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FORMULATIONS OF PRIMER, ACRYLIC PAINT AND PASTEL IN TRADITIONAL THAI STYLE COLOUR

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งานวิจัยนี้มีเป้าหมายเพื่อปรับปรุงสารรองพื้นแบบไทยโบราณที่ใช้สำหรับจิตรกรรมฝาผนังให้มีสมบัติยับยั้งการเติบโตของแบคทีเรีย รวมถึงการสร้างสูตรสารรองพื้นแบบใหม่ที่สามารถยับยั้งการเติบโตของแบคทีเรีย ทนต่อการขัดถูและการล้าง และเพื่อสร้างสูตรสีไทยแบบโบราณที่สอดคล้องกับพจนานุกรมคำเรียกสีไทย โดยทั้งสารรองพื้นและสีไทยดังกล่าวนี้มีเป้าหมายเพื่อใช้ในงานจิตรกรรมฝาผนังไทย งานวิจัยแบ่งออกเป็น 3 ส่วนหลัก ประการแรกคือการปรับปรุงสารรองพื้นแบบโบราณและการสร้างสูตรสารรองพื้นแบบใหม่ให้มีคุณสมบัติยับยั้งการเติบโตของแบคทีเรีย ทนต่อการล้างและการขัดถู ประการที่สองคือการสร้างสูตรสีอะคริลิกและสีพาสเทลที่สอดคล้องกับพจนานุกรมคำเรียกสีไทย ประการสุดท้ายคือการวิเคราะห์หาความยาวคลื่นที่ส่งผลให้เห็นความแตกต่างของความสว่างระหว่างภาพของสีไทย สารรองพื้น อันเนื่องจากผลกระทบของความร้อน ความชื้น และแสงยูวี ผลการศึกษาพบว่าสารรองพื้นแบบโบราณที่ทำจากส่วนผสมของดินสอพองและกาวมะขามต่อการทนต่อสภาวะแวดล้อมรวมทั้งจุลินทรีย์ได้ยากเนื่องจากส่วนผสมดังกล่าวเอื้อต่อการเติบโตของแบคทีเรีย ไททาเนียมไดออกไซด์และอนุภาคเงินซึ่งมีผลต่อการยับยั้งการเติบโตของแบคทีเรียได้ถูกนำมาเป็นส่วนผสมของสูตรสารรองพื้น และการการทดสอบการยับยั้งต่อแบคทีเรีย 4 สปีชีส์ ซึ่งพบบนภาพจิตรกรรมฝาผนังของวัดโสมนัสราชวรมหาวิหาร กรุงเทพมหานคร แบคทีเรียดังกล่าวได้แก่ *Bacillus subtilis, B. cereus, B. mycoides, and Leclercia adecarboxylata* พบว่าสารรองพื้นแบบโบราณไม่ว่าจะมีหรือไม่มีอนุภาคเงินก็ไม่สามารถยับยั้งแบคทีเรียดังกล่าวได้เลย ในขณะที่สารรองพื้นแบบใหม่ที่มีส่วนผสมของทั้งไททาเนียมไดออกไซด์ อะลูมิเนียมซิลิเกตและอนุภาคเงิน มีประสิทธิภาพในการยับยั้งแบคทีเรียดังกล่าวได้ดีที่สุดทั้ง4 สปีชีส์ ส่วนสารรองพื้นแบบใหม่ที่มีเฉพาะส่วนผสมของอะลูมิเนียมซิลิเกตและอนุภาคเงินสามารถยับยั้งได้เป็นอันดับสอง นอกจากนั้นสารรองพื้นแบบใหม่ทนต่อการขัดถูและการขัดล้างได้ดีกว่าแบบโบราณ ในส่วนของสีมีการสร้างสูตรของแม่สีจำนวน 11 สีสำหรับสีอะคริลิก และ 12 สีสำหรับสีพาสเทล แม่สีเหล่านี้ถูกใช้ในการสร้างฐานข้อมูลเพื่อการสร้างสูตรสีอะคริลิกและพาสเทลแบบไทยโบราณ ได้ทดลองสร้างตัวอย่างสีไทยแบบโบราณจำนวน 20 สีสำหรับสีอะคริลิก และ 40 สีสำหรับพาสเทล โดยค่าความต่างสี CIEDE2000 ที่กำหนดต่ำกว่า 3 และได้มีการทดสอบความพึงพอใจต่อการทดลองใช้สีไทยดังกล่าว และค่าความคลาดสีที่ศิลปินยอมรับ นอกเหนือจากที่กล่าวมาแล้ว ได้มีการนำเทคนิคด้านมัลติสเปกตรัมมาใช้ในการศึกษาสมบัติสเปคโตรสโคปิกของสีอะคริลิก พาสเทล และสารรองพื้นที่ได้รับผลกระทบจากการเปลี่ยนแปลงของความร้อน ความชื้นและแสงยูวี

ภาควิชา	เทคโนโลยีทางภาพและการพิมพ์	ลายมือชื่อนิสิต	....
สาขาวิชา	เทคโนโลยีทางภาพ	ลายมือชื่อ อ.ที่ปรึกษาหลัก	....
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NAWARAT KAEW-ON: FORMULATIONS OF PRIMER, ACRYLIC PAINT AND PASTEL IN TRADITIONAL THAI STYLE COLOUR. ADVISOR: ASSOC. PROF. PICHAYADA KATEMAKE, Ph.D., CO-ADVISOR: ASSOC. PROF. KAWEE SRIKULKIT, Ph.D., PROF. ALAIN TREMEAU, Ph.D., 262 pp.

This research aimed to improve Thai traditional primer, used for mural painting, with antibacterial property, to formulate novel primers having antibacterial behavior, scrub resistance and washability as well as to formulate paints according to Thai color dictionary. Both primers and paints were aimed to use in mural painting. We divided the research into 3 parts: 1) improved traditional primer and formulated novel primer with antibacterial, washable and scrub resistance properties; 2) formulated acrylic paints and pastels according to Thai color dictionary and 3) investigated the wavelengths used for distinguishing the change of paint caused by light, moist and heat using multi-spectrum imaging technique. Traditional primers that were made of natural constituents particularly tamarind glue and white clay hardly resist to environmental factors including the microorganisms because the natural components encourage their growth. Titanium dioxide, TiO_2, and silver nanoparticles, AgNPs having antibacterial property, were used in the formulations. Subsequently they were tested against 4 bacterial species; *Bacillus subtilis, B. cereus*, *B. mycoides, and Leclercia adecarboxylata* that were found on the mural painting surface of Somanas Rajavaravihara temple in Bangkok, Thailand. The presence of TiO_2 and AgNPs in the novel primers inhibited the growth of these 4 bacteria, while neither the traditional primer with AgNPs nor the one without showed inhibition activity against all 4 bacterial species. On the other hand, the novel formulated primers containing TiO_2, aluminum silicates and AgNPs showed the best inhibition and the second best was the primer with aluminum silicates and AgNPs. The latter gave better scrub resistance and washability than the former. Primary colours were formulated, 11 colours for acrylic paint and 12 colours for pastel. These primary colours were used as database to formulate traditional Thai style colour for acrylic paint and pastel respectively. Samples of traditional Thai style colour were made, twenty colours for acrylic paint and forty colours for pastel. The color differences CIEDE2000 between the formulated and the Thai color dictionary's CIELAB values were less than 3. The pass-fail color tolerance and brush testing were carried out by Thai artists. In addition, multi-spectrum imaging technique was employed to study the spectroscopic characterization of paints, pastel and primers that were influenced by changing of moist, heat and UV radiation.

Department:	Imaging and Printing Technology	Student's Signature	....
Field of Study:	Imaging Technology	Advisor's Signature	....
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		Co-Advisor's Signature	....

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Nawarat Kaew-on, June 2018

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CHAPTER 1

Introduction

Thai artifacts, including ancient mural painting, have been degraded over time. Environmental factors such as high humidity, temperature and microorganisms caused the degradation (1). In addition, the constituents of paint and primer are also part of the degradation problem (2). Materials that are used in Thai ancient mural are mostly made of natural components (3, 4), Traditional primers and paints are formulated with various recipes. One particular primer recipe is a mixture of white clay and tamarind glue. Traditional paint recipes are mostly made from the mixture of natural pigments and gum Arabic, also called acacia gum (4). These materials deteriorate over time due to environmental factors. Moreover, there are problems regarding the restoration or re-creation of Thai artifacts and murals due to Thai color names and according paints have not been written or recorded. Katemake et al. stated that the formulation of Thai color paints is one of the obstacles in Thai artifact conservation, since only a few artists today possess the knowledge inherited from their elders to produce traditional Thai colors from natural pigments. There is no general accepted recipe among artists to produce any of these colors by means of pigment proportions and dilutions (3, 5). Furthermore, the book owned by the Crown Property Bureau (4) mentioned that traditional recipes of the paints and primers have disappeared. When the mural paintings in the Grand Palace were restored, they made tempera by mixing synthetic pigments with gum Arabic. The tempera was painted on the wall prepared by traditional method. Adhesion and absorption of the tempera on the surface were studied; the samples were placed under direct sunlight to see if the colors would fade (4). The report did not find any scientific or significant statistical data. Therefore, obtaining the correct Thai color cannot be guaranteed for restoration and re-creation.

Several researchers have studied Thai color identification. Siripant carried out the research on matching the Thai color names with the Munsell and CIE color systems. He took 209 color names from four Thai dictionaries of art, two Thai encyclopedias of art, seven textbooks, seven volumes of archival correspondence and one journal and matched 50 colors out of them (6). Twenty-two years later, Katemake et al. studied Thai names of 147 colors used in Thai mural paintings, Khon masks and general application (3, 5). The Thai color dictionary's CIELAB values included Thai color names that were related to the international standard color patches, was created (5). However, producing the paints and pastels corresponding to the traditional Thai color dictionary's CIELAB values has not been done. This research, therefore, focused on producing paints including acrylic and pastel that correspond to the traditional Thai color dictionary's CIELAB values and recording multi-spectral imaging of produced paints before and after exposing to light and moisture (5). In addition, producing of acrylic base primer having antibacterial property was also focused.

