 1.4: Scanning electron micrographs of (a) pure silica flakes and (b) a silica flake coated with $\alpha - Fe_2O_3$ [5].

The substrate surface of color travel pigments is uniform, smooth, and regular. The light can be reflect or refract by the layer. The SiO_2 flake has its own interference color which can be change by layer thickness difference. The thickness of SiO_2 flake and layer thickness of the metal oxide make color effect for color travel pigments together. The thickness of the SiO_2 flakes used in practice is in the order of 400 nm; therefore they are comparable to that of the mica particles' average thickness. Some of the silica-based pigments demonstrate color travel effects such as green-red, violet-green, red-gold or gold-blue. These pigments such as the others have applications in automotive effect coatings, cosmetic formulations, security printings and decorative plastics [4, 12].

1.3. Optical properties

Pearlescent and interference pigments reflect light in a specular manner similar to a mirror. Because the reflection of absorption pigments is scattered and diffuse, when the two are mixed, color effects are observed [10].

Combination of pigments can be formed when absorption colorants are straightforwardly precipitate on interference pigments. In this way, three different colors can be distinguished base on the colorants and the angle of observation. The reflection color from interference pigment is seen at the specular angle, the second color can be observed by absorption colorants at the diffuse angle, and finally the transmission is observed as the third color which is totally different from the reflection and absorption color [10].

1. 3.1. Spectrophotometers for Special Effects Colors

Studying the quality of color components and matching them has always been a challenging work. Metallic and pearlescent pigments which have special effects and change appearance with viewing angle has made a need to introduction an instrument than can measure and quantifying these effects [14].

The researchers who are studying on these special effects desired to know for more consistent and accurate means of quantifying color in the manufacturing process. When evaluating these colors, the most important area that they consider is instrument geometry. Other parts that they focus on them are paint technologies, part configuration, color standards, part orientation, and visual comparison [14].

Older instrument geometries such as diffuse/8, known as sphere, and 0/45, can offer some indication as to what kind of color difference exist but none can provides the correlation to visual assessment or correlation to process parameters needed to make adjustments. Using a multi-angle spectrophotometer make it possible to accurately monitor and control colors [14].

To determine the quantify of the color differences that exist, a equipment which may have several line to line color match areas and multiple components supplied by multiple vendors, painted with differing paint technologies supplied by different paint suppliers, without a single color mismatch issue can be use [14].

Three major geometries of color instrumentation need to be considered for color measurement by using an instrument; the first one is 0/45, and others are 45/0 sphere (d/8) and multi-angle. Each of these geometries is designed to measure particular samples for color of “color and appearance” features [14].

Although the 0/45 geometry instruments can be use in quality control situations where standards and samples have similar textures and gloss levels and do well, the problem is that they can only estimate color at a single angle. So, the appearance of a color at multiple viewing angles which would be required with metallic pearlescent or special effects colors can not be achieved by these instruments [14, 15].

1.3.2. Multi Angle Geometry

As discussed in last parts, the metallic, mica flakes and special effects colors actually change in color when the viewing angle changes; so the multi-angle spectrophotometer which is able to distinguish color variations at different angles of reflection, can be used. For the instrument with 45 degree angle of illumination, detection angles of 15, 25, 45, 75 and 110 are considered. Valuable objective and numerical information can be provided by this type of instrument [14, 15].

A color measurement instrument is a tool for recording the “lifecycle” of any color. The goal is to keep the integrity of a color in design, implementation, production, final assembly and delivery [14, 15].

1.4. Classification of color and color order systems

The spectral reflectance is defined as the "fingerprint" of an object surface and affords the most primary information for the estimation of the object under different viewing condition. It also is very critical in many applications such as textile dye with colorants and an input of computer program for color-matching algorithms.

1.4.1. CIE Colorimetric system

A color depends on three factors to create from physical point of view:

- Light source which lights the object.
- Object which is lit by the source.
- Eyes and brain which receive the color.

Since each of above factors have an important role in the development of color, in order to measure color physically, each of these factors is required [16, 17]. In order to better understand the CIE colorimetric system first need to be reminded that there are two types of color mixing:

A) Subtractive Color Mixing: Subtractive Color Mixing occurs when color materials are combined together, so that each color material attracts part of light and is done by selectively removing certain colors, for instance with optical filters. In subtractive mixing there are three primary colors; yellow, magenta, and cyan. In subtractive mixing of color, all three primary colors are showing. The result is black. The absence of color is white. Figure 1.5 (a) shows the secondary [18, 19].

B) Additive Color Mixing: Additive Color Mixing occurs when two or more light and color was added to each other and are twisted on the certain surface. The three primary colors in additive mixing of colors are three primary colors: red, green, and blue. The black color will be appearing when no colors are showing. All three primary colors make white color (figure 1.5 (b)). The red and green makes yellow and when red and blue combine, the result is magenta. Additive mixing is used in television and computer monitors to produce a wide range of colors using only three primary colors [18, 19].

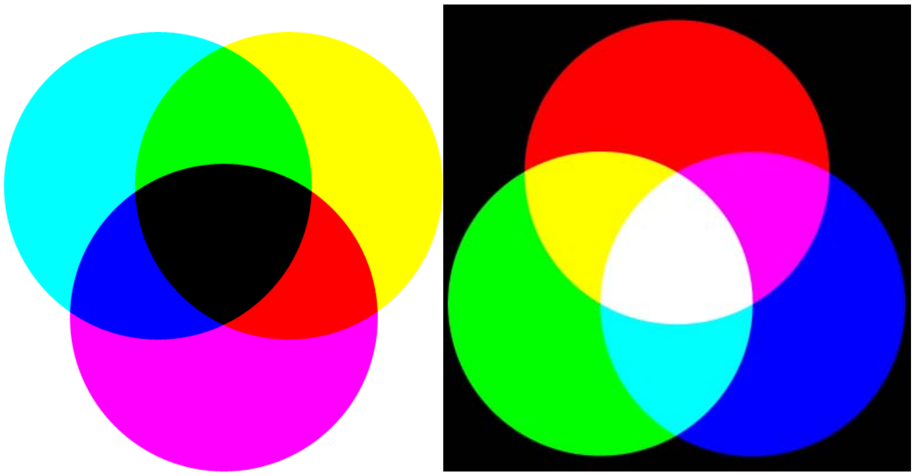


Figure 1.5: a) A simulated example of Subtractive Color Mixing, b) A simulated example of Additive Color Mixing [20].

1.4.1.1. CIEXYZ system

In 1931, the International Commission on Illumination created the CIE 1931 XYZ color space. In this color space, three parameters describe a color sensation. The amounts of three primary colors in a three-component additive color model make the tristimulus values of a color (X, Y, and Z).

Three color-matching functions ($\bar{x}, \bar{y}$, and $\bar{z}$) are defined by CIE as the spectral sensitivity curves of three linear light detectors to yield the CIE XYZ tristimulus values X, Y, and Z [1].

$$X = \sum_{\lambda=400}^{700} \bar{x}.R.E \tag{1.1}$$

$$Y = \sum_{\lambda=400}^{700} \bar{y}.R.E \tag{1.2}$$

$$Z = \sum_{\lambda=400}^{700} \bar{z}.R.E \tag{1.3}$$

here, R is the Spectral reflection and E is Spectral power distribution of light source.

1.4.1.2. The CIE *xy* chromaticity diagram.

The brightness and chromaticity are two concept of color. The CIE XYZ color space was intentionally designed, with the intention that the brightness or luminance of a color defined as the Y parameter. Then the chromaticity of a color was specified by the two derived parameters x and y, two of the three normalized values which are functions of all three tristimulus values (X, Y, and Z) [1]:

$$x = \frac{X}{X + Y + Z} \quad (1.4)$$

$$y = \frac{Y}{X + Y + Z} \quad (1.5)$$

$$z = \frac{Z}{Z + X + Y} \quad (1.6)$$

The CIE xyY color space is derived by x, y, and Y.

1.4.1.3. CIELAB color order system

In 1973, Mac Adam suggested to exchange the third root function of L * instead of Munsell data in ANLAB space in order to get a more uniform space and simplify calculations. The reform formally proposed in 1976 as a color space 1976 CIEL * a * b and it officially recognized under the letters CIELAB. L*, a*, and b* are three coordinates of CIELAB which respectively represent the lightness of the color (L*) that 0 valu for L* yields black and 100 indicates diffuse white; its position between red/magenta and green (a*) that green are in the negative values despite the fact that positive values indicate magenta and finally its position between yellow and blue (b*) that negative values indicate blue and positive values indicate yellow [1].

The equations (1-7) to (1-9) are related to conversion of the CIE tristimulus to CIELAB chromaticity coordinates:

$$L* = 116(Y / Y_n)^{1/3} - 16 \quad (1\text{-}7)$$

$$a* = 500[(X / X_n)^{1/3} - (Y / Y_n)^{1/3}] \quad (1\text{-}8)$$

$$b^* = 200[(Y/Y_n)^{1/3} - (Z/Z_n)^{1/3}] \quad (1\text{-}9)$$

here, X_n, Y_n, and Z_n are the CIE XYZ tristimulus values of the reference white point (the subscript n suggests "normalized") [16].

In this system, the purity is calculated according to equation (1-10) [1]:

$$c^*_{ab} = \sqrt{a^{*2} + b^{*2}} \quad (1\text{-}10)$$

In addition, equation (1-11) shows the CIELAB color difference between two samples [1]:

$$\Delta E = \sqrt{\left(L_1^* - L_2^*\right)^2 + \left(a_1^* - a_2^*\right)^2 + \left(b_1^* - b_2^*\right)^2} \quad (1\text{-}11)$$

CHAPTER 2:

Aim and Problem formulation

2. Aim and Problem formulation

2.1. Aim

The aim of the project is to study pearl luster and color travel pigments and their optical mechanisms. State of the art, using effect pigments for textile applications, in general and also more specific for technical textiles as well as possibility to get reproducibility in the printing process will be reviewed. Possibility to plot the figures for the effect pigments in a CIE diagram and its special equipment needed for that will also be considered.

2.2. Problem formulation

Patterns on textile fabric which changes its expression by using effect pigments were printed. Then the colors of samples were investigated in CIE diagram in five different angles. For finding the textile application in general, and how much people like using these special pigments, some questions about the fabric, printed by effect pigments, were asked from randomly chosen people. Finally, all pigments were printed on same fabric for second time to investigate whether it is possible to get reproducibility in the printing process or not.

CHAPTER 3:

Practical Works

3. Practical Works

3.1. Materials and Instruments

3.1.1. Materials

a) Pigments:

The information of the pigments which were used in this project, are listed in the Table (3-1).

Table 3.1: Six effect pigments data.

COMMERCIAL NAME	CHEMICAL COMPOSITION (%)			INTERFERENCE COLOR
	Mica	TiO_2 *(rutile)*	SnO_2	
4597 Iriodin 225 Rutile Blue Pearl	46-51	49-53	0-1	Blue
4288 Iriodin 9225 Rutile Blue Pearl SW	47-55	45-52	0-1	Blue
41099 Pyrisma T30-27 Indigo	43-58	35-45	7-12	Lilac-blue
41099 Pyrisma T40-27 Indigo	43-58	35-45	7-12	Lilac-blue
40897 Colorstream T10-03 Tropic Sunrise	51-64	35-45	1-4	Green/silver/red/orange
58096 Colorstream T20-03 WNT Tropic Sunrise	49-59	39-45	1-3 ZnO_2 = 0-3	Green/silver/red/orange

b) Binder:

The binder was used is acrylate.

c) Fabric:

Type: polyamide and cotton/PET (50%/50%)

3.1.2. Instrument:

a) Dying machine

b) Spectrophotometer instrument

The information of spectrophotometer instrument is listed below:

Model: MA 68B (MA 68 II)

Ser Nr: 100 239

X-Rite Inc Grandville, MI

15, 25, 45, 75, 110 Grd

Production year: 1997

3.2. Method

3.2.1. Dyeing

In order to investigation of the pigments on black and white fabrics, the polyamide fabrics were dyed by black dye and black fabrics were achieved.

3.2.2. Printing

In this part, in order to find the best ratio of the pigments in the emulsion, the fabrics were printed by different ratio from 5% to 20%. Since, the samples which printed by 20% concentration effect pigments have more effect on fabric, other samples were prepaid by this concentration. As the goal of this project is investigation of the effect pigments and finds the textile application for these pigments, the samples are prepaid in different conditions and on different fabrics. The informations of all samples are listed in below:

Sample number 1:

Polyamide fabric (white) is printed by Iriodin 225 (20%) pigment.

Sample number 2:

Polyamide fabric (white) is printed by Iriodin 9225 (20%) pigment.

Sample number 3:

Polyamide fabric (white) is printed by Iriodin 225 (20%) pigment and Blue pigment (0.25%).

Sample number 4:

Polyamide fabric (white) is printed by Blue pigment (0.20%).

Sample number 5:

Polyamide fabric (black) is printed by Iriodin 225 (20%) pigment.