Primer is one of major layers for wall surface preparation before paint is applied. A three-layered wall is traditionally used for painting Thai murals. The first layer is the base construction of brick and mortar. The second layer is a plaster, which is the mixture of lime, sand, gums made of animal skin, plants and sugarcane juice. After applying the plaster, the extracted solution from Senna leaves is rinsed on the surface for adjusting pH of the surface from alkalinity to neutral. Turmeric is drawn on the surface for checking pH before applying the primer (4, 7). If the pH range is approximately between 7.4 and 8.6, the color of drawn turmeric will change from yellow to red (8). Once the pH of the plaster is ready to use, the mixture of white clay and tamarind gum is applied on it and subsequently it is the painting process. The process of preparing the plaster and the traditional primer are complicate, inconvenient and time consuming. Regarding the tamarind glue, tamarind seeds is the major component and is not available throughout the year. It is seasonal. Boiling tamarind seeds takes time due to its hardness is too high. Thai mural artists prefer making tamarind glue from scratch to making tamarind glue from imported powder.

Alternative materials that are particularly durable, washable and contain antimicrobial property that can be substituted or used with the traditional primer recipe have never been studied. The researcher considered producing the novel primer by using white pigments, acrylic base binder, silver nanoparticle, ceramic microsphere and other additives. In addition, improving the traditional primer property by adding some additives for enhancing the antimicrobial property was in our scope of study.

It is accepted that the biodegradable activity of microbial can cause wall painting degradation (1, 9-13). Pepe et al. stressed that the wall painting supports the growth of microorganisms commonly involved in bio-deterioration, which contributed to the destruction of paint. Their deterioration constituted a loss affecting part of the world's cultural heritage (9). The microbial colonization of masonry and historic wall paintings by fungi, algae and bacteria may result in structural and/or aesthetic deterioration of the artwork (10). The growth of fungi on wall paintings manifested most commonly by discoloration or deterioration of the surfaces and microbial population caused discoloration of pigments and physical decay when fungal hyphae grew either on or below the surfaces. This caused chemical decay of paintings through their metabolites and enzyme production like gluconic, citric, oxalic, malic and etc. (1, 11, 12).

Titanium Dioxide (TiO_2) is known as a photocatalytic having ability to deactivate the growth of microorganisms which can be harmful to the mural due to its biodegradation activity (14-17). TiO_2 is the most important compound in a wide range of white pigment products such as paints, plastics and paper. Roughly 90% of TiO_2 is used as a pigment and the majority of this is in paintings and coatings. The most important qualities of white pigment are its ability to give white to the paint or coating and to give opacity because of its scattering property; however, white pigment, such as TiO_2, can cause embrittlement, lack of gloss, chalking and discolor the paints. The reason for this is that TiO_2 has excellent photocatalytic properties and effectively transforms the light energy to chemical energy (14-17). When it absorbs UV light, the possibility of the production of radicals is initiated. These radicals can attack the surroundings of the pigment and can cause a breakdown of the organic medium resulting in embrittlement, loss of gloss, or chalking. When colorants, pigments or dyestuffs are involved, the color can also be affected (18). It may be possible that replacing some amount of TiO_2 with other white pigment would reduce the undesirable effect.

Silver nanoparticle (AgNPs) is known as antimicrobial material (18-20) that can be added into the primers. A significant number of researchers have explained using AgNPs as an antimicrobial. Kim et al. mentioned that AgNPs could be used as effective growth inhibitors in various microorganisms, making them applicable to diverse medical devices and antimicrobial control system (19).

Ceramic microsphere, spherical and hard particle, is another additive used in paint and coatings. Its advantages when used as architectural coating applications are well documented (21). These particles offer the formulators opportunities to lower the binding demand and control the viscosity and VOCs while increasing burnish and scrub resistance (21).

Beside the primer, paint itself is another factor affecting the longevity of the artifacts. In ancient times, artists used natural pigment mixed with gum from plant or animal, as a binder (4). Pigment has been evolved and advances have been made since prehistoric times, from earth pigments used by primitive man to decorate the walls of caves to the synthetic pigments developed in more recent times and likewise the gum or binder (22). Artists today use a mixture of modern synthetic organic pigments having high stability and color intensity. Natural organic pigments and inorganic pigments are rarely used (23). In ancient Thailand, natural pigment was ground to fine powder and mixed with gum made from plants or animals. The mixture is called “tempera color (4, 24) which is less resistant to water. At the Fine Arts department of the Ministry of Cultural, Thailand, only a few artists know the traditional recipe of Thai colors. Usually commercial pigments and acacia gum are simply mixed. Sometimes the famous Rembrandt pastels are preferred to obtain specific shade. They will be ground into fine powder mixed with acacia gum. For certain projects of mural painting, imported acrylic paints are applied on large canvas, which is subsequently glued on the wall instead of painting directly on the wall. Many shades of Thai traditional colors need mixing of more than one single pigment.

Acrylic paint is a modern artist paint. The pigment is mixed with the acrylic resin-base polymer instead of natural gum. It is water resistant after completely dried. Artists can also use latex-based acrylics with little or no expose to organic solvent vapors

(25). Acrylic polymers have been used in artist paints since the 1940s (23). It became commercially available around 1950, and quickly became the preferred technology for most acrylic artist paints. At present, about half of artists worldwide are classed as “acrylics” (22). Acrylic paints, contained suspended pigment in the emulsion of acrylic polymers, are quick drying paints having water-soluble property. After drying the paint layer turns to water resistant film and as a result of this property, acrylic paints do not represent color migration which is a typical characteristic found in water reducible paints such as gum Arabic-based ones (26). Due to these characteristics along with the variety of colors, acrylic paints are commonly used by artists and conservators specialized in paintings on wall, paper, wood and other painted cultural materials (26-30).

Therefore, this research focused on three major areas: 1) improved traditional primer and formulated novel primer with antibacterial property, scrub resistance and washability properties; 2) formulated acrylic paint and pastel corresponding to Thai color dictionary’s CIELAB values and 3) investigated the wavelength used for distinguishing the change of paint and primer caused by light, humidity and heat using multi-spectrum imaging techniques. In terms of primers, the traditional one was modified by adding silver nanoparticles for antimicrobial property. The novel primer with durability and antimicrobial properties was produced by consisting of styrene/acrylic binder, TiO_2, Aluminium silicate (Al_2SiO_5), ceramic microsphere and AgNPs. In terms of paints, the acrylic paints and the pastels that corresponding to the traditional Thai color dictionary’s CIELAB values were optimized. Acrylic paints were made of synthetic pigments and styrene/acrylic binder, while for pastel the gum tragacant was used as binder. To formulate traditional Thai style color, paints’ calibration and database were built and the recipes that match quantitatively traditional Thai color dictionary’s CIELAB values were calculated. In addition, brush testing and artists’ satisfaction on optimized primers and traditional Thai style color acrylic paint and pastel were also performed by Thai artists.

Objectives:

1. Formulate the traditional and novel primers that meet Thai artists' satisfaction and resist the tropical environmental factors.
2. Formulate the acrylic paints and pastels in traditional Thai style colors.

CHAPTER 2
Literature Review

2.1 Thai mural painting

Thailand is rich in culture especially art. Thai art is magnificent in honor and tradition found in architecture, sculpture and painting. Thai mural painting has its own and unique style to the visual arts. The uniqueness of Thai mural is that it creates scenes without shading or shadows. It pays no particular attention to perspective anatomy. This painting uses colors to indicate space, scale importance, and zigzag lines for a change of place. It shows the same character repeatedly in the same space even if that character is at a different time within the same story. Most of the content inside these paintings were influenced by the Ramayana stories and the stories of the Buddha's past ten lives before reaching Enlightenment. Thai mural paintings show a strong relationship between Buddhism and Thai people's life (31).

Thai mural painting has evolved through history. The original style was found in the Ayutthaya dynasty and could still be found in early period of Rattanakosin period. The significant change happened during the period of King Rama 4, when Thailand (called Siam at the time) started diplomacy with western countries. This change brought modification to Thai paintings by having perspective, light and shadow. The story inside the painting was not only about the Buddha but also in literature and people lives. The evolution in Thai mural paintings has continued to evolve through present day (32).

Materials used for Thai mural paintings have also gradually changed from natural to synthetic paints. In the Ayutthaya period, a fresco technique, line drawings on a plastered wall, were found in mural paintings. The surrounding area was embedded with a vermillion color and then color was applied in a planar fashion. The lines were simple and drawn solidly. The colors used in that period were only black, white, red and gold foil. It was believed that black was from carbon black, white from lime or white earth and red was from cinnabar. Gold foil was particularly used for important parts in the scene and ceilings (33).

The Rattanakosin period has reached 235 years old in 2017 and there have been dramatic changed in this period. The evolution of the paintings can be divided into three periods: the early period (King Rama I–III), middle period (King Rama IV–VI), and the late period (King Rama VII to the present) (33).

During the period of King Rama I's reign (1782–1809), new buildings in a new architectural style were built. The most important temple was Wat Prakaew, located in the grand palace area. The corridor walls of Wat Prakaew were painted at that time. The techniques retained the features of Ayutthaya art. The images were expressed with vivid colors and gold. The reign of King Rama II (1809–1824) appeared a lively cultural exchange with Portugal and India. Thai students were sent to India for learning architecture and other technologies. During the period of King Rama III (1824–1851), Thai art was influenced by Chinese art. Almost all pigments were imported from China (34).