Sample number 6:

Polyamide fabric (black) is printed by Iriodin 9225 (20%) pigment.

Sample number 7:

Polyamide fabric (white) is printed by Iriodin 9225 (20%) pigment (reproduction).

Sample number 8:

Cotton/PET (50%/50%) fabric (white) is printed by Iriodin 9225 (20%) pigment.

Sample number 9:

Polyamide fabric (white) is printed by Pyrisma T30-27 Indigo (5%) pigment.

Sample number 10:

Polyamide fabric (white) is printed by Pyrisma T30-27 Indigo (20%) pigment.

Sample number 11:

Polyamide fabric (white) is printed by Pyrisma T40-27 Indigo (20%) pigment.

Sample number 12:

Polyamide fabric (black) is printed by Pyrisma T40-27 Indigo (20%) pigment.

Sample number 13:

Polyamide fabric (black) is printed by Pyrisma T30-27 Indigo (20%) pigment.

Sample number 14:

Polyamide fabric (white) is printed by pink pigment (0.25%).

Sample number 15:

Polyamide fabric (white) is printed by Pyrisma T40-27 Indigo (20%) pigment and pink pigment (0.25%).

Sample number 16:

Polyamide fabric (white) is printed by Pyrisma T40-27 Indigo (20%) pigment (reproduction).

Sample number 17:

Cotton/PET (50%/50%) fabric (white) is printed by Pyrisma T40-27 Indigo (20%) pigment.

Sample number 18:

Polyamide fabric (white) is printed by Iriodin 9225 (10%) and Pyrisma T40-27 Indigo (10%) pigments.

Sample number 19:

Polyamide fabric (white) is printed by Colorstream T10-3 (20%) pigment.

Sample number 20:

Polyamide fabric (white) is printed by Colorstream T20-3 (20%) pigment.

Sample number 21:

Polyamide fabric (black) is printed by Colorstream T10-3 (20%) pigment.

Sample number 22:

Polyamide fabric (black) is printed by Colorstream T20-3 (20%) pigment.

Sample number 23:

Polyamide fabric (white) is printed by Colorstream T20-3 (20%) pigment (reproduction).

Sample number 24:

Polyamide fabric (white) without printing.

Sample number 25:

Polyamide fabric (black) without printing.

3.3. Program used (Matlab)

In order to plot data in two and three dimensional, the Matlab program was used in this work. One example of the program, which is written, is attached in the appendix A.

CHAPTER 4:

Results and Discussion

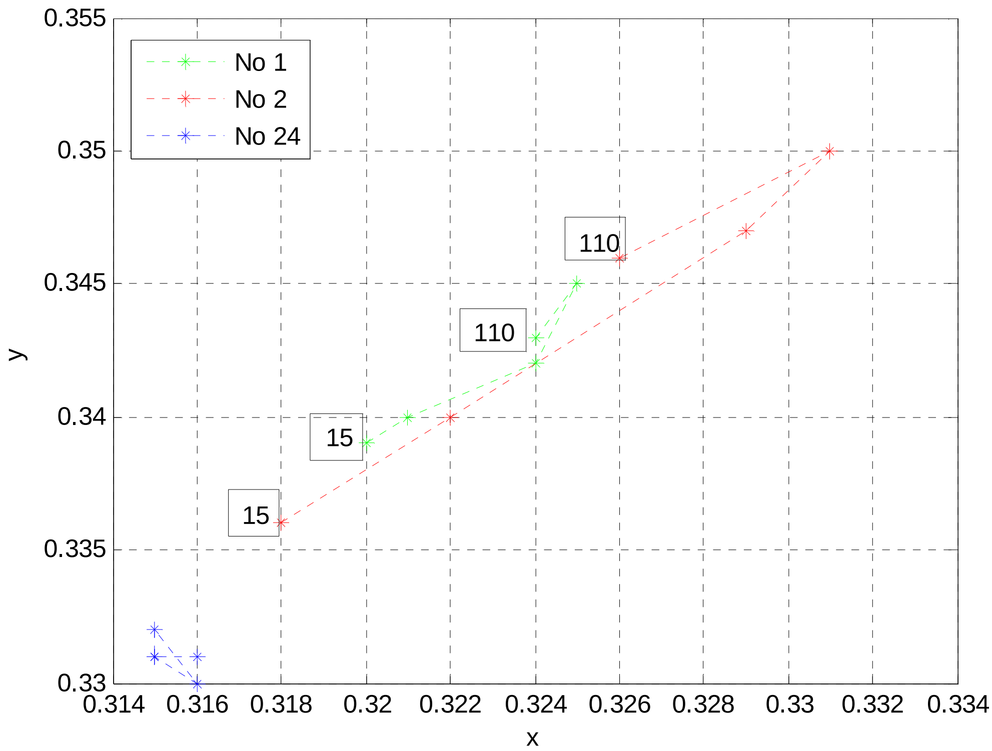
4. Results and Discussion

4.1. Determine the color gamut in color space CIExy

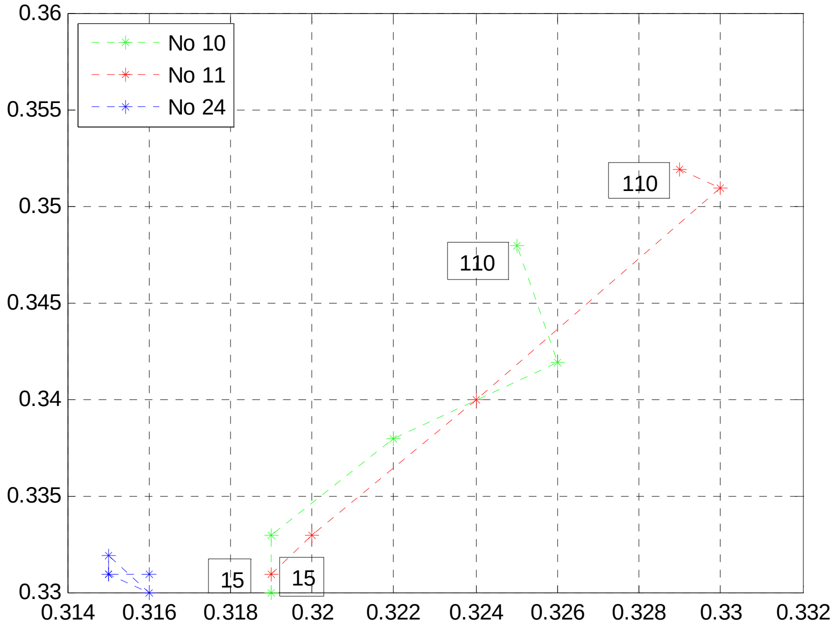
The tristimulus values of all samples were determined under the CIE Illuminant D65 and in five different angles: 15, 25, 45, 75, and 110 are listed in appendix B (table (7.1)).

In order to determine the color gamut of six effect pigments (Iriodin 9225, Iriodin 225, Pyrisma T30-27, Pyrisma T40-27, Colorstream T10-3, and Colorstream T20-3) in the CIExy color space, first the tristimulus values of the samples, printed by these pigments on white fabrics (samples number 1, 2, 10, 11, 19, and 20), were plotted in xy diagram (figure (4.1)). In figure (4.1), the difference between each sample and sample without printing (sample number 24) was shown.

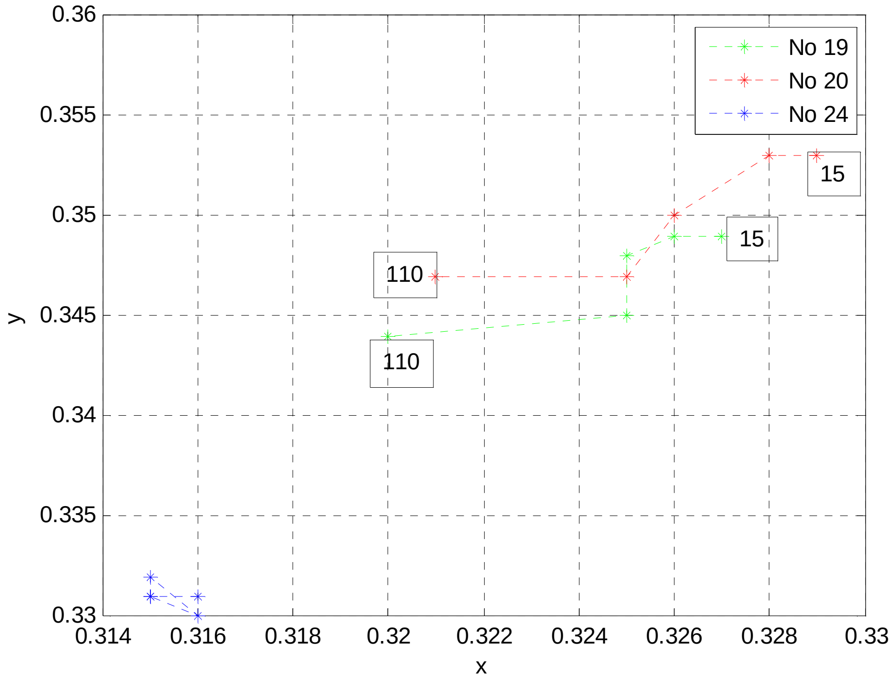
In all diagrams, 15 means the tristimulus value in 15 degree and 110 means 110 degree and other stars, between 15 and 110, show the tristimulus values in 25, 45, and 75 degrees respectively.



(a)



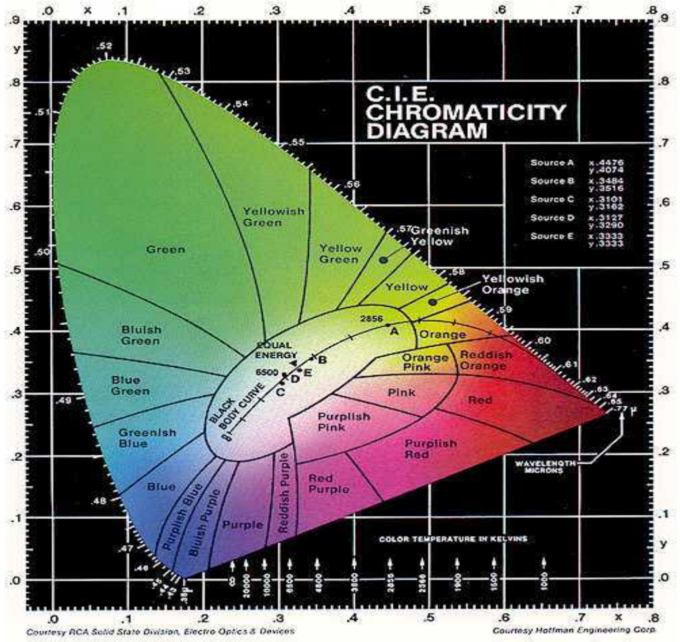
(b)



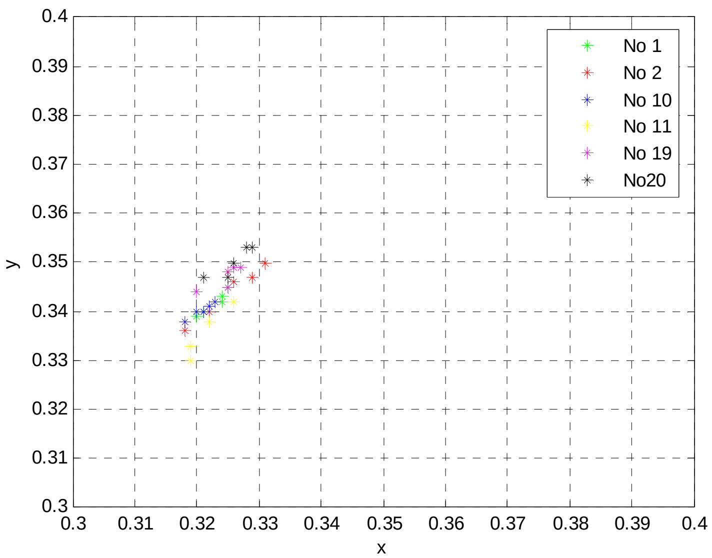
(c)

Figure 4.1: The CIExy color system of samples number a) 1 & 2, b) 10 & 11, and c) 19 & 20.

As we can see in figure (4.1) and table (7.1), the differences in x, y, and z values for each pigment in different angles are very small. Figure (4.2) shows the place of all six pigments in CIE-Chromaticity diagram.



(a)



(b)

Figure 4.2: a) CIE. Chromaticity diagram b) CIExy of samples number 1, 2, 10, 11, 19, and 20.

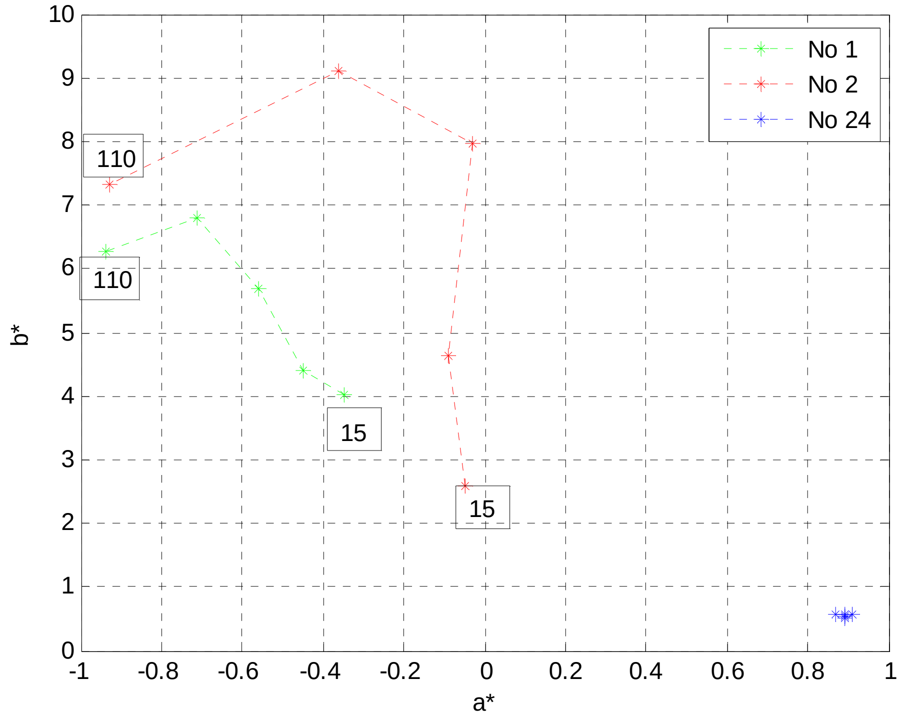
Figure (4.2) shows the CIE chromaticity diagram (part a) and the samples number 1, 2, 10, 11, 19, and 20 are plotted in the same diagram (part b). Considering that in the part (a) the axis are between 0 and 0.9, and in part (b) are between 0.3 and 0.4, we can find the place of theses pigments in the CIE chromaticity diagram. All six pigments almost are in the white area with a lead to yellow and green.

4.2. Determine the color gamut in color space CIE L*a*b*

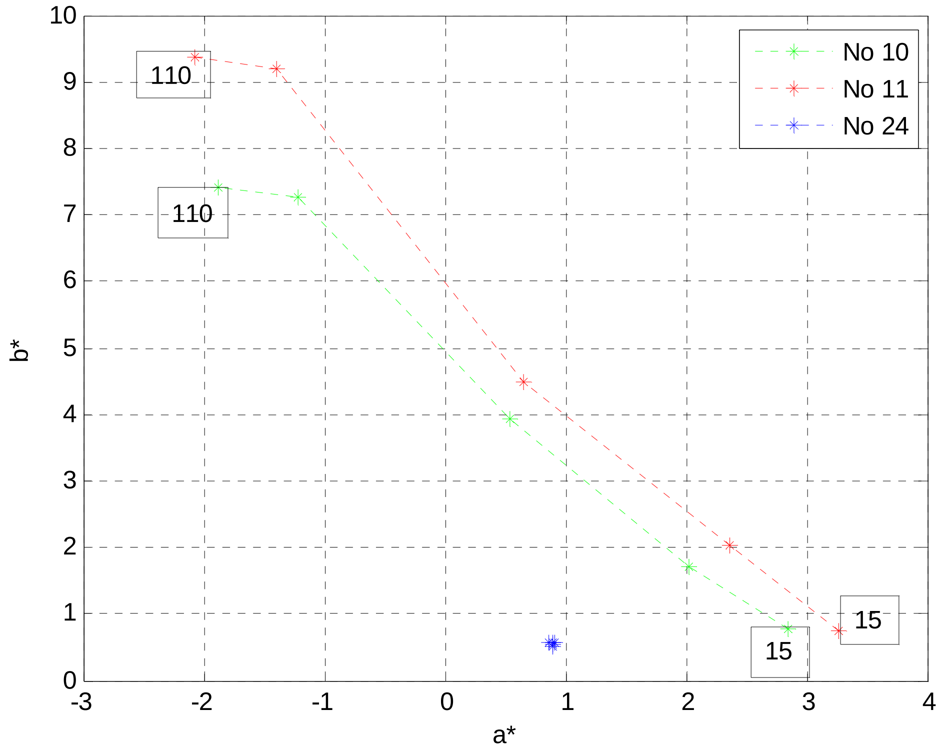
The chromaticity coordinates of all samples were determined under the CIE Illuminant D65 and in five different angles: 15, 25, 45, 75, and 110 (listed in appendix B (table (7.2))).

In order to determine the gamut of color for six effect pigments (Iriodin 9225, Iriodin 225, Pyrisma T30-27, Pyrisma T40-27, Colorstream T10-3, Colorstream T20-3), first the chromaticity coordinates of the samples, printed by these pigments on white fabrics (samples number 1, 2, 10, 11, 19, and 20), were plotted in CIEL*a*b* diagram (figure (4.3)). In figure (4.3), the difference between each sample and sample without printing (sample number 24) was shown.

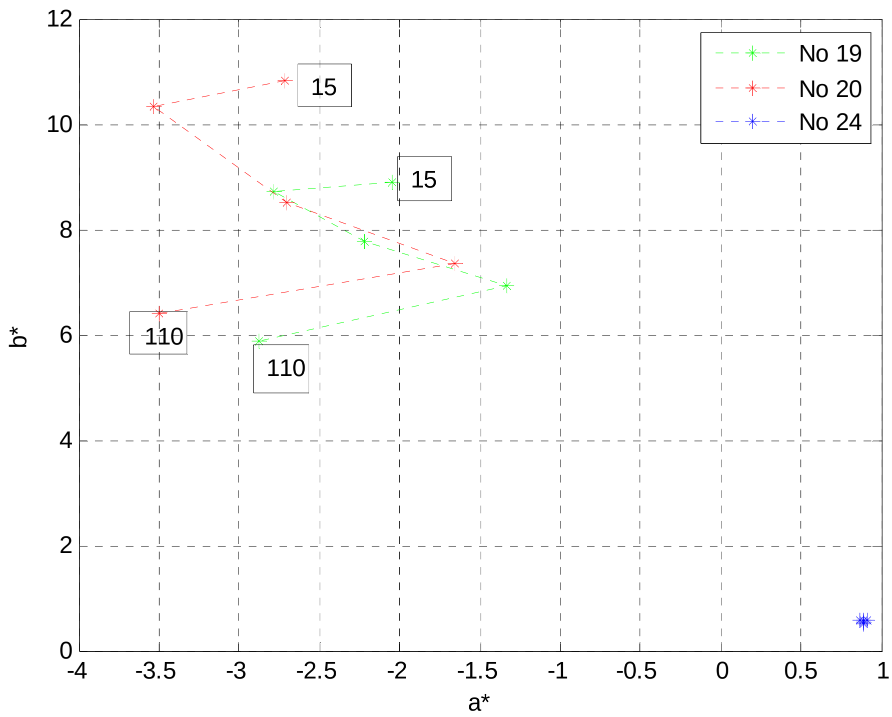
In all diagrams, 15 means the chromaticity coordinates in 15 degree and 110 means 110 degree and other stars, between 15 and 110, show the chromaticity coordinates in 25, 45, and 75 degrees respectively.


No 1
No 2
No 24
110
110
15
15
b*
a*
10
9
8
7
6
5
4
3
2
1
0
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1

(a)

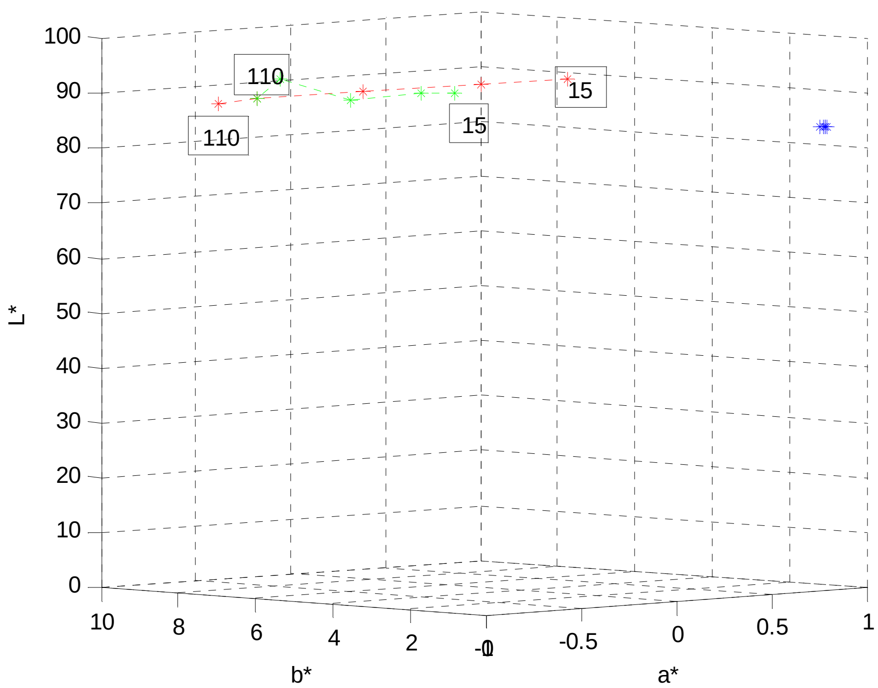

No 10
No 11
No 24
110
110
15
15
b*
a*
10
9
8
7
6
5
4
3
2
1
0
-3
-2
-1
0
1
2
3
4

(b)

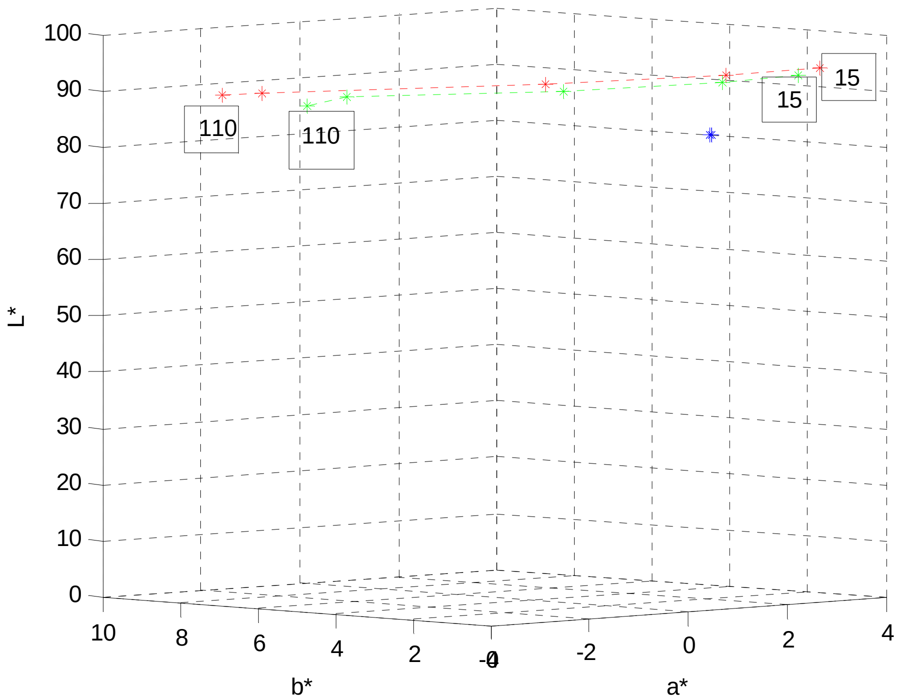


(c)

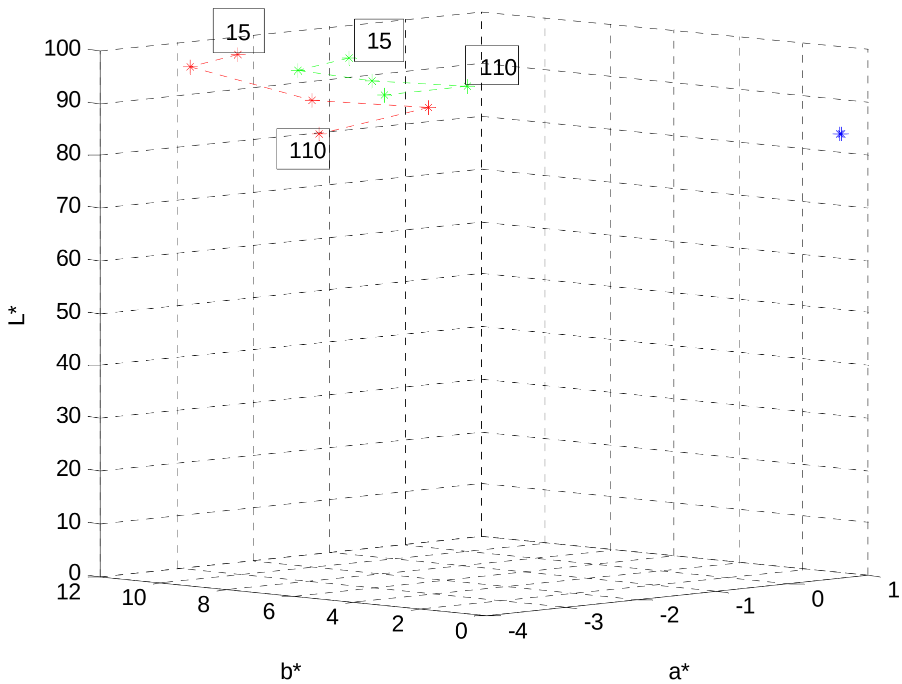
Figure 4.3: The CIEa*b* color space of samples number a) 1 & 2, b) 10 & 11, and c) 19 & 20.