In the period of King Rama IV (1851–1868), there were exchanges with the western countries. Pigments and painting materials were imported. The mural paintings were influenced by the west. The subject was changed from Buddhist themes to fables and a distinctive style was created by combining the realism of Europe. These perspective was presented in the painting (32). During the periods of King Rama V (1868-1910) and King Rama VI (1810-1925), foreign exchanged students were sent to Europe and western people were hired as official artists. Paintings in the Ananta Samakhom throne hall was an example of the art painted by this group of artists. In this period, the influence of the west was clearly shown in Thai murals and has evolved to be the art of the present. In the reign of King Rama IX, the mural painting are rendered realistically that the people in the painting can be recognized, and vivid colors are used in these works (32). The painting in the Royal Pantheon (Pra Budhdharattanastarn) was created. It presented a current mural painting which has its own style to the mural painting (4).

2.2 Mural painting degradation

Many of the mural paintings that were constructed in the late Ayutthaya period have been degraded. A temple that is only 300 years old could not resist these changes. The painting in Pra Ubosot of **Wat Yai Suvannaram** (Yai Suvannaram temple) is an example. This temple was constructed in the period of King Prasartthong (A.D. 1656-1688) in Petchaburi province. Its mural paintings were almost degraded as presented in Figure 2.1. Though the murals that were painted in Rattanakosin period (1782-present) have also been degraded; the mural painting in **Mai Thong Sen temple** was done in the period of King Rama III and **Somanas Rajavaravihara temple** was built in the period of King Rama IV were great examples as shown in Figure 2.2 (a) and (b) respectively.

Figure 2.1 the mural painting in Wat Yai Suvannararm

(a) (b)

Figure 2.2 (a) the mural painting in Mai Thong Sen temple and (b) the mural painting in Somanas Rajavaravihara temple.

To understand the reasons for the degradation in the mural paintings, traditional painting and modern painting literatures were reviewed. The differences of degradation depended on different factors such as materials used, weather, humidity, temperature, microorganism (1). Changing of humidity, temperature and climate conditions cannot be avoided. These factors cause degradation of artifacts including the mural painting both directly and indirectly. In addition, tropical climate condition can quickly support growth of microorganism which can degrade the mural painting indirectly by the bioactivity. Numerous literature stated that degradation of traditional mural painting was caused by these environmental factors. Moreover, misusing of materials and methods for restoration is a factor that deteriorate mural paintings unintentionally.

Traditional painting

There was not much literature that mentioned Thai mural paintings, especially though the degradation and conservation of Thai mural painting. In 1970, Micaela du

Guerny mentioned two major factors that caused the degradation in Thai mural painting, materials and painting techniques. They classified these factors as chemical problems, chromatographic problems, and the layer of paints. For chemical problems, the mortar is the main ingredient which contains a high proportion of lime (40 to 50 % of the volume). It is fragile, soluble and easily attacked by acidic elements in rainwater. There are also some hygroscopic elements in the mortar, which increased the capillarity. For chromatographic problems, in tempera, the pigments used with an organic water-soluble adhesive, generally base on gum, may not be detectable and created a complex technical problem. The last problem was the extremely thin layer of paint, generally under 0.01 mm. Due to the tempera technique, these layers were very fragile, and the problem of flacking was particularly acute (2).

In addition to Thai mural painting, Nabil A. Bader and Waeel B. Rashedy studied and analyzed the origin of archeological raw materials of the paint layer in mural painting of the Krabia school in Egypt. The authors mentioned that the deterioration aspects that affected the mural painting were flacking, powdering, cracking, discoloration, salt effects, numerous dirt, stains and insects remains (35). David Saunders and Jo Kirby reported that effect of humidity conditions on different grounds used for painting such as wood, paper, fabric, plasters and mortars on a wall painting was widely concerned. The problems were caused on both painted surfaces by atmospheric moisture condensation and within the walls by movement of water. This phenomenon within the wall surface can bring more and long term damage because of the movement of water and dissolved salts in the structure of the wall painting. This is different from the easel painting that can also be damaged by moisture but only at its surface. Warping or separating of paint film from the substrate surface was found if there were repeated cycling of humidity applied (36). Xiang He et al presented the deterioration mechanism caused by moisture and thermal of wall-painting in Magao Grottoes. This work focused on the deterioration that happened after conservation materials were applied. The authors reported that different layers in the wall painting had different physical properties, such as thermal and moisture expansions which changed after the conservation materials penetrated into the painting. The different properties caused stress between the layers in the paintings with the change of environmental factors, which finally led to deterioration of wall painting (37). Rafat K and Abdou A also mentioned that mural paintings in an ancient Egyptian tomb in West Thebes suffered from deterioration factors such as variations of temperatures, relative humidity, salts efflorescence, crypto-fluorescence, cracking, and bio-deterioration. Bacteria and fungi accelerated mechanical weathering, chemical changes and aesthetic deterioration, like the penetration of mycelium below plaster layers, decomposition, disintegration, alterations and discoloration (15). M.P. Nugari et al stated that mural paintings in rocky environments such as crypts, tombs, caves, etc. suffered from bio-deterioration, which is generally influenced by high values of humidity, together with light conditions, and nutrient input. These factors supported biological growth. Their research presented the plan for conservation treatment of the Crypt of the Original Sin in Italy. The mural showed a phenomenology of alteration varying from brilliant green, dark green, brown, and black stuff patinas with powdery aspect, to rosy discoloration. These phenomena were linked to different microbial colorizations (13).

Modern painting

Since the early 1960s, synthetic binder became well known and dramatically replaced the traditional binding media. It widely used by artists for modern mural and easel painting. These synthetic polymers Acrylic emulsion artists' paints were popular due to its excellent physical properties and variety application. It is waterborne, as well as its fast drying times, high resistance to chemicals, and flexibility (38, 39). Acrylic paints are a favorite art for media at present, today many brands of artists' acrylic paint are available in the market (39). About half of artists worldwide are class as "acrylic"(22).

Thai artists at the Fine Art department in the Ministry of Culture noticed that Thai mural painting currently paint using synthetic paint such as acrylic paints or pastel. Instead of direct painting on the wall, they used canvas and glued them on the wall. Mural painting in Kusinagar Chalermrat temple, India is an example of this technique.

Thai artists used acrylic paints to paint the object on the canvas. The work was done in Thailand and brought the finished art work to the temple in India (40).

Though synthetic paint replaced traditional material 50-60 years ago, but degradation of synthetic materials has also occurred. It was reported that indoor air pollutants and dirt accumulated on surface of painting may take 50 years to become perceptible by human eyes. Therefore, numerous painting that were created 50 year ago are being cleaned and restored (41). Three mural paintings of Keith Haring which were painted between 1984-1989 were good examples (42). These three mural paintings located in Pisa, Paris, and Melbourne were analyzed by Py-GC/MS in 2015. This was to understand the materials used for these art works in order to correlate their chemical composition with conservation, and the results were presented that the binder used for these works was styrene/n-butylacrylate copolymer, alkyd, vinyl, and acrylic resin (42).

In the last few decades, deterioration of these synthetic polymers has become an interesting subject. Conservators and scientists who work in conservation science field have focused on this matter to understand their mechanical and chemical long-term stability. (43). There is numerous literature that presented degradation of art works using synthetic media. Degradation of these materials was caused by many weathering factors such as light, air pollution, temperatures, and humidity. Simulated method and in situ verification were conducted in order to understand the degradation mechanism of mural painting, and to propose the preventive methods. Mecklenburg presented that temperature influenced on mechanical property of the acrylic paint film. Increasing of the temperature of the paint film can increase free swelling strain. Studying tensile stress-strain confirmed that high temperature led to the increase of paint film elasticity but decreased the bulk material strength. It was suggested that high temperatures increased the kinetic of chemical process that led to the deterioration. At the low temperature acrylic paint film was stable without any damage due to their increasing of bulk material strength. At the temperature below Tg, acrylic paint film became brittle and lost significant ability to elongate (44). In addition to temperature, increasing in RH also increased free-swelling-strain. Stress-strain testing confirmed that increasing of RH, acrylic paint film increased in elasticity and decreased in bulk material strength (44). In Mecklenburg's study, it was also mentioned that the change of RH range (10-80%) caused a larger mechanical property change than the change of temperature range. (-28°C to 27°C) (44).

It was believed that acrylic paintings naturally accumulated soil over time due to the mechanical softness of the acrylic paint film in addition to the presence of the surfactant residue on the film surface. Environmental factor influenced these variables and hence the rate of soiling (41). Ian Ziraldo studied the influence of temperature and humidity on swelling and surfactant migration in acrylic emulsion paint film. The results showed that when the temperature rose above 20°C or as RH increase above 40%, the surfactant moved from the surface into the paint film. This made the paint film changed in volume and thickness (41). Cycling of RH above and below 20°C provide mechanism to move surfactant between paint surface and paint bulk, and may entrain soils along with it. This likely may conclude that above approximately 20°C, paint film surfactant and soil will move into the paint film, while below this temperature paint films are more brittle and move surfactant and possibly entrained soil to their surface. Above 40% RH, the films also softened and swelled in volume and surfactant move into the paint film. Below 40% RH, surfactant moved out from the paint body to the paint surface. This agreed with th the Smithsonian Institution's RH and temperature guideline that is 45 ± 8% RH and 21 ± 2 °C (41). Marta Melchiorre et al compared the stability to outdoor weathering condition of vinyl, acrylic and styrene acrylic formulations used in waterborne paint in contemporary mural, by means of photochemical degradation. The results showed that stability of acrylic and styrene-acrylic waterborne paints used to create exterior mural were more stable than the vinyl waterborne paints. It also showed that the degradation of binders led to variations in the morphology of the paint layers, which led to color changes (45). M.B. Kasiri et al studied photo-oxidative stability of a series of Red Acrylic Paints. Accelerated UV light exposure was applied to a series of red acrylic paints to study their degradation. Paints in scope were Carmine, Quinacridone scarlet, Alizarin crimson, Brilliant red, Vermillion and Cadmium red hue. After photo-aging for a total time 1,200 hours, the results of FT-IR spectroscopy showed structure changes of cadmium, Quinacridone scarlet, primary magenta and vermilion. Colorimetric measurements indicated the reduction in the absorption of visible light due to photo-degradation of the pigment structure. Furthermore, alizarin crimson and brilliant red underwent more weight loss compared to the others, which resulted in rapid formation of VOCs (30).