(a)



(b)



(c)

Figure 4.4: The CIEL*a*b* color space of samples number a) 1 & 2, b) 10 & 11, and c) 19 & 20.

According to the chapter (4.1), all six pigments almost are in the white region by leading to the yellow and green in the CIE chromaticity diagram. In this section, we discussed the color gamut in CIEL*a*b*. In CIE, color stimulus are exhibited L* as brightness and two chromatic channel yellow-blue (b*) and red-green (a*).

For instance, the a*, and b* values for sample number 1 are between (-0.94, -0.35) and (4.03, 6.81) respectively, which from these values we can say that the sample number 1 has color between yellow and green, but this is not enough and therefore the brightness factor was added to determine the color gamut precisely. So the three dimensional diagram were plotted in figure (4.4). The brightness values (L*) for sample number 1 are between (89.85, 93.49). Theses values show that the sample number 1 has a high brightness, therefore the color of sample number 1 looks like a light mixture of green and yellow. Five other pigments have been studied and the results are listed in the table (4.1).

Table 4.1: Color gamut of six pigments used in project base on CIE L*a*b*.

Sample's Number	***Range of a****	***Range of b****	***Rang of L****	Results
2	-0.03 – -0.93	2.58 – 9.11	87.77 – 93.88	Mixture of Green - yellow with high brightness.
10	-1.88 – 2.84	0.78 – 7.42	87.25 – 93.28	Mixtures of Green - yellow and red - yellow with high brightness.
11	-2.7 – 3.26	0.75 – 9.37	88.60 – 94.40	Mixtures of Green - yellow and red - yellow with high brightness.
19	-2.88 – -1.33	5.87 – 8.91	92.30 – 97.60	Mixture of Green - yellow with high brightness.
20	-3.53 – -1.65	6.42 – 10.81	86.67 – 98.05	Mixture of Green - yellow with high brightness.

In parts 4.1 and 4.2, the color gamuts of six pigments used in this project were discussed. In the next part, the different angels and their effects on the color fabric will be discussed.

4.3. Study pigments which used by different angles

The tristimulus values and the chromaticity coordinates of all samples in five different angles (15, 25, 45, 75, and 110) were reported in appendix B (tables (7.1) and (7.2)) and their diagrams were plotted in figures (4.1) to (4.4). As it is clear, the tristimulus values don't change a lot in different angles which is predictable because color space CIExy doesn't show little differences in color difference truly. Whereas color space CIEL*a*b* shows these differences better. For example, L*, a*, and b* values for sample number 11 in 5 angles respectively are 94.40, 3.26 and 0.75 for 15 degree, 93.08, 2.36 and 2.02 for 25 degree, 91.01, 0.65 and 4.59 for 45 degree, 88.60, -1.22 and 7.26 for 75 degree, and 88.61, -2.97 and 9.37 for 110 degree. From these values we can conclude that sample number 11 ,which was printed by Pyrisma T40-27 Indigo (20%) pigment, in 15 degree looks like a very light red (maybe even better to say pink). In 25 degree the color of sample changes a little and is mixture of light red and light yellow. By changing the angle from 25 to 45, the sample's color is yellower than 25 degree and in 75 degree it turns to green and yellow and finally in 110 degree, the sample is more yellow and green in compare to 75 degree with the same brightness. As discussed above, the sample number 11 shows different color in difference angles in color space CIEL*a*b*, but whether human visualization observes the same, is an open question. This will be discussed in chapter (4.5). Five other pigments have been studied and the results are listed in the table (4.2).

Table 4.2: The color of six pigments in five different detection angles.

Sample's Number	***(L*, a*, b*) 15 degree***	***(L*, a*, b*) 25 degree***	***(L*, a*, b*) 45 degree***	***(L*, a*, b*) 75 degree***	**(L*, a*, b*) 110 degree**
1	(91.2, -0.35, 4.0)	(91.3, -0.45, 4.4)	(89.8, -0.56, 5.6)	(90.6, -0.71, 6.8)	(93.4, -0.94, 6.2)
	Mixture of yellow and green (high brightness)	The same as 15 degree	A little yellower and greener than 15 and 25 degree	Yellower and greener than three other angles	Greener than other angels
2	(93.8, -0.05, 2.5)	(91.9, -0.09, 4.63)	(88.8, -0.03, 7.98)	(87.7, -0.36, 9.11)	(89.1, -0.93, 7.31)
	Yellow (high brightness)	yellower and lower brightness than 15 degree	Yellower and lower brightness than two others	Mixture of Yellow and green (lower brightness than others)	Less yellow and greener than 75 degree
10	(93.2, 2.84, 0.78)	(92.1, 2.02, 1.71)	(90.2, 0.54, 3.92)	(88.70, -1.22, 7.26)	(87.2, -1.88, 7.42)
	Very light red (pink)	The same as 15 degree	yellower than two other angels	Mixture of yellow and green and lower brightness than others	The same as 75 degree
19	(97.6, -2.05, 8.91)	(96.3, -2.79, 8.72)	(93.9, -2.22, 7.78)	(92.3, -1.33, 6.93)	(93.6, -2.88, 5.87)
	Mixture of yellow and green (high brightness which makes it look like gray or silver)	The same as 15 degree	The same as 15 and 25 degrees but less brightness	Less green than other angles	Greener and less yellow than others
20	(98.0, -2.70, 10.8)	(95.3, -3.53, 10.34)	(90.7, -2.70, 8.51)	(88.5, -1.65, 7.35)	(86.6 -3.50, 6.42)
	Mixture of yellow and green (high brightness which makes it look like gray or silver)	Greener than 15 degree with lower brightness	Less yellow with lower brightness than 15 and 25 degrees	Less green and yellow and lower brightness than 15, 25, and 75 degrees	Greener and less yellow and lower brightness than others (it is less silver than others)

The samples number 10, and 11, printed by Pyrisma pigments, reflects colors more differently by changing angles than other pigments which used in this project. As one can say from the table (4.2), the color differences between different angles for other pigments are not sensible a lot. Even thought, these pigments are effect pigments and one of the most important characteristic of these pigments is showing variable color in different illumination/detection angles, they don’t have this characteristic on the fabric truly.

4.4. Color differences

In this chapter, samples are compared with together. The CIELAB color differences were calculated between the two samples, using the equation (1.11).

The samples compared with each other and ΔE values are categorized in table (4.3):

Table 4.3: The ΔE values for samples which are compared together.

Number	The samples which are compare	ΔE
1	Sample number 1 and sample number 24.	9.0376
2	Sample number 2 and sample number 24.	9.2670
3	Sample number 3 and sample number 4.	5.9416
4	Sample number 5 and sample number 25.	25.7839
5	Sample number 6 and sample number 25.	22.3879
6	Sample number 7 and sample number 2.	3.1134
7	Sample number 8 and sample number 2.	2.2154
8	Sample number 9 and sample number 24.	9.1015
9	Sample number 10 and sample number 24.	8.3225
10	Sample number 9 and sample number 10.	4.5838
11	Sample number 11 and sample number 24.	9.7398
12	Sample number 12 and sample number 25.	23.5863
13	Sample number 13 and sample number 25.	27.2876
14	Sample number 14 and sample number 15.	7.5053
15	Sample number 16 and sample number 11.	1.2444
16	Sample number 17 and sample number 11.	3.3081
17	Sample number 18 and sample number 24.	10.7390
18	Sample number 18 and sample number 2.	2.5252
19	Sample number 18 and sample number 11.	2.7871
20	Sample number 19 and sample number 24.	13.3591
21	Sample number 20 and sample number 24.	12.4940
22	Sample number 21 and sample number 25.	25.6732
23	Sample number 22 and sample number 25.	56.6667
24	Sample number 23 and sample number 20.	2.2080

The comparison between samples for Iriodin pigments are reported in this section. The results for Pyrisma and Colorstream pigments are also relevant, so they are reported in appendix C.

4.4.1. Samples number 1, and 2.

The CIE chromaticity diagram and CIEL*a*b* diagram for samples number 1 and 2, printed by Iriodin 225 and 9225 (20%), were plotted in chapter (4.3). the ΔE value for these samples with unprinted fabric are 9.0376 and 9.2670 which are very high value for color difference and show big difference between samples by effect pigments and without effect pigments.

4.4.2. Samples number 3, and 4.

The CIEa*b* diagram for samples, which were printed by Iriodin 225 (20%) pigment with Blue pigment (0.25%) (number 3), and only Blue pigment (0.25%) (number 4), are plotted in figure (4.5).

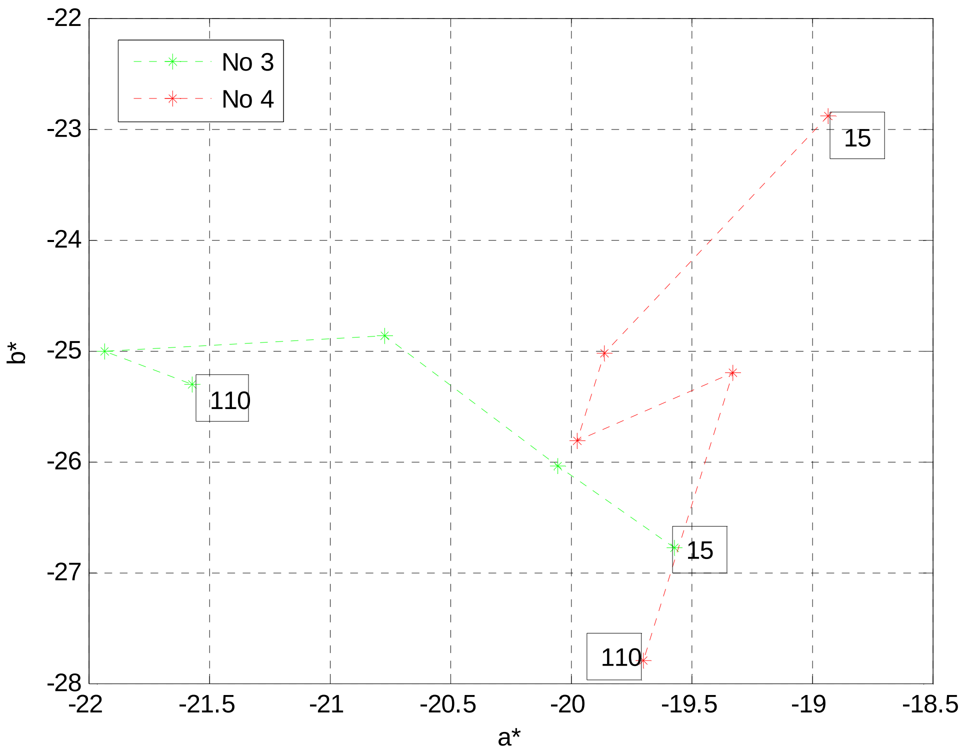


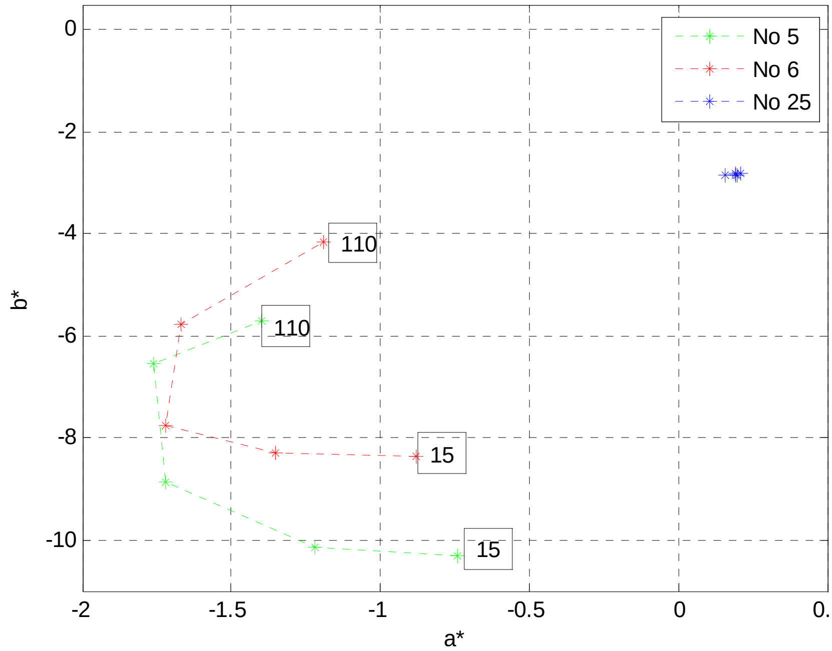
Figure 4.5: The CIEa*b* color space of samples number 3 and 4.