Biodeterioration

As mentioned previously, humidity and other weather parameters support the growth of microorganism, which can cause the degradation of mural and artifacts.

Biodegradation is defined as any undesirable changes in a material brought by the activities of organisms (46). Bacteria (archaea, fungi and lichens as well as insect pests) is constantly causing problems in the conservation of cultural heritage because of its bio-deteriorative potential (46). Microorganisms that deposited on painted surfaces came from the surrounding environment. On external surfaces, rain and wind bring small fragments of plant and animal origin, spores and microbial cells, as well as minerals and air pollutants. On internal surfaces, the aerial microorganisms are derived from the external air, but the population is also influenced by human activities within the building (20). Research insisted that these microorganisms found on mural paintings in temples, churches and caves, and many types of material. They have deteriorated the ancient wall mural paintings for decades (46). Cifferri insisted that microorganisms' activity played an important role in the deterioration of mural paintings (10). Among these, lichens played a minor role in colonization. Algae and bryophytes although, often abundant in the plasters and mortars, are considered less important in biodegradation but they supported the colonization and development of allied heterotrophic population of bacteria and fungi (47) which were the main biodeteriogens responsible for esthetical damage (overgrowth and discoloration) and structural damage (due to the formation of organic compounds). Pepe et al. stated that the wall painting supports the growth of microorganism commonly involved in bio-deterioration, contributing to the destruction of paint; their deterioration constituted a loss affecting a significant part of the world's cultural heritage artifacts (9). Moreover, reports also mentioned that the growth of fungi on wall paintings manifested most commonly by discoloration or deterioration of the surfaces. Microbial population caused discoloration of pigments, physical decay when fungal hyphae grow either on or below the surfaces, cause chemical decay of paintings through their metabolites and enzyme production like gluconic, citric, oxalic, malic etc. (1, 11, 12, 48). Thailand is geologically located in a tropical climate zone where the temperature and humidity are high. These factors supported the growth of microorganism. Thus the mural painting could not be avoided from the biodegradation.

2.3 Materials used in traditional Thai mural painting

2.3.1 Traditional Primer

Primer is a key material when creating mural art. Traditionally, primers used for Thai mural painting were made of natural ingredients; a particular type used tamarind glue as a binder and natural clay as pigment. To prepare the wall surface before applying the painting, artists constructed three layers. The first layer was a construction of bricks and mortar, a second layer was a plaster which is a mixture of lime, sand, fiber, and gum. After applying the plaster, Senna (or *Ki-lek* in Thai language) leaves extracted solution was rinsed on the surface to adjust the pH of the surface from Alkaline to neutral. This was supposed to remove any trace of salt (49). Subsequently, a Tumeric (*Khamin Chan*) was drawn on the surface in order to check the ready pH by mean of turmeric color changing before applying the third layer. The third layer was a mixture of marl and Tamarin glue. Once the pH of the plaster was ready to be used, the primer was applied (4).

The ancient artists used natural ingredient to make the art materials even though they did not know chemical structure or chemical property. Research supported the accuracy of this knowledge. Literature mentioned that white clay filler or marl or marlstone, which played a role as pigment in the primer, was normally a white clay that had a percentage of calcium carbonate of more than 80%. In addition to calcium carbonate, it contains variable amount of magnesium carbonate, calcium oxide, silicon oxide, aluminium oxide, iron oxide and magnesium oxide, etc. Marl or white clay filler does generally look like white kaolin; it is fine, white, grayish or brownish, or yellowish depend on the mineral composition. Marl can be found all over Thailand but mostly in Lopburi province (50). While the binder, tamarind glue was produced from boiling of tamarind seed. Research stressed that it consists of polysaccharide, mainly xyloglucan, about 75%. Xyloglucan has the ability to form gel and used widely as a thickening, stabilizing, or gelling agent, it is also known as jellose (51).

Senna (*Cassia siame)* is a tree native to Asia. It is a medium size tree, up to 15-20 m tall, with a straight trunk, up to 30 cm in diameter. Its leaves and flower are used in many applications (52). Young leaves and flower are used as food and herbs. Old leaves are typically used in wall preparation before mural paint is applied. Leaves are decocted and its extracted solution is used to treat the wall surface (4).

Tumeric (*Curcuma Longa)* is traditionally called *Indian saffron* since its deep yellow-orange color is similar to the prized saffron. It comes from the root of the *Curcuma longa* plant and has a tough brown skin and a deep orange flesh. Thai artists use turmeric to check the ready to use pH of the concrete wall surface prepared for mural painting (4). Its color is yellow in acidic and neutral condition and turns brown to reddish-brown in alkaline solutions, with transition between pH of 7.4 and 8.6 (8).

2.3.2 Traditional Paints

Paints used in Thai mural painting traditionally are the mixture of two major ingredients, natural pigment and with glue made of animal leather or gum. Paints and pigments in Thai arts in artists' pallets have been changed and developed over time while the binder has mainly remained as gum Arabic and several more.

2.3.2.1 Binder used in Thai Painting

The type of gum that was traditionally used is gum Arabic, which is still used today. Gum Arabic is a natural gum consisting of the hardened sap of various species of the acacia tree. It dissolves easily in water and varying amount of pigment of any color is suspended within this gum. Water acts as a vehicle or a diluent to thin the paint and helps to transfer the paint to a surface such as paper or canvas. Another gum that was used is named *ma-kwit* in Thai language. Ma-dua tree (*Ficus hispida urticaceae*) is also used particularly as a glue to adhere the gold foil (49).

2.3.2.2 Pigment found in Thai Painting

General pigments used in traditional murals were made of natural materials such as stone, soil, or animal etc. Records from the Ayutthaya dynasty showed only a few colors, such as yellow, red, white, and black (33). Even late in the Ayutthaya period, there were still not many colors found on the mural arts. The colors were still black, red, white and gold foil. It was believed that black was taken from lamp black or bone, while white was made of lime or white earth-powder and red was made from cinnabar or ochre earth (33), (49). In addition to these colors, yellow was taken from the gum of *Rong* plant (or gamboge); green from green stone and blue color was taken from the boiled leaves of *cram* tree (49).

Colors used in the Thai artists' palette have been developed over time. The dramatic changing in artists' palettes was happened in early period of Rattanakosin dynasty especially in the mid of 19t century, during the period of King Rama 3-4. There was a record in the list of "import and export to Thailand" written in 1852 by D. E. Mulloch, an employee of the British East India Company. Mulloch mentioned that there were four major sources of pigment. Pigments resourced locally were Dragon's blood, gamboge, gold dust (for local temple), indigo (local use only), and lead white and black. Pigments that were imported from India were Arsenic (white and yellow), red and yellow ochre, turpentine, gum tragacanth (or gum dragon from Turkey), gum Arabic, and verdigris. Gold leave (for large quantity for temples), glue, varnish, paint (red, blue, black, white, and green) were imported from China. Green, blue, black, and red paint was imported from British (53). Jo Feng Huang studied the historical information on Thai manuscripts, results presented that there were huntite, lead white, calcite, indigo, red lead, vermilion, gamboge, ultramarine, and red earth in the 18th century manuscripts. While the 19th and 20th century manuscripts, the analyses indicate lead white, calcite, red lead, vermilion, gamboge, chrome yellow, emerald green and Prussian blue, as well as possible barium sulfate, titanium white, and viridian. Moreover, the results suggested that different blue pigments were used in different centuries: indigo in the 18th century, ultramarine and Prussian blue in the 19th century and Prussian blue alone in the 20th century (53). Even though Jo Feng Huang studies were focused of paints on manuscripts, a connection can be made based on art historians' claims that there is a parallel relationship between the murals, sculptures, banners, and manuscripts in the history of Thai art (53).

Additional scientific analyses of Thai mural were found and thought to be helpful to this study. In 1990, Prasartset C. studied the materials used for mural painting of Maitepnimit temple where their mural painting was suggested by historian that it was made at the early of Rattanakosin or late Ayutthaya dynasty (54). The analitical method was chemical testing; SEM/EDX, XRD, and TLC, HPLC, and mass spectroscopy. The results revealed that the white pigment used in the white patterns was hydrocerussite. Gypsum and kaolinite were found as white pigments mixed as fillers in other paint layers of various color samples. The red pigments found were cinnabar, minium, and hematite. The blue pigments were indigo and cumengeite. The green pigment found was malachite. Carbon was found as black pigment. Gamboge was found as yellow pigment under the gold layer in the gold sample and also found mixed in the paint layer of the leaf green sample (55). Another study was done by Katheric et al. who researched the materials and techniques of Thai painting by using the x-ray fluorescence (XRF), Raman spectroscopy, Fourier Transform Infrared Spectroscopy (FTIR), X-ray diffraction (XRD) and scanning electron microscopy with energy dispersive microanalysis (SEM-EDS). The results supported and aligned with other literature that Thai artists' palette dramatically changed starting in the 19th century due to trading with western countries. The most notably pigments during the 19th and early 20th century, were emerald green, Prussian blue and chrome yellow.

While the green pigment used on most 18th century manuscripts was an organic copper salt, a hydrated copper citrate (56), (54). Among the referred studies, the result suggested the paints applied were usually not homogeneous in composition. Various transparent whites such as gypsum, kaolin, or calcite were mixed into all of the colors.

2.4 Novel Primer

Primer is important in preparation the support or ground surface before paints are applied. New technology which has been developed by the coating industry expanded dramatically the new paint media, and then artist adopted it. Primers have been made by many brands, and commercially available in the market. In the research of Christina Young, market branded primer were presented in the Table 2.1 (57).

Table 2.1 List of primer samples tested by Christina Young

Primer Brand & Name	Pigment	Binder	Extender	Manufacturer's Recommended Use
Golden Gesso Primer	TiO_2	p(BA/MMA) acrylic	Silica	Priming all surfaces for oil and acrylic paint
Winsor & Newton Oil Painting Primer	TiO_2	Alkyd	Aluminium Silicate	Priming all surfaces for oil and alkyd
Spectrum Thixotropic Alkyd	TiO_2	Alkyd	None detected	Priming all surfaces for oil and alkyd
Roberson Oil Primer	TiO_2	Modified oil Alkyd	Aluminium Silicate	Priming canvas and wood for oil
Roberson Acrylic Primer	TiO_2	p(BA/MMA) acrylic	Calcium carbonate	Priming all surfaces for oil, acrylic and tempera

In this research, a novel primer that would be an alternative for Thai artist was focused. Synthetic media, pigment, extender and other additives were literate.

2.4.1 Binder

Binder is a very important ingredient that affects almost all properties of the paints or coating, especially its durability and resistance to blistering, cracking, peeling, scrubbing, chalking and fading. This ingredient also affects the application properties such as flow, leveling, film building, and gloss development. Synthetic resin used as binder in paint and coating were tracked and recorded since the late 1920s. And it was notable in 1960 because acrylic emulsion paint was introduced commercially to the market (38, 45, 58). Generally, there are four classes of synthetic resins that have been being utilized in paints; acrylic, alkyd, polyvinyl acetate (PVA) and nitrocellulose. Polyurethane, epoxy and chlorinated rubber, are also used but mostly in coating to restrict weather and corrosion and resistant (58). **Acrylic resin** is most well-known and useful binder. Its physical properties, especially the glass transition temperature (Tg) is properly used in thermoplastic paint. The Tg is around room temperature, which is high enough to prevent the dried film from becoming tacky. For example, Acrylic-monopolymer, *poly (n-butyl methacry)* which was used in acrylic solution paints has Tg around 22^{o}C. The acrylic that has been used in acrylic emulsion paint is an acrylic copolymer such as Ethylacrylate/methlymethalate (EA/MMA) copolymer. In addition, acrylic copolymer that contains different composition is also commonly used. **Styrene/acrylic copolymer** has been household emulsion (58), and are also used in artist quality paint due to its low-cost (58). Studying about stability to outdoor conditions of waterborne paints in contemporary mural presented that the acrylic and styrene-acrylic had minor degradation while the vinyl products had slightly more (45).

In this research, styrene/acrylic emulsion was used as binder in the novel primer as well.

2.4.2 Pigment

TiO_2 (Titanium dioxide) is a white pigment (PW6) that is mostly used in a wide range of products such as paint, plastics, and paper. Roughly, 90% of the TiO_2 is used as a pigment in paint and coatings. Its important property is an ability to give a paint white color and to have a high opacity to cover the substrate. TiO_2 appears white due to its ability to scatter visible light. However, TiO_2 in the rutile form is not perfect white since it absorbs some of the light in the 400–500 nm range, thus it gives cream-toned whites. Refractive index of TiO_2 are 2.488 for anatase, 2.583 for brookite, and 2.609 for rutile (59). Typically a TiO_2 pigment is given a surface treatment to optimize desirable paint qualities such as dispensability, opacity, and gloss (60). In addition to providing white color, the TiO_2 is also a known photocatalytic that can deactivate the growth of microorganism that is harmful to the mural due to its biodegradation activity (14-17). The mechanisms of TiO_2 nanoparticles depend on the bactericidal effect, which are a result of mechanical interactions on cell walls and/or membranes of microorganisms in the presence of photocatalysis (15).

2.4.3 Filler

Filler (or extender) is normally used to reduce the cost of production. They do not add much hiding power but they have an impact on many properties, such as sheen, scrub resistance, exterior color retention, and others. There are several common fillers used in paints and coating industry. In this research, aluminium silicate was focused. **Aluminum silicates** (also called kaolin or clay) is a name commonly applied to chemical compounds that are from Aluminium oxide and silicon dioxide. It is a white cream color with reflective index as 1.56-1.62 and the density is 2.58 to 2.62 g/m^2 (61). It has a low viscosity at high solid concentrations. It is used in many industrial including paint and paper coating because it physical properties that include viscosity (both low and high shear), brightness, whiteness, gloss, smoothness, adhesive demand, film strength, ink receptivity, and print ability. However, the application in paint is also related to these good physical properties and the fact that it is near chemically inert between pH 3 to 9 (62). This material is not only mainly used in interior paints, but also in some exterior paints.

2.4.4 Additives - Silver nanoparticle

It is well-known that nanoparticles of metal have antimicrobial properties. Silver nanoparticle is the one of the most interesting metal that Ag ions and Ag-based compound are highly toxic to microorganisms. Though the effect of Ag nanoparticles on microorganism and antimicrobial mechanism has not been reveled clearly, but however, significant number of researches have explained and supported this fact. (63, 64) Silver nanoparticle was widely applied in not only hospital and healthcare environments but also home, coating, painting and industrial applications, especially the coating and painting industrial. They were developed for paint. They can protect coatings from biofilm formation and are generally not released into the environment, thus avoiding the pollution problems of biocides (63).

Kim et al mentioned that Ag nanoparticles can be used as effective growth inhibitors in various microorganisms, making them applicable to diverse medical devices and antimicrobial control system (19). Q.L. Feng et al stressed that nanoparticle of silver and copper had strong inhibitory and antimicrobial effects, as well as, broad spectrum of biocide activities (19, 65). Furthermore, it is known that DNA of microorganism loses its replication ability and cellular proteins become inactivated on Ag^+ treatment (65). It was also shown that Ag^+ bonded to functional groups of proteins, resulting in protein denaturation (65). Some studies have reported that the positive charge on the Ag ion is crucial for its antimicrobial activity through the electrostatic attraction between negative charged cell membrane of microorganism and positive charged nanoparticles (19). One other reason mentioned in the literature is that nanoparticles of these metals interact with the elements of bacterial membrane resulting in the structural changes leading to the cell death. Moreover, when silver nanoparticles have enough small size, they can disrupt the bacterial cell membranes because they can gain entry in order to disrupt the enzyme function.

Therefore, part of this research is to use the silver nanoparticle as an additive for anti-bacterial in the painting primer.

2.4.5 Additive - Ceramic Microsphere

Ceramic microsphere has been mentioned that its spherical and hard particles offer the formulators the chances to lower binder demand, and to control viscosity and VOCs while increasing burnish and abrasion (21). Kevin reported the coating that was added ceramic microsphere has better abrasion resistance (21). In addition, ceramic microsphere can replace the zinc phosphate which is the anticorrosive pigment but increasing of using this zinc phosphate produced eutrophication of water body. Ceramic microsphere can give the anticorrosive of the paint (66).

In this research, ceramic microsphere was added in the primer to improve the wash ability and abrasion property of the primer.

2.5 Artist Paints

Human like to leave the mark on their environment. Scratching, carving and especially painting were discovered in the cave, dating back since pre-historic times (22). Painters used natural pigments to color the surface, and it was found that pigment worked well when it was mixed with glue or gum as binder. Therefore, there were many types of paints that have been used since pre-historic till today. Oil colors were on the art works since the fifteenth century. It was majorly pigment mixed with oil base solution such as linseed oil. Tempera was the powder pigment mixed with gum, glue or egg yolk, it has record of the thousands of years. Watercolor had a gum Arabic as a binder. It also has a very long history as it was the result since prehistoric and it is still popular till today. In the long history of art, acrylics are fairly new compared with other materials, acrylic paint has pigment and acrylic resin as major component (25).

2.5.1 Pigment for artist paints

Pigment is the major component to create colors of art. In general, same type of pigment can be applied using in many types of paints; acrylic, water color, oil color, pastel, etc. Just like binder media, human has developed pigment used in art and industry overtime since earth to modern synthetic pigment. In a matter of chemical composition, pigment can simply be divided into two types, organic and inorganic ones. But if pigments are based on sources, they may be divided into 3 groups; earth, traditional and modern pigment (23).

Earth pigment were used since pre-historic as they were available naturally. Painters were able to find it in home, soot from burning animal fat and charcoal from the fire (22). This group of pigment are the ochres, siennas, umbers and mars. Color were yellow orchre, red orchre and black basically. The chemical composition of the yellow orchre is ferric oxide monohydrate $Fe_2O_3.H_2O$, Red Orchre is produced by heating the yellow one in order to drive off the water and produce anhydrous ferric oxide, by controlling the heating it is possible to produce range of warm yellows to bright red. Brown color was made by mixing black with red and yellow. Brown pigment was called "raw humber", it was comprised of hydrate iron and manganese oxides. Heating raw humber can produce burnt humber which is a richer brown. Raw sienna is an orchre containing silicic acid. It could be calcined to produce the richer burnt sienna (22).