According to the figure (4.5), in the CIEa*b* color space, the samples number 3 and 4 are in the same color gamut (green and blue) but their brightness are different and then ΔE value for them is 5.9416. The brightness in sample number 4, just printed by blue pigment is more than sample number 3 that effect pigment was also added to the blue pigment. This result is not predictable for effect pigments because they should decrease the brightness by making effect on fabric.

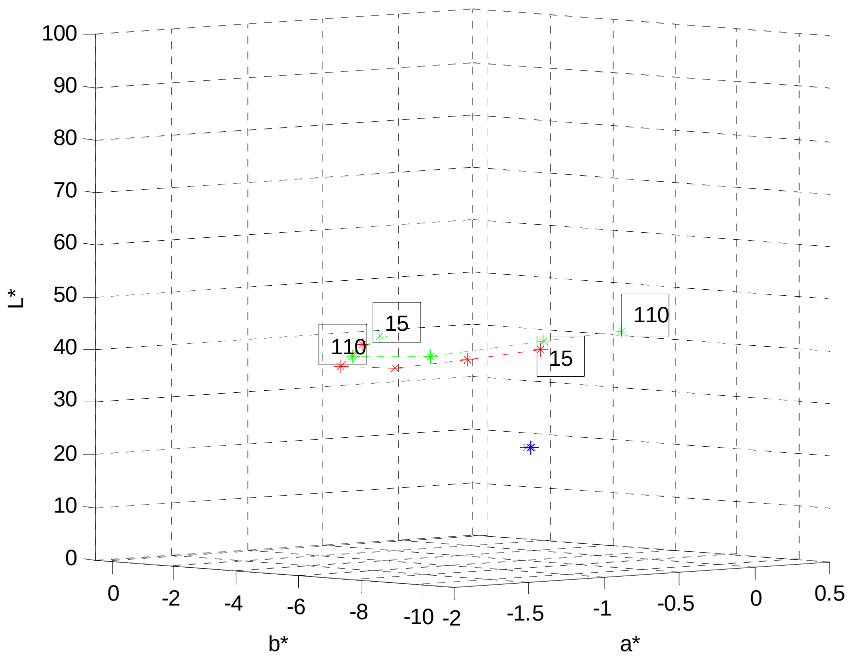
4.4.3. Samples number 5, and 6.

Figure (4.6) shows the chromaticity coordinates of the samples number 5 and 6, printed by Iriodin 225 and 9225 (20%) on black fabrics.

The samples, printed on black fabric are completely blue. As we can see in figure (4.6) (part b) their brightness are much more than unprinted black fabric. Comparing the white fabric and black one, the ΔE value from samples number 1 & 24 and also 2 & 24 are 9.0376 and 9.2670. These values for samples number 5 & 25 and 6 & 25 are 25.7839 and 22.3879. So, the Iriodin pigments have a much more effect on black fabric. They completely change the color of fabric from black to blue. Therefore, the Iriodin pigments change the color of white fabric to yellow and they make blue color for black fabrics.



(a)



(b)

Figure 4.6: a) The CIEa*b* color space, b) The CIEL*a*b* color space of samples number 5 and 6.

4.4.4. Sample number 7.

Samples number 7 was printed by Iriodin 9225 (20%) pigment for the second time to investigate whether it is possible to get reproducibility in the printing process or not. So in this part the sample number 7 is compared with sample number 2, printed the same as number 7. Figure (4.7) shows the chromaticity coordinates of the samples number 2 and 7.

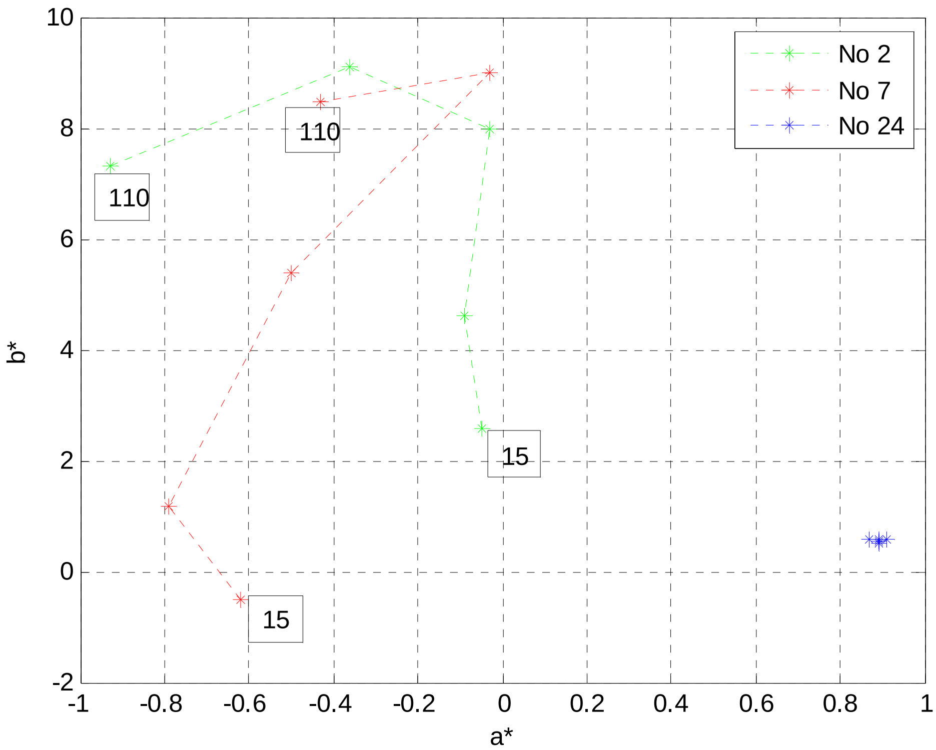


Figure 4.7: The CIEa*b* color space of samples number 2 and 7.

The sample number 7 is tending towards the blue area in CIEa*b* diagram. The chromaticity coordinates of samples number 2 and 7 are very close; but the ΔE value for samles number 2 and 7 is 3.1134 that it is big value and it shows that the reproducibility of Iriodin 9225 pigments isn't very good.

4.4.5. Sample number 8.

To investigate how important is the texture of fabric, used with effect pigments, the samples number 8, which Iriodin 9225 was printed on cotton/polyester (50%/50%) fabric, was produced. The CIEa*b* diagram of samples number 8 and 2 is plotted in figure (4.8).

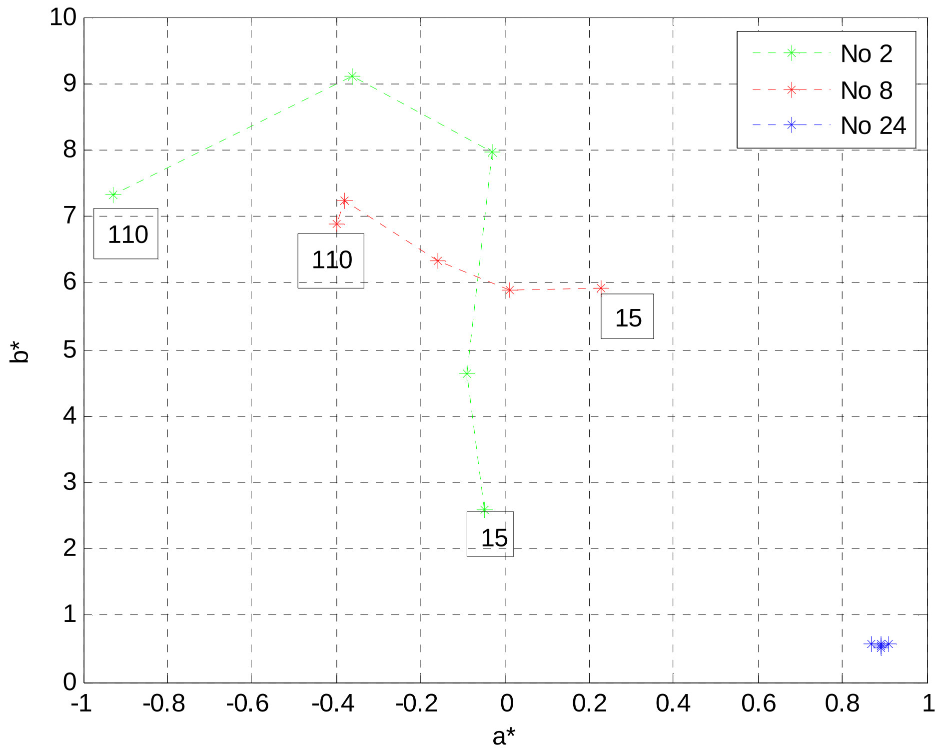


Figure 4.8: The CIEa*b* color space of samples number 2 and 8.

According to the table (4.5), the ΔE value of number 2 and 8 is 2.2154 which it shows two different fabrics have different color by using same Iridion pigment but this difference is not very big. Figure (4.8) also shows this fact.

4.5. Statistical result

As discussed before, effect pigments used in this project have ability to show the elegant luster and they have become very popular in the creation of luster effects in coatings. These pigments have discussed from color science point of view in section (4.1) to (4.4). In this chapter, the result from a statistical work is reported in order to investigate the feeling of human about this special pigments and how much they would like to use these pigments. For this goal, some questions about the fabric, which are printed by effect pigments, were asked from 27 persons. These questions asked from people who never have seen samples before when I asked them and also all 27 have been asked in the same situation (same place and same light). The question was also same for all (the question's form is attached in the appendix D). In addition, the mean age of people who has been asked is 31. The results of this work are categorized in table (4.4).

Table 4.4: Statistical results for a) Iriodin 9225, b) Iriodin 225, c) Pyrisma T30-27, d) Pyrisma T40-27, e) Colorstream T10-03, and f) Colorstream T20-03.

(a)

pigment	Iriodin 225 Rutile Blue
Special effect	72.2% say this pigment on fabric has special effect.
Color (white fabric)	54%: cream and white, 27%: silver, 18%: brown and yellow.
Color (black fabric)	57.2%: gray, 42.8%: blue.
Color difference in different angles(white fabric)	62%: Yes, 38%: No.
Color difference in different angles(black fabric)	56%: Yes, 44%: No.
How much like this color and prefer use it more than none effect one.	42%: like this color for women cloths, 35%: doesn't like to use it. 23%: say depending on design and price they can decide to wear cloths by these color.

(b)

pigment	**Iriodin 9225 Rutile Blue**
Special effect	70% say this pigment on fabric has special effect.
Color (white fabric)	50%: cream and white, 30%: silver, 20%: brown and yellow.
Color (black fabric)	52%: blue, 48%: gray.
Color difference in different angles(white fabric)	55%: No, 45%: Yes.
Color difference in different angles(black fabric)	74%: Yes, 26%: No.
How much like this color and prefer use it more than none effect one.	32%: like this color for women cloths, 50%: doesn't like to use it. 18%: say depending on design and price they can decide to wear cloths by these color.
Reproducibility	75%: Yes, 25%: No.

(c)

pigment	**Pyrisma T30-27 Indigo**
Special effect	56.25 % say this pigment on fabric has special effect.
Color (white fabric)	33.3%: cream and white, 33.3%: yellow, 22.2%: pink and light green, 11.1%: silver.
Color (black fabric)	42.8%: violet, 28.7%: Purple, 28.5% gray with green part.
Color difference in different angles(white fabric)	65%: No, 35%: Yes.
Color difference in different angles(black fabric)	77%: Yes, 23%: No.
How much like this color and prefer use it more than none effect one.	52%: like use this color for night dresses, 23%: doesn't like to use it. 25%: think this color is good for baby cloths.

(d)

pigment	Pyrisma T40-27 Indigo
Special effect	50 % say this pigment on fabric has special effect.
Color (white fabric)	33.3%: yellow, 33.3%: light green, 22.2%: cream and white, and 11.1%: pink.
Color (black fabric)	32%: violet, 30%: yellow with green, 21%: Purple, 19%: gray.
Color difference in different angles(white fabric)	50%: No, 50%: Yes.
Color difference in different angles(black fabric)	75%: Yes, 25%: No.
How much like this color and prefer use it more than none effect one.	52%: like to use this color, 25%: doesn’t like to use it. 23%: like color but don’t like wear cloth by this color.
Reproducibility	83.33%: Yes, 16.67%: No.

(e)

pigment	Colorstream T10-03 Tropic Sunrise
Special effect	87.5 % say this pigment on fabric has special effect.
Color (white fabric)	44.4%: green, 22.2%: yellow, 22.2%: silver and blue, and 11.1%: pink.
Color (black fabric)	33.3%: green, 22.2%: yellow, 22.2%: silver, 11.1% brown, and 11.1%: pink.
Color difference in different angles(white fabric)	100%: Yes.
Color difference in different angles(black fabric)	100%: Yes.
How much like this color and prefer use it more than none effect one.	80%: like to use this color, 20%: like color but don’t like wear cloth by this color.