Traditional pigments are the metal based ones such as cobalt, cadmium, titanium and ultramarines (22). For example, cobalt metal pigments can give a variety of colors. It included cobalt blue, cobalt green, and cobalt violet. Cobalt blue is a combination of cobalt oxide with aluminium, phosphorous, tin, zinc and other metal. Heating quartz, potassium carbonate and cobalt choride gives a blue pigment called smalt. Cobalt green is a combining of cobalt and zinc oxides with an alkaline carbonate and heating the mixture. Cobalt violet is made of cobalt phosphate or cobalt arsenate. Cobalt yellow is a cobalt aluminium nitrite. Cerulean blue is a compound of cobalt oxide and tin oxide.

Cadmium metal was discovered in 1817. Its hues range from lemon yellow to a deep orange. Cadmium yellow was made by mixing cadmium sulphide with an acidified solution of cadmium chloride or sulphate and heated with hydrogen sulphide gas.

Modern or synthetic organic pigments which have high permanence and intensity has been becoming popular in artists pallet since 1990. This group of pigment include Phthalocyanines, Quinacridones, Perylenes and Pyrroles, for example (22).

New technology and expert manufacturers serve the market by making preparation pigment which its powder was mixed in the vehicle, dispersant agents and sometime antifoaming agent were added. Paint manufacture is convenient to produce their products.

Despite modern technology, the artist's palette remains a mixture of the pigments used by cave artists, natural pigments used in the middle ages, and modern organic compound (23).

In this research, organic pigments were utilized in a part of acrylic paint. And both organic and inorganic pigments were used in pastel.

2.5.2 Acrylic Paint

Acrylic polymers has been used in artist paints since the 1940s (23). It became commercially available around 1950, and quickly became the preferred technology for most acrylic artist paints. Acrylic emulsion paint was introduced commercially to the market in 1960 (38, 45, 58). It dries much faster than oils. Some artists like the faster drying, while others prefer the slower cure of oils. Fast dry is a clear advantage for layering, masking, re-working and when thick layers of paint are being applied (23). Thick layers of oil paints dry very slowly and are vulnerable to cracking (21). Acrylic can also resist water when it is completely dried. Therefore, it can be thinned and cleaned up with water (38). It adheres to anything: canvas, paper, metal, wood, concrete and plastic. Since it was originally used to paint the exterior of houses, it has inherent durable, high resistance to chemicals, excellent flexibility, good gloss retention, good adhesion, good stability with respect to hydrolysis, and superior stability under prolonged thermal stress and exposure to light (38).

About half of the artist paints used worldwide now is classed as "acrylics" (22).

And it share 50% of artist market (58).

This material of artists’ paint was formulated with an acrylic polymer resin that was emulsified with water. The pigment is mixed with the acrylic resin-base polymer instead of natural gum. Basic components of acrylic artist paint include acrylic base resin as binder, pigment, filler and additive.

2.5.2.1 Binder

Binder used for acrylic artists’ paints is also called waterborne acrylic paints, acrylic paints’, ‘acrylic emulsions’, ‘latex’, and ‘polymer colors (38). It was adopted from the exterior paint. The binder for professional grade artists’ acrylic is usually based on acrylic copolymer resins. Three different types of acrylic co-emulsion are commonly used for paint formulations: (1). poly(ethyl acrylate/methyl methacrylate (EA/ MMA), (2) poly(butyl acrylate/methyl methacrylate) (nBA/ MMA), and (3) 2-ethylhexyl acrylate/methyl methacrylate (2EHA/MMA). The earliest paints were based on p(EA/MMA) (poly ethyl acrylate/methyl methacrylate) copolymer emulsions (67). From the late 1980s to the late 2000s, the majority of artists’ acrylic paints were based on p(nBA/MMA) (poly-n-butyl methacrylate/ methyl methacrylate) copolymers, which tend to be slightly tougher and more hydrophobic than the pEA/MMA resins, making them more durable to outdoor exposure (67). In addition to these two type, acrylic copolymer with other composition such as styrene has sometime part or wholly replaced the MMA component to save manufacturing costs. Styrene-acrylic copolymer are often used in low-cost household emulsion (styrene is cheaper than acrylics), but are also used in artist quality paint. (38, 58).

Examples of the market branded acrylic paints that has different binder polymer were listed; **Flashe by LeFranc & Bourgeois (L&B**), consists of a poly(vinyl acetate-co-vinyl versatate resin, pVAc/VeoVa; **Heavy Body (H.B.) by Liquitex**, consists of a poly(n-butyl acrylate-co-methyl methacrylate) resin, p(nBA/MMA); **Brera by Maimeri** , consists of a poly(n-butyl methacrylate- co- styrene -co- 2-ethylexyl acrylate) resin, p(nBMA/styrene/ 2EHA) (45).

2.5.2.2 Extender

There are different type of extender used in paints for example, talc ($Mg_3(Si_4O_{10})(OH)_2$), barite ($BaSO_4$), calcite ($CaCO_3$), kaolinite ($Al_2Si_2H_4O_9$) and various form of silica (67).

2.5.2.3 Additives

Additives normally perform multiple functions within the wet and dry states of the paint; primarily influencing paint stability, longevity, flow and film formation. General types of additives are emulsion stabilizers, coalescing agents, pigment dispersants, defoamers, freeze-thaw agents, pH buffers, preservatives, humectants, matting agents, biocides, surfactants, thickeners, wetting agents and protective colloids (68). However, these components continue to vary over time due to many reasons such as manufacturers made changes of formulation and raw materials changes made by, change to comply with law, price changes, and discontinued production, availability of materials, as well as technical evolution (69).

Wetting and Dispersing Agents are used to wet the pigment surfaces allowing pigment agglomerates to break apart in order to develop color strength and to provide steric and/or electrostatic stabilization of the pigments. Typical wetting agents are alkyl phenol ethoxylates, acetylenic diols, alkylaryl sulfonates and sulfosuccinates (26). while typical dispersing agents are polyphosphates (generally calcium or potassium salts of oligophosphates with two to six phosphate units) or polycarboxylates (23).

Coalescing Solvents' function is to insure film formation under varying atmospheric conditions. They are slow evaporating solvents with some solubility in the polymer phase. They act as a temporary plasticizer, allowing film formation at temperatures below the system's glass transition temperature (T_g) after which they slowly diffuse to the surface and evaporate, increasing the hardness and block resistance of the film (25).

Defoamers is used to reduce the foam. They are typically mineral oils or silicone oils. The mechanism by which defoamers function is not fully understood, but essentially these very hydrophobic materials are thought to move to the air-liquid interface, allowing the air to release (23, 25).

Preservatives: is added to avoid the effect of dilution as water and other components are added.

Thickeners and rheology modifiers: required to achieve the desired viscosity and flow properties. Thickeners function through multiple hydrogen bonds to the acrylic polymer, thereby causing chain entanglement, looping and/or swelling which results in volume restriction. The most common group is cellulose derivatives, including hydroxyethylcellulose, methylcellulose and carboxymethylcellulose (25).

Freeze-thaw Stabilizers: if a waterborne paint freezes, ice crystals will form, thereby disrupting the dispersion stability and causing permanent damage through polymer coagulation. However, the incorporation of two to ten percent ethylene or propylene glycol ensures the water, surfactants and protective colloids will return to the acrylic emulsion surface in an orderly way (23).

2.5.3 Pastel

Pastels is an art medium which its normal form is stick. The components are common, as it is made by mixing of a binder with powder pigment and a white diluent powder such as clay or chalk (69, 70). Pastels are defined as being either soft or hard. The strength of the binder determines this property-the stronger it is, the harder the pastel. Soft pastels are by far the most useful and have superior brilliance, intensity, and paintlike qualities. They are indispensable for laying in large color areas and for building up heavy pigment. Hard pastels are primarily useful for refining and drawing purpose (70).

Pastels have been used by artists since the Renaissance and gained popularity in the 18th century. It is said that pastels originated in France. Leonardo da Vinci referred to them in his Codice Atlantico (1495) as “anewdrysubstance” (71).

Process to produce pastels is common. The mixture of pigment and medium are moistened and made into dough, which is molded into sticks. When dry, a properly formulated pastel will produce a line when drawn across a sheet of paper. High volume of binder produces a hard stick that gives no line and too little binder makes the stick unusable as it fragments when used (69, 70). In normal handling, pastel drawings are unstable as the pastel pigment is only loosely attached to the paper. Often artists employ polymeric fixatives in solution to consolidate the friable surface to avoid pigment loss by gravity, vibration, high air velocity and abrasion. A fixative would render a pastel drawing less susceptible to loss of pigment when washed and sufficient fixative might make a pastel drawing stable to water treatments. Artists have also used steam as a fixative (72). Thai artists bring the stick pastel that is available in the market to grind and mix with gum Arabic when painting their mural.

2.5.3.1 Binder for pastel

There are many kinds of gum or glue that are used as a binder for pastels. Vincent Daniel, the well-known pastel artist mentioned that a common gum that is used for pastel is gum tragacanth (72). Kurt Wenner also supported that the best quality glue for pastels is gum tragacanth (69). Gum Tragacanth is a natural gum obtained from the dried sap of Middle Eastern Legumes. Gum Arabic, also known as acacia gum, is a natural gum made of hardened sap taken from two species of the acacia tree. Of the two, gum Tragacanth is more suitable binder than gum Arabic. Glues are less suitable, but wheat paste, wallpaper paste, (Methyl cellulose), and even white glue are sometimes used as binders. Binders for pastel must have very little strength; otherwise the pastel will become too hard and will not leave a mark on the drawing surface (69).

2.5.3.2 Pigment for pastel

Powdered pigment for pastel as we know can date from the 17th century and it became popular in the late 1800s as Manet, Degas, Renoir and Toulous-Lautree used them (68). Both metal oxide and organic Pigments have been used for pastels. Pigments for pastel recommended by Kurt were listed as below; (69)

Whites: Titanium Dioxide White and Zinc White.

Blacks: Carbon Black and Mars Black

Reds: Red pigments include Ferrous Oxide Reds (Red Ochre, Mars Reds, and Burnt Sienna) and synthetic red pigments (Cadmium Red, Chrome Red and the organic pigments red-Alizarin Crimson Quinacridone Red).

Oranges: Orange pigments include Ferrous Oxide Oranges (dark Yellow Ochre, and Mars Orange) and synthetic orange pigments (Cadmium Orange and the organic pigment- Quinacridone Orange).

Yellows: Yellow pigments include Ferrous Oxide Yellow pigment (light, medium, and dark) and synthetic yellow pigments (Cadmium yellow-light, medium, and dark, Chrome Yellow, and the organic pigment- Quinacridone Yellow).

Blues and Greens: Only Ultramarine is a natural or ferrous oxide but it is not recommended for pastels and must be used in a mixture with other pigments. Synthetic blues and greens include the organic Phthalocyanines colors are all extremely useful. Cobalt Blue is useful as well but it is expensive.

Violets: Violet comes as Mars Violet which is a Ferrous Oxide. A tint of Phthalocyanines can also be used. Cobalt Violet is hard to use in pastel since it is extremely expensive.

Browns and earth tones: Ferrous oxides and earth pigments can give brown color. Earth tones such as Burnt Sienna and Burnt Umber are chemically similar to oxides, but occur naturally, these can be used in pastel as well.

2.5.3.3 Filler for pastel

Fillers are not necessary for pastels and are mostly used for reducing costs. However, they can provide smoother blends for artists that like to work “impasto” (69). One common filler used for pastel is chalk (calcium carbonate, $CaCO_3$) which is a soft, fine-grained white mixture. While Talcum powder, hydrated magnesium silicate, is often an ingredient in French pastels. Silica, (silicon dioxide), is similar but more refined filler than calcium carbonate, and has even less tincture strength (69).

2.6 Thai color name

Besides the degradation of the mural painting, the color names used in Thai mural painting and artifacts were also considered. As these two matters are related each other, changing or losing the names of the Thai color affected the creation or restoration of the mural painting and other artifacts (3, 5).

As mentioned previously that Thai mural paint is applied by tempera which is the mixture of dry powder pigment and Arabic gum or glue. The result of mixing gives different colors and each color has different name. Thai color names that were identified by Siripant in 1988 had 209 names. Those names were collected from four Thai dictionaries of art, two Thai encyclopedias of art, seven textbooks, seven volumes of archival correspondence and one journal. Among 209 color names, 50 color names were painted by the Thai artist and matched with Munsell and CIE color systems, 159 color names were left without knowing how they look like (6). One reason of losing Thai color is that there was no record by mean of scientific data. The ingredients to mix these colors were transferred from elder to younger artists, from teachers to students, from generation to generation. There was neither publication quantitatively describing the characteristics of Thai colors nor the comparison with the standard color patched. During the restoration of the Temple of the Emerald Buddha for the Rattanakosin Bicentennial celebrations in 1982, the difficulties and inconsistencies of Thai color name came to light (6). In 2013, Katemake et al. referred Siripant's work to identify the Thai color name again, the same 209 color names were given to the best qualification and experienced artists in the Fine Art department, ministry of culture. 10 Artists involved in painting the Thai color according to 209 color name. This research came up with the Thai color dictionary that matches the Thai color names with the Munsell and NCS system. However, only 147 color name were identified, 62 color names were disappeared since the artists did not know how these colors look like (5).

Color of Khon masks is an example of painting using Thai style colors. The colors painted on Khon masks were solid without gradation, highlight, or shadow. Each color identify the particular character of each actor who has different roles. If the colors changed a little, the audience might misunderstand that it had another role (3). Two important roles of Khon were monkeys and giants. There were many characters for monkeys, such as ‘‘Sukreep’’ who was represented by ‘‘Dang Chad’’ (bright red and red), ‘‘Komut,’’ represented by ‘‘Bua Roay’’ (faded rose), ‘‘Tao Maha Chompu,’’ represented by ‘‘Khab’’ (dark blue), and ‘‘Nilapat,’’ represented by ‘‘Nam Rak’’ (dark sepia). While the giant roles were such as ‘‘Visanuraj,’’ represented by ‘‘Dok Ta Baek’’ (deep azure and blue purple) and ‘‘Chompu Malee,’’ represented by ‘‘Hong Sabat’’ (light red). Thai mural paintings and Khon masks shared the color names but there was told by artists that some colors used for Khon masks were somewhat different from those used for mural paintings (3).

Currently, traditional paints were not easy to find. Artist satisfied using the new media because it is more convenient. However, most acrylic paint and pastel are imported; they have varieties of color shades but are not exact to Thai colors. Artists needed to mix those colors to match Thai style colors. Concern is that not all artists, especially the young generation ones know the Thai style color well. We, therefore, aimed to make the Thai style colors for pastel and acrylic paint that matched with the Thai color dictionary.

2.7 Color difference and color tolerance

Color difference is the amount of difference between two colors under specified conditions. It is abbreviated by ΔE symbol, which also has subscript that explains different versions of that color difference. The Commission Internationale de l’Eclairage (CIE), the organization is responsible for the development of international color standards including color differences. Color difference was developed before 1976, started from CIE L*a*b*, CIE L*C*h*, CMC, CIE94 and CIEDE2000 (73). In general color description, the basis of color difference formula is CIE 1976 L*a*b* (CIELAB) as presented in the Equation 2.1.

$$\Delta Eab^* = \sqrt{\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}}$$

Equation 2.1

Where;

L* is the lightness coordinate.

a* is the red/green coordinate, +a* indicating red, and -a* indicating green.

b* is the yellow/blue coordinate, +b* indicating yellow, and -b* indicating blue.

ΔL* being the lightness difference.

Δa* being the red/green difference.

Δb* being the yellow/blue difference

However, CIELAB is not perceptually uniform especially in the saturated region. This model does not agree with visual assessment because eye does not detect differences in hue, Chroma, and lightness equally. Human see hue difference first, Chroma difference second and lightness difference last. After that, CIECMC (abbreviated with symbol ΔE*CMC) which generally correlate better with visual assessment, in both acceptability and perceptibility applications was adopted. CIE1994 (abbreviated with symbol ΔE*94) was further developed. CIE94 formula is similar to the CIECMC that based on CIE lightness (L*), Chroma (C*) and hue (H*). It was based on visual assessments on glossy paint samples and mainly been used in paint and coating industry. CIE94 formulation was presented in the Equation 2.2.

$$\Delta E_{94}^* = \sqrt{\left(\frac{\Delta L^*}{k_L S_L}\right)^2 + \left(\frac{\Delta C_{ab}^*}{k_C S_C}\right)^2 + \left(\frac{\Delta H_{ab}^*}{k_H S_H}\right)^2}$$

Equation 2.2

where SL, SC, and SH are weighting function; SL = 1; SC = 1 + 0.045 C*; SH = 1 + 0.015 C*.

k_L, k_C, k_H are numeric parametric factors that permit the independent weighting of lightness (ΔL*), Chroma (ΔC*) and hue (ΔH*) differences. The k_L, k_C and k_H are considered for variation in experimental conditions such as luminance level, background, texture, separation, etc. For all applications except for the textile industry, a value of 1 is recommended for all parametric factors. For the textile industry, the k_L factor is recommended as 2 while the k_C and k_H factors is 1. The parametric factors may be defined by industry groups depending on typical viewing conditions for that industry.

However, in this research CIED2000 formula (with abbreviated ΔE_{00}) was adopted to calculate the color difference of the samples that were made comparing with the standard color in the Thai color dictionary (5). CIED2000 was developed and announced in the year 2000, it addressed 5 problems that CIELAB encounters including 1) a lightness weighting function (S_L); 2) a Chroma weighting function S_C); (3) a hue weighting function (S_H); 4) an interactive term (RT) between Chroma and hue differences for improving the performance of blue colors; and 5) a factor (1 + G) for rescaling the CIE a* scale for improving the performance for grey colors (73). ΔE_{00} is proper to use when the color difference of two samples is below 5. Formula for calculating the ΔE_{00} was shown as below in the Equation 2.3.

$$\Delta E_{00} = \sqrt{\left(\frac{\Delta L'}{k_L S_L}\right)^2 + \left(\frac{\Delta C'}{k_C S_C}\right)^2 + \left(\frac{\Delta H'}{k_H S_H}\right)^2 + R_T \frac{\Delta C'}{k_C S_C}\frac{\Delta H'}{k_H S_H}}$$

Equation 2.3

where $S_L = 1 + \frac{0.015(\bar{L}'-50)^2}{\sqrt{20+(\bar{L}'-50)^2}}$

and $S_C = 1 + 0.045\bar{C}'$

and $S_H = 1 + 0.015\bar{C}T$

where $T = 1 - 0.17\cos(\bar{h}' - 30^*) + 0.24\cos(2\bar{h}') + 0.32\cos(3\bar{h}' + 6^*) - 0.20\cos(4\bar{h}' - 63^{*\prime})$

and $R_t = -\sin(2\Delta\theta)R_C$

where $\Delta\theta = 30exp\left\{-\left[(\bar{h}' - 275^*)/25\right]^2\right\}$

and $R_C = 2\sqrt{\frac{\bar{C}'^7}{\bar{C}'^7+25^7}}$

and $L' = L^*$

$a' = (1 + G)a^*$

$b' = b^*$

$C' = \sqrt{a'^2 + b'^2}$

$h' = \tan^{-1}(b'|a')$

Where $G = 0.5\left(1 - \sqrt{\frac{\bar{C}^{*7}}{\bar{C}^{*7} + 25^7}}\right)$

2.8 Mixture Design

The mixture design method was employed to obtain the optimized formulation of the mixtures in this research. There are several methods used for the mixture, such as simplex, extreme vertices and lattice. The proportion of the mixture between zero and one; the sum of their recipe is one (100%). The mixture properties are functions of the relative proportions rather than their absolute amount. Changing one ingredient can change the proportion of one or more to compensate. Simplex centroid is one of the mixture design methods. Its distinct points is 2q-1 when q is number of the component (74).