(f)

pigment	**Colorstream T20-03 WNT Tropic Sunrise**
Special effect	100 % say this pigment on fabric has special effect.
Color (white fabric)	40%: green, 30%: yellow and orange, 20%: silver and blue, and 10%: pink.
Color (black fabric)	36.3%: green, 27.2%: yellow, 18.1%: pink, 9.1% blue, and 9.1%: cream.
Color difference in different angles(white fabric)	100%: Yes.
Color difference in different angles(black fabric)	100%: Yes.
How much like this color and prefer use it more than none effect one.	80%: like to use this color (33% recommend this color for t-shirt and 24% for women night dresses), 20%: like color but don't like wear cloth by this color.
Reproducibility	61.11%: Yes, 38.89%: No.

CHAPTER 5:

Conclusion

5. Conclusion

The six effect pigments, used in this project, have been investigated in both CIE Colorimetric system and human visualization. In chapter 4 and appendix C, all 25 samples are plotted in CIE diagram (CIExy and CIEL*a*b*); and the colors of fabrics, printed by these six different pigments, have been studied. In addition, the colors which people see from these samples have been asked from randomly chosen people and compared with colors from science point of view. For instance, according to chapters (4.2) and (4.3) the color of fabric, printed by Iriodin 225 Rutile Blue pigment on white fabric, is light yellow or light green that the color of fabric changes between these two colors in different angles. In contrast, the color of same fabric for human eyes is different. According to table (4.4), 54% of people see the color of fabric as cream or white, 27% silver and others brown and yellow. As we can see nobody see the green color on samples and less than 18% of people see the yellow on fabrics. This result demonstrates that the color of 225 Rutile Blue pigments, which applied on polyamide fabric, doesn't show the color in human visualization as expected. The comparisons between other pigments on white and black fabrics are reported in table (5.1).

As it is clear from table (5.1), some pigments look the same color for human as we expected and some of them not. But the important point is that different people see different color from these pigments and no two people say the same color for same sample.

Base on table (4.2), the color of fabric, printed by pyrisma pigments, change in five different angles from pink through yellow to green, and these changes are more than other kinds of effect pigments (Iriodin and Colorstream pigments). In contrast, according to table (4.4), only 67% of people distinguish Pyrisma pigments as color travel; but 100% are agree with color travel property for Colorstream pigments.

Furthermore, base on table (4.4), 67% of people, who have been asked, like to use these pigments. The applications, which they would like to use, are night dresses, baby cloths and fashion stuff.

For answering the question that is it possible to get reproducibility in the printing process, we can say that this property is very good for Pyrisma pigments but for Iriodin and Colorstream, reproducibility in the printing process are not very good.

Table 5.1: The comparisons between the color of six effect pigments on white and black fabrics according to CIE diagram and human visualization.

pigment	*The color of fabric*	*The color of fabric according to human visualization*
Iriodin 225 on black fabric	Blue	Gray and blue
Iriodin 9225 on white fabric	Yellow and green	cream and white, silver, brown and yellow.
Iriodin 9225 on black fabric	blue	Blue and gray
Pyrisma T30-27 on white fabric	Pink, yellow and green in different angles	cream and white, yellow, pink, light green, and silver.
Pyrisma T30-27 on black fabric	Red and blue (purple)	Violet, purple, gray with green part
Pyrisma T40-27 on white fabric	Pink, yellow and green in different angles	yellow, light green, cream and white, and pink.
Pyrisma T40-27 on black fabric	Red and blue (purple)	Violet, yellow with green part, purple, and gray
Colorstream T10-03 on white fabric	Yellow and green	green, yellow, silver , blue, and pink.
Colorstream T10-03 on black fabric	Yellow and green	green, yellow, silver, brown, and pink.
Colorstream T20-03 on white fabric	Yellow and green	green, yellow, orange, silver, blue, and pink.
Colorstream T20-03 on black fabric	Yellow and green	green, yellow, pink, blue, and cream.

CHAPTER 6:

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6. References

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CHAPTER 7:

Appendix

7. Appendix

7.1. Appendix A

7.1.1. The Matlab program for plotting CIEa*b* and CIEL*a*b* and measuring the ΔE values for samples number 1, 2, and 24.

```
L1=[91.27 91.35 89.85 93.49 90.69]
a1=[-0.35 -0.45 -0.56 -0.71 -0.94]
b1=[4.03 4.41 5.68 6.81 6.27]
L2=[93.88 91.91 88.82 87.77 89.18]
a2=[-0.05 -0.09 -0.03 -0.36 -0.93]
b2=[2.58 4.63 7.98 9.11 7.31]
L24=[83.93 83.95 83.92 83.95 83.94]
a24=[0.87 0.91 0.89 0.89 0.89]
b24=[0.57 0.58 0.52 0.57 0.55]
for i=1:5
M1(i)=((L1(1,i)-L24(1,i))^2+(a1(1,i)-a24(1,i))^2+(b1(1,i)-
b24(1,i))^2)^0.5
end
E1=(M1(1,1)+M1(1,2)+M1(1,3)+M1(1,4)+M1(1,5))/5

for i=1:5
M2(i)=((L2(1,i)-L24(1,i))^2+(a2(1,i)-a24(1,i))^2+(b2(1,i)-
b24(1,i))^2)^0.5
end
E2=(M2(1,1)+M2(1,2)+M2(1,3)+M2(1,4)+M2(1,5))/5

figure(1)
plot(a1,b1,'g*:',a2,b2,'r*:',a24,b24,'b*:')
legend('No 2','No 7','No 24')
grid on
xlabel('a*'),ylabel('b*')
hold
figure(2)
plot3(a1,b1,L1,'g*:',a2,b2,L2,'r*:',a24,b24,L24,'b*:')
grid on
axis([-1 1 0 10 0 100])
xlabel('a*'),ylabel('b*'),zlabel('L*')
```

7.2. Appendix B

The tristimulus values and chromaticity coordinates of all samples in 5 different angles are reported in this appendix.

Table 7.1: The tristimulus values of samples in a) 15, 25 and 45 degrees b) 75 and 110 degrees.

(a)

Sample's Number	15 degree		25 degree		45 degree	
	x	y	x	y	x	y
1	0.320	0.339	0.321	0.340	0.324	0.342
2	0.318	0.336	0.322	0.340	0.329	0.347
3	0.219	0.282	0.217	0.283	0.215	0.285
4	0.232	0.293	0.226	0.288	0.223	0.286
5	0.278	0.296	0.276	0.296	0.277	0.299
6	0.281	0.300	0.279	0.300	0.278	0.301
7	0.312	0.330	0.314	0.333	0.323	0.342
8	0.325	0.342	0.325	0.342	0.325	0.344
9	0.323	0.342	0.322	0.341	0.321	0.340
10	0.319	0.330	0.319	0.333	0.322	0.338
11	0.319	0.331	0.320	0.333	0.324	0.340
12	0.285	0.283	0.283	0.282	0.282	0.285
13	0.284	0.279	0.281	0.277	0.279	0.279
14	0.325	0.324	0.325	0.324	0.324	0.323
15	0.318	0.305	0.322	0.310	0.331	0.323
16	0.321	0.333	0.321	0.335	0.324	0.341
17	0.325	0.337	0.326	0.339	0.328	0.343
18	0.316	0.334	0.319	0.337	0.324	0342
19	0.327	0.349	0.326	0.349	0.325	0.347
20	0.329	0.353	0.328	0.353	0.326	0.350
21	0.324	0.350	0.322	0.352	0.321	0.350
22	0.333	0.361	0.330	0.363	0.327	0.359
23	0.332	0.357	0.330	0.356	0.328	0.352
24	0.316	0.331	0.315	0.331	0.315	0.332
25	0.299	0.314	0.299	0.315	0.299	0.314

(b)

Sample's Number	**75 degree**		**110 degree**	
	x	**y**	**x**	**y**
1	0.325	0.345	0.324	0.343
2	0.331	0.350	0.326	0.346
3	0.216	0.287	0.215	0.286
4	0.228	0.288	0.222	0.283
5	0.284	0.307	0.289	0.311
6	0.285	0.309	0.294	0.315
7	0.331	0.350	0.330	0.349
8	0.327	0.346	0.326	0.345
9	0.320	0.340	0.318	0.338
10	0.326	0.342	0.325	0.348
11	0.330	0.351	0.329	0.352
12	0.287	0.295	0.293	0.304
13	0.283	0.290	0.291	0.301
14	0.324	0.322	0.322	0.321
15	0.336	0.332	0.332	0.330
16	0.329	0.350	0.328	0.350
17	0.329	0.347	0.328	0.348
18	0.331	0.349	0.329	0.348
19	0.325	0.345	0.320	0.344
20	0.325	0.347	0.321	0.347
21	0.322	0.350	0.319	0.347
22	0.325	0.350	0.321	0.348
23	0.328	0.351	0.324	0.352
24	0.316	0.330	0.315	0.331
25	0.299	0.315	0.298	0.314

Table 7.2: The chromaticity coordinates of samples a) 15, 25 and 45 degrees b) 75 and 110 degrees.

(a)

Sample's Number	15 degree			25 degree			45 degree		
	L*	a*	b*	L*	a*	b*	L*	a*	b*
1	91.27	-0.35	4.03	91.35	-0.45	4.41	89.85	-0.56	5.68
2	93.88	-0.05	2.58	91.91	-0.09	4.63	88.82	-0.03	7.98
3	62.97	-19.57	-26.78	61.31	-20.05	-26.04	59.43	-20.77	-24.86
4	67.51	-18.93	-22.89	66.42	-19.86	-25.03	65.45	-19.97	-25.82
5	46.04	-0.74	-10.30	44.71	-1.22	-10.14	42.31	-1.72	-8.87
6	41.87	-0.88	-8.35	40.91	-1.35	-8.29	39.49	-1.72	-7.75
7	97.23	-0.62	-0.51	95.40	-0.79	1.19	91.82	-0.50	5.40
8	91.36	0.23	5.92	90.71	0.01	5.88	89.87	-0.16	6.33
9	92.78	-0.55	5.52	91.75	-0.67	5.13	90.32	-0.84	4.48
10	93.28	2.84	0.78	92.10	2.02	1.71	90.22	0.54	3.92
11	94.40	3.26	0.75	93.08	2.36	2.02	91.01	0.65	4.50
12	42.93	4.68	-11.86	41.66	4.11	-11.93	39.61	2.95	-10.96
13	46.48	5.92	-14.23	44.79	5.24	-14.38	42.29	3.85	-13.18
14	85.46	8.60	-0.14	84.67	8.51	-0.38	83.59	8.50	-0.90
15	85.03	14.73	-8.49	82.56	13.51	-5.70	79.18	11.21	0.18
16	93.93	2.42	2.31	92.85	1.88	2.97	91.07	0.34	5.56
17	90.93	2.67	4.25	89.90	2.11	4.89	88.60	1.14	6.39
18	96.56	-0.62	1.79	94.78	-0.56	3.37	92.04	-0.38	5.85
19	97.60	-2.05	8.91	96.37	-2.79	8.72	93.99	-2.22	7.78
20	98.05	-2.70	10.81	97.35	-3.53	10.34	90.78	-2.70	8.51
21	46.92	-1.70	4.22	44.41	-2.56	4.09	40.92	-2.40	3.50
22	83.45	-4.09	11.86	79.25	-5.56	11.40	71.56	-4.63	9.01
23	99.68	-3.49	12.67	95.55	-4.02	11.60	89.09	-2.69	9.23
24	83.93	0.87	0.57	83.95	0.91	0.58	83.92	0.89	0.52
25	18.65	0.19	-2.82	18.65	0.20	-2.85	18.66	0.16	-2.86

(b)

Sample's Number	**75 degree**			**110 degree**		
	L*	**a***	**b***	**L***	**a***	**b***
1	90.69	-0.71	6.81	93.49	-0.94	6.27
2	87.77	-0.36	9.11	89.18	-0.93	7.31
3	61.81	-21.93	-25	61.15	-21.57	-25.31
4	67.44	-19.33	-25.20	66.43	-19.70	-27.80
5	41.34	-1.76	-6.56	44.27	-1.40	-5.71
6	38.90	-1.67	-5.78	41.59	-1.19	-4.17
7	87.60	-0.03	9.01	88.10	-0.43	8.46
8	89.33	-0.38	7.24	88.85	-0.40	6.89
9	92.44	-0.96	4.37	92.19	-0.92	3.34
10	88.70	-1.22	7.26	87.25	-1.88	7.42
11	88.60	-1.40	9.19	88.61	-2.07	9.37
12	38.96	1.63	-8.23	41.24	1.15	-6.23
13	41.65	2.29	-10.24	44.63	1.62	-7.72
14	84.62	9.00	-1.36	84.42	8.49	-1.78
15	79.38	9.23	3.80	79.03	8.57	2.55
16	89.48	-1.29	8.73	89.50	-1.83	8.61
17	87.89	-0.12	7.81	87.92	-0.68	7.85
18	88.88	-0.18	8.83	90.25	-0.54	8.39
19	92.30	-1.33	6.93	93.64	-2.88	5.87
20	88.51	-1.65	7.35	86.67	-3.50	6.42
21	40.65	-2.22	3.56	43.84	-2.24	3.11
22	66.31	-2.40	6.22	69.07	-3.18	5.40
23	87.00	-2.13	8.72	87.44	-4.22	8.42
24	83.95	0.89	0.57	83.94	0.89	0.55
25	18.63	0.19	-2.83	18.64	0.21	-2.82

7.3. Appendix C

The comparison between samples printed by Pyrisma and Colorstream pigments (samples number 9 to 23) are reported in this appendix.

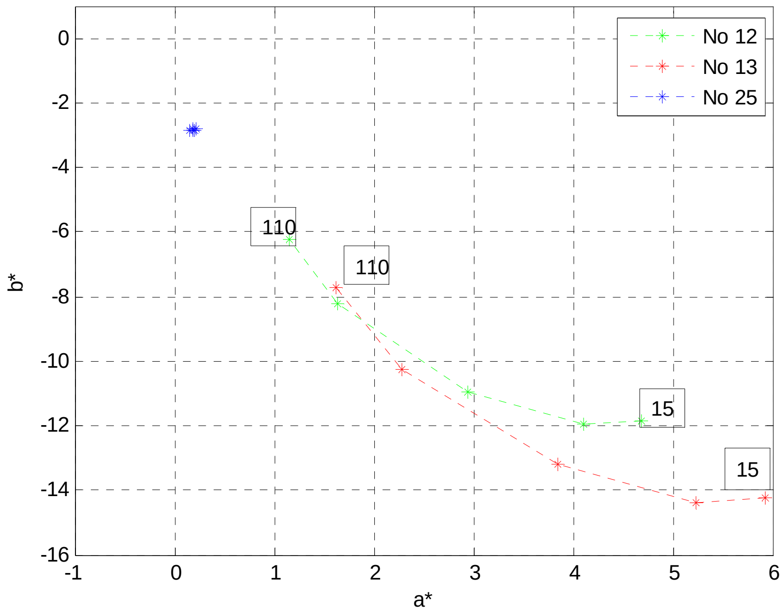
7.3.1. Samples number 9, 10, and 11.

The CIE chromaticity diagram and CIEL*a*b* diagram for samples number 10 and 11, printed by Pyrisma T30-27 Indigo and T40-27 Indigo (20%), were plotted in chapter (4.3). The ΔE values for these samples with unprinted fabric are 8.3225 and 9.7398 which makes a very big value for color difference. In addition, number 9 is polyamide fabric (white), printed by Pyrisma T30-27 Indigo (5%) pigment. The ΔE value for this sample and unprinted fabric is 9.1015. The ΔE value for this sample and sample number 10, printed by 20 percent of Pyrisma T30-27 Indigo, is 4.5838. These results show that adding 15% more Pyrisma T30-27 Indigo pigment make more effect on fabric.

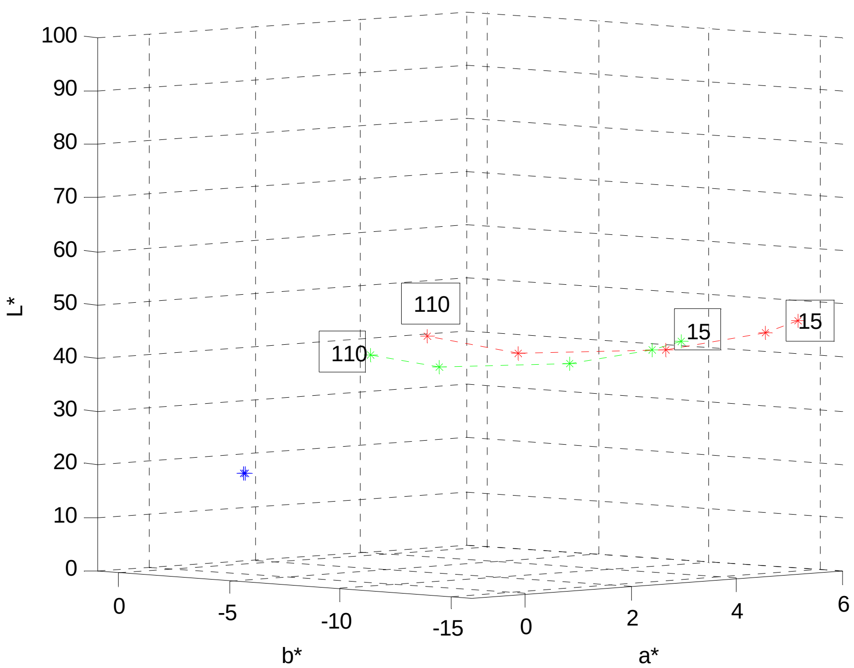
7.3.2. Samples number 12 and 13.

The samples number 12 and 13 are printed by Pyrisma T30-27 Indigo and T40-27 Indigo (20%) on black fabrics and CIEL*a*b* diagram of these samples and unprinted black fabric are plotted in Figure (7.1).

The color of samples, printed on black fabric, tends toward red and blue. As we can see in figure (7.1) (part b) their brightness are much more than unprinted black fabric. In addition, in compare to the white and black fabrics for Pyrisma pigments, ΔE from samples number 10 & 24 and also 11 & 24 are 8.3225 and 9.7398. These values for samples number 12 & 25 and 13 & 25 are 23.5863 and 27.2876. Therefore, the Pyrisma pigments make the black fabric to be colorful.



(a)



(b)

Figure 7.1: a) The CIEa*b* color space, b) The CIEL*a*b* color space of samples number 12 and 13.

7.3.3. Samples number 14 and 15.

Figure (7.2) shows the CIEa*b* diagram for samples, printed by pink pigment (0.25%) (0.25%) (number 14), and Pyrisma T40-27 Indigo (20%) pigment with pink pigment (0.25%) (number 15).

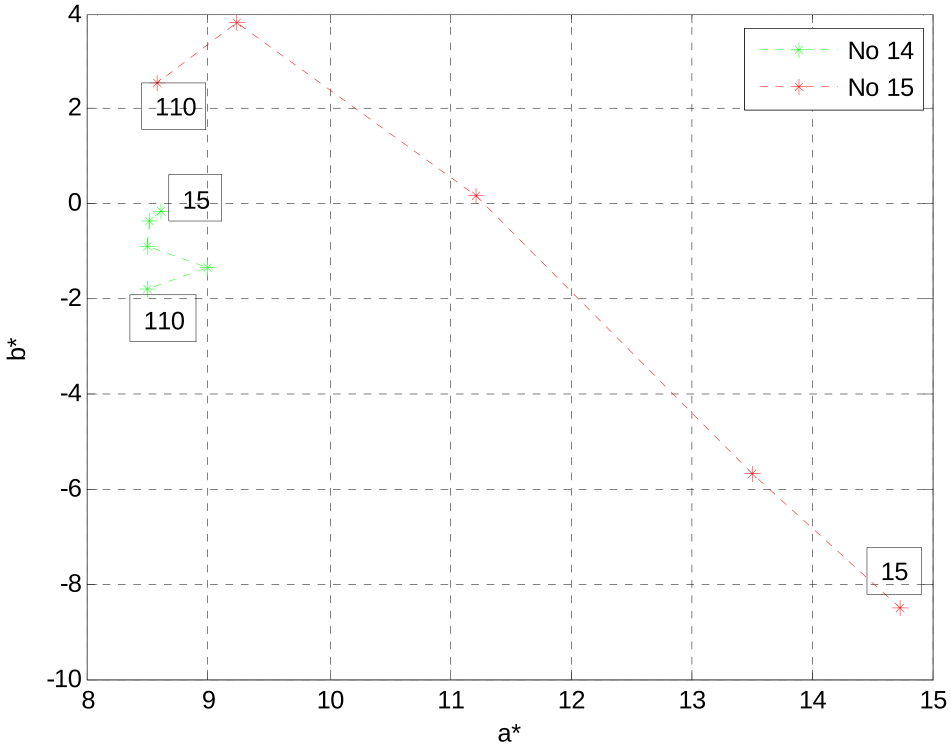


Figure 7.2: The CIEa*b* color space of samples number 14 and 15.

According to the figure (7.2), the chromaticity coordinates of sample number 14 in five different angles concentrate in one area. In contrast, as it is clear from figure (7.2), the sample, printed by pink and effect pigment, shows different color in different angles. The ΔE value for them is 7.5053. In addition, the brightness value for sample, printed just by pink pigment, is more than sample with effect pigment and pink pigment.

7.3.4. Sample number 16.

To investigate the reproducibility in printing process for pyrisma pigment, the Pyrisma T40-27 Indigo (20%) pigment is applied on polyamide fabric for the second time (sample number 16). In this part, the sample number 16 and 11 are compared with each other. Figure (7.3) shows the chromaticity coordinates of the samples number 16, 11, and 24.

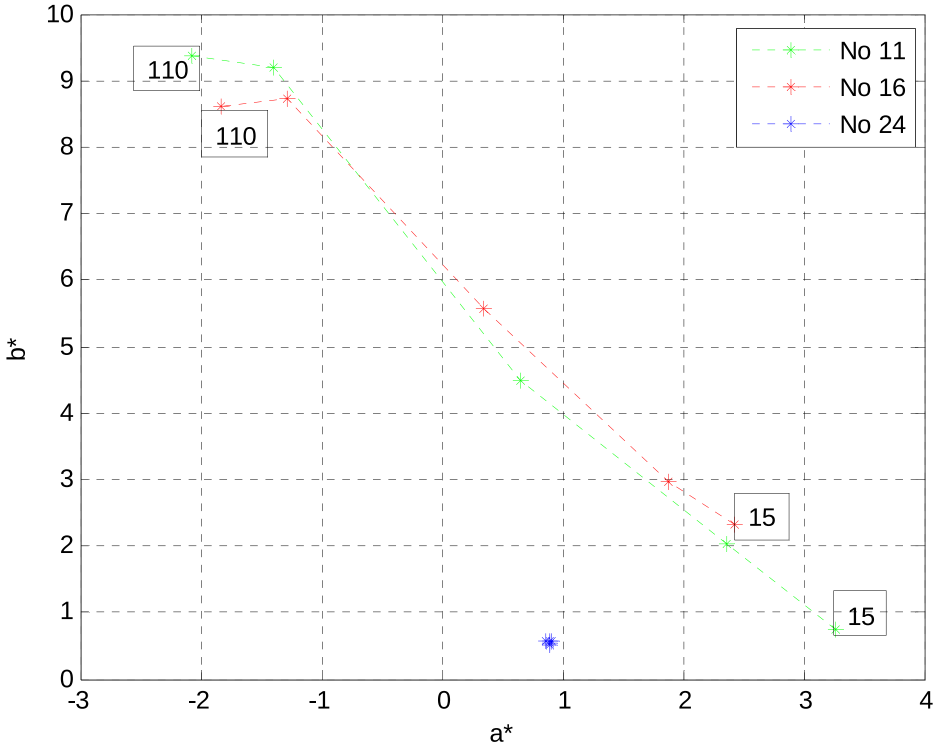


Figure 7.3: The CIEa*b* color space of samples number 11 and 16.

The ΔE value for samples number 11 and 16 is 1.2444 which is very small value confirming that pyrisma pigment has a good reproducibility in printing process. This result is also predictable from figure (7.3).

7.3.5. Sample number 17.

As discussed before in part (4.4.5), the Pyrisma T40-27 Indigo (20%) pigment is applied on cotton/polyester (50%/50%) fabric to investigate how important is the texture of fabric, used with effect pigments. The CIEa*b* diagram of samples number 17 and 11 is plotted in figure (7.4).

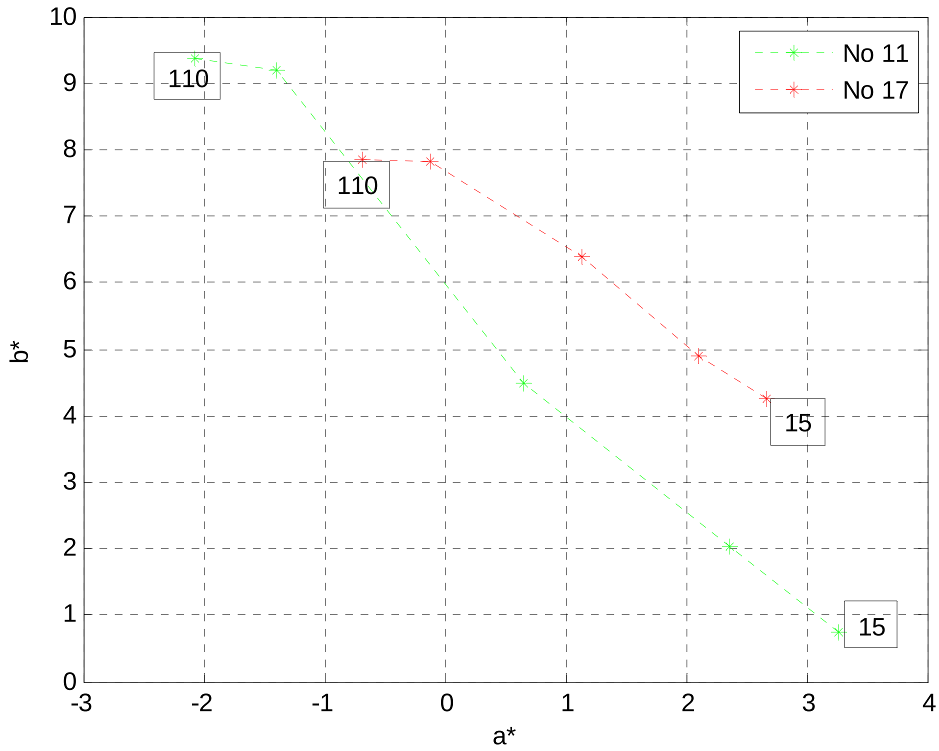


Figure 7.4: The CIEa*b* color space of samples number 11 and 17.

Although in figure (7.4), the samples number 11 and 17 are in the same color gamut but according to the table (4.3), ΔE value for them is 3.3081 which is not small value and show color difference between two different fabrics by same pigment.

7.3.6. Sample number 18.

Sample number 18 is printed by both Iriodin 9225 (10%) and Pyrisma T40-27 Indigo (10%) pigments. Figure (7.5) shows the CIEL*a*b* diagram of samples number 2, 11, 18, and 24.

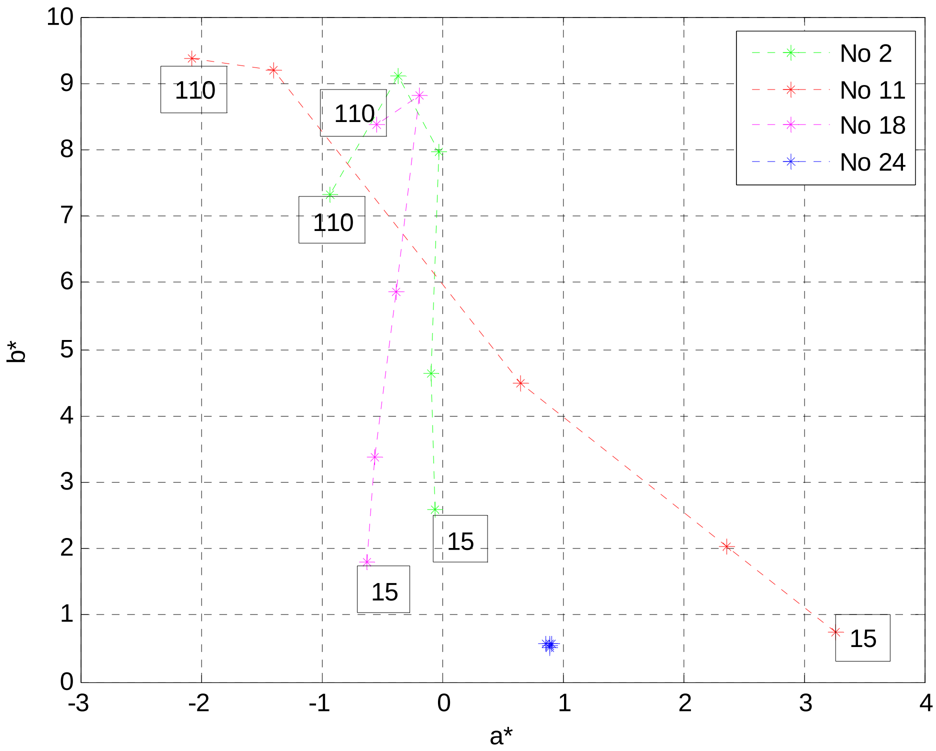


Figure 7.5: The CIEa*b* color space of samples number 2, 11, and 18.

According to the table (4.3), the ΔE value of samples number 18 & 24 is 10.7390, and this value between samples number 18 & 2 and between 18 & 11 are 2.5252 and 2.7871 respectively. These values show that the mixture of two pigments have a small color difference with each of the individual pigment, but as it is clear from figure (7.5), the dispersion of fabric, printed by mixture of effect pigments data, is more close to dispersion of sample, printed by Iridion pigment, than sample by Pyrisma. The color of samples number 18 and 2 are mixture of green and yellow, whereas the sample number 11 tends towards red and yellow color area in color gamut.

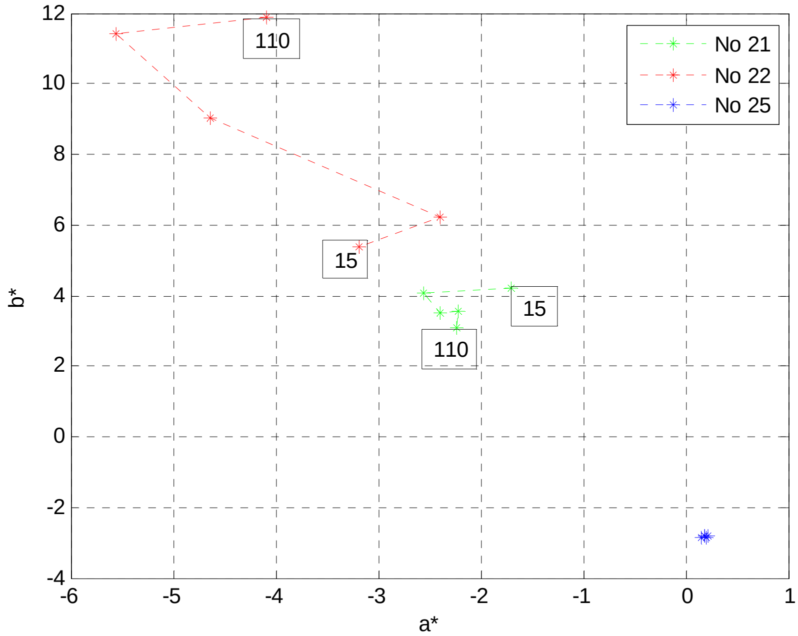
7.3.7. Samples number 19 and 20.

The CIE chromaticity diagram and CIEL*a*b* diagram for samples number 19 and 20, printed by Colorstream T10-3 and T20-3 (20%) pigments were plotted in chapter 4.3. The ΔE values for these samples with unprinted fabric are 13.3591 and 12.4940 which are very big values for color difference.

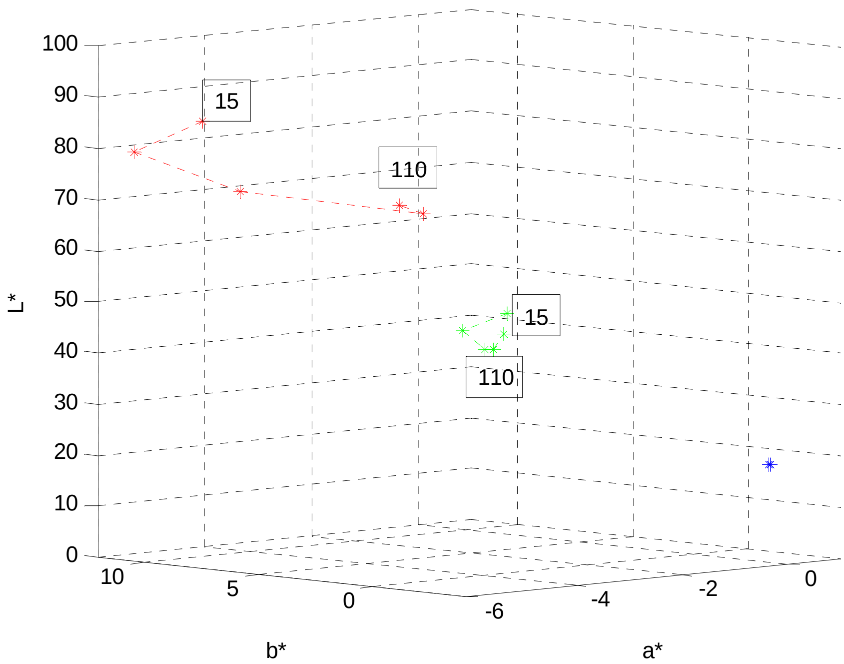
7.3.8. Samples number 21 and 22.

The samples number 21 and 22 are printed by Colorstream T10-3 and T20-3 (20%) pigments on black fabrics and CIEL*a*b* diagram of these samples and unprinted black fabric are plotted in Figure (7.6).

The color of sample, printed on black by colorstream pigments are mixture of yellow and green. Their brightness is much more than unprinted black fabric. The sample number 22 is greener, yellower, with more brightness than sample number 21. The ΔE value also confirms these differences (ΔE from samples number 21 & 25 and also 22 & 25 are 25.6732 and 56.6667).



(a)



(b)

Figure 7.6: a) The CIEa*b* color space, b) The CIEL*a*b* color space of samples number 21 and 22.

7.3.9. Sample number 23.

In this part the reproducibility in printing process for Colorstream pigment is investigated. The Colorstream T20-3 (20%) pigment is applied on polyamide fabric for the second time (sample number 23). In this part, the sample number 23 and 20 is compared with each other. Figure (7.7) shows the chromaticity coordinates of these samples and unprinted white fabric (sample number 24).

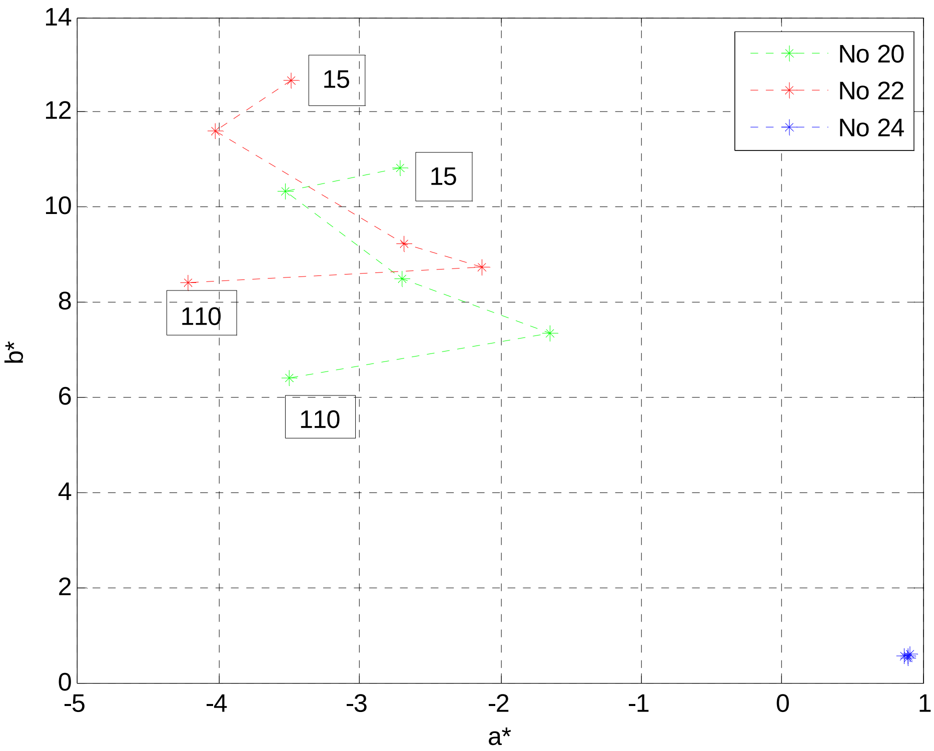


Figure 7.7: The CIEa*b* color space of samples number 20 & 23.

According to table (4.3), the ΔE value for samples number 23 and 20 is 2.2080 which it shows the reproducibility of Colorstream T20-3 pigment is not very good.

7.4. Appendix D

7.4.1. Question's form

Name: **Age:**

Iriodin pigments

	Gray Scale	color and effect	Special effect			Application recommended
Number 1 and 24.	W:		YES	NO	Maybe	
Number 2 and 24.	W:		YES	NO	Maybe	
Number 5 and 25.	B:		YES	NO	Maybe	
Number 6 and 25.	B:		YES	NO	Maybe	
Number 7 and 2.	W:		YES	NO	Maybe	

Pyrisma Pigments

	Gray Scale	color and effect	Special effect			Application recommended
Number 10 and 24.	W:		YES	NO	Maybe	
Number 11 and 24.	W:		YES	NO	Maybe	
Number 12 and 25.	B:		YES	NO	Maybe	
Number 13 and 25.	B:		YES	NO	Maybe	
Number 16 and 11.	W:		YES	NO	Maybe	

Colorstream pigments

	Gray Scale	color and effect	Special effect			Application recommended
Number 19 and 24.	W:		YES	NO	Maybe	
Number 20 and 24.	W:		YES	NO	Maybe	
Number 21 and 25.	B:		YES	NO	Maybe	
Number 22 and 25.	B:		YES	NO	Maybe	
Number 23 and 19.	W:		YES	NO	Maybe	