The design points in the Simplex-Centroid design support the polynomial:

$$E(Y) = \sum_{i=1}^{q} \beta_i X_i + \sum_{i=1}^{q} \sum_{i<1}^{q} \beta_{ij} X_i X_j + \sum_{k=1}^{q} \sum_{j<k}^{q} \sum_{i<j}^{q} \beta_{ijk} \beta X_i X_j X_k + \cdots + \beta_{12\ldots q} X_i X_{j\ldots} X_q,$$

Equation 2.4

which is the q^{th} is order mixture polynomial. For q=2, it is the quadratic model. For q=3, it is the special cubic model. For example, the run for a 3-component simplex centroid design of degree 2 are: (1,0,0), (0,1,0), (0,0,1), (0.5,0.5,0), (0.5,0,0.5), (0, 0.5, 0.5), (1/3,1/3,1/3).

Simplex Centroid is suitable for the component that has the same range between 0-100, and there are no constrains on the design space. When there is twodimensions, the simplex term refers to the geometry form of a triangle, and tetrahedron when in three-dimensions. In addition, this method of the mixture design is more uniformity distributed in the interior of the triangle and helps to detect curvature of respond surface (75). Cornell and Piepel explained steps in planning a mixture experiment as shown below (76).

1. Define the objectives of the experiment.
2. Select and study the mixture components and other factors that may include process variables or the total amount of the mixture.
3. Identify any constraints on the mixture components in order to specify the experimental region.
4. Identify the response variable (s) that will be measured.
5. Propose an appropriate model for modeling the response data as functions of the mixture components and other factors that are selected for the experiment.
6. Select an experimental design that is fit and sufficient the proposed model, and also allows a test of model adequacy.

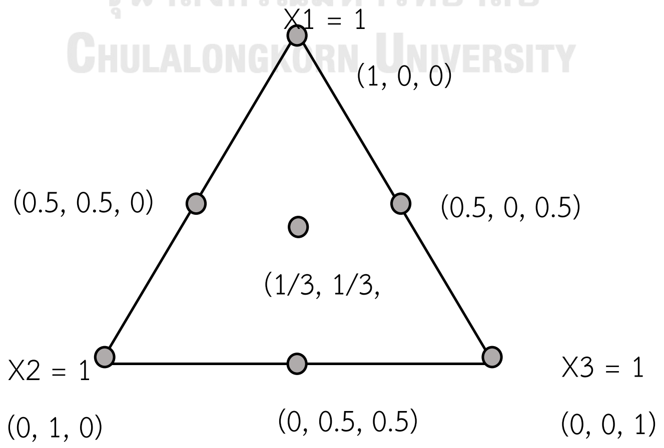


Figure 2.3 Triangle of the mixture design, simplex centroid.

2.9 Kubelka - Munk Theory

In color physics, the important part that related with colors is the prediction of the amount of light that a surface will reflect or transmit at each wavelength from knowledge of the concentration of each colorant in the layer. Kubelka and Munk presented basic and simple theory regarding to this in 1931 by referring from Arthur Schuster who proposed in 1905. Several revisions were done later that by astrophysicists in order to apply the theory for prediction of reflectance of light (77).

"Two fluxes of energy" was used to explain the interaction of light with the layer. There are two types of energy flux that present the light direction. The **i** energy flux includes all light directions that have a component travelling towards the illuminated surface, and the **j** energy flux includes all light directions that have a component travelling away from the illuminated surface. For most viewing conditions, objects are illuminated from above and as a result i and j are often termed the down flux and up flux respectively, as presented in the Figure 2.4.

Figure 2.4 (a) Direction of light included in the *i* energy fluxes and (b) Direction of light included in the *j* energy fluxes.

The interaction of light within the layer is described by absorption coefficient K, and a scattering coefficient S. These coefficients can be related to the fundamental optical optics properties of the layer ε and σ, as shown in the Equation 2.5.

$$K = 2\varepsilon \qquad \text{and} \qquad S = \sigma \ ,$$

Equation 2.5

where ε is the linear absorption extinction coefficient and σ is the linear scattering extinction coefficient.

The Kubelka-Munk function is shown in the equation 2.6, this function presented that the reflectance of the opaque layer depends only on the ratio of *K* to *S* and not on their absolute values.

$$\frac{K}{S} = (1 - R_\infty)^2 / \, 2R_\infty$$

Equation 2.6

where R_∞ = energy flux reflected from top surface/energy flux incident on to surface.

Under ideal condition, absorption and scattering coefficient of the mixture is the summation of absorption and scattering of each component in the mixture. If the component in the mixture are A and B, the K of the mixture is the summation of K of A and K of B. as same as the scattering coefficient.

$$K_M = K_A + K_B$$
$$S_M = S_A + S_B$$

Equation 2.7

Kubelka-Munk theory was adopted to use in color match prediction for pigmented material. In doing this, well preparation of calibration panels will reward the accuracy of the prediction results. The method of preparation panel includes weighting, mixing, application, drying and reflectance measurement. To prepare the calibration panel, 2 major steps were employed: the concentration series of the colorants and the panel production. Database preparation or producing calibration panels is straightforward and the sequence of mixtures mentioned in the Table 2.2 is often used.

Table 2.2 Recommended concentration sequence of calibration panels for a finished system

Test material (colored paint) %	Reference material (standard base) %
2.5	97.5 white
5	95.0 white
10	90.0 white
20	80.0 white
40	60.0 white
70	30.0 white
100	0.0 white
99	1.0 black

Reference materials: the reference white material must be of consistent strength throughout the entire database panel set. It should have the highest reflectance value and no contamination or yellowing.

Substrates: specially prepared card is used. It is printed with contrast black and white pattern that indicates clearly if the coating layer is not opaque.

Measuring out components: recommendation of the resolution of the measurement must be better than 0.01% of the batch size. For example, the components for 100 g batch must be weighted accurately to within 10 mg. Suggestion is to measure the largest component into the mixing vessel first and add remaining component later in order to avoid the small component to be trapped by the larger amount.

Mixing, dispersing, application and drying: they affect the color strength exhibited. The optical properties of a pigment dispersion depend on the distribution of sizes of the pigment dispersion. Well-dispersion give a better tinting strength compare with poor dispersion. The smaller the average particle size of the dispersion, the higher the color strength is presented. Application and drying also affect the color exhibited of the formulation.

Match prediction method of the opaque layer can be divided into seven steps:

1. Specify the color of the standard.
2. Select the colorants to be used in the formulation from the database list. Two to five colors are normally selected.
3. Calculate the amount of each colorant in the formulation.
4. At each wavelength in the spectrum, sum the contribution from each colorant in the formulation to determine the total absorption (K_M) and total scattering (S_M) coefficients.
5. Calculate the reflectance spectrum of the mixture from the inverse Kubelka-Munk equation.
6. Convert the reflectance R_M to reflectance ρ_M that would be measured by the spectrophotometer by mean of the Saunderson equation.
7. Calculate the color coordinates of the recipe spectrum and compare with those standard.

Calculation of reflectance spectrum of a known recipe is very straightforward. The K/S value of a recipe that contains n colorants is obtained by summing the contributions to K and S from each component as shown in Equation 2.8:

$$\frac{K_M}{K_S} = (K_1 + K_2 +_{\dots} + K_n)/(S_1 + S_2 +_{\dots} S_n)$$

Equation 2.8
where M, 1, 2 and n denote values that refer to the mixture and colorant 1, 2 and n respectively.

2.10 Multi-Spectrum Imaging

Multispectral imaging (MSI) is an image data captured within specific wavelength ranges across the electromagnetic spectrum. The wavelengths can be separated by filter or by the use of instruments that are sensitive to particular wavelengths, including light from frequencies beyond the visible light such infrared and ultraviolet. In painting and arts' conservation field, MSI is a non-invasive technique that has been employed to map and identify pigments, binder, retouches on work of arts and also used to visually improve old and faded documents (78). The painting is irradiated by ultraviolet, visible and infrared and the reflected radiation is recorded in a camera that is sensitive in the regions of the spectrum. Sampling important work of art is normally not permitted, only non-invasive technique is allowed to be conducted and MSI can serve this requirement. In addition to these advantages, this method is simple, affordable, lightweight and small. It also gives a low-cost survey even for large areas. (78, 79). However, MSI has limitations. This method is more accurate when one single layer of pigments was applied on the artwork. For the ones that have glazed or mixed pigments, it is not always success. Therefore, complementary with at least one other material specific technique must be used with MSI imaging diagnostics, in order to identify the pigment at an acceptable degree of certainty (78, 79).

Using MSI for art conservation is simply performed. It can be equipped with a variety of equipment setup, basically a monochromatic camera and a set of band-pass filters. This setup is adaptable and can be applied to fit with different tasks and size of the examined objects. Studying the large artwork, an MSI camera can be equipped with a panoramic head, whereas, studying the small thing such as historical postage stamps, macro lenses can be joined with the camera (78). Cosentino applied using multispectral imaging technique with different sizes of art works. Firstly, panoramic photography of a large panel painting (size 163 (w) x170 (h) cm) of the *Visitation between Saint and Joseph and Saint Zachara* (1480-1490) by Antonino Giuffre was studied by composing the CCD monochrome camera and set of 12 band-pass filters with panoramic head. Results revealed identification of pigments and binder used for this picture. In addition to this, area of retouching was found. Secondly, the macro photography of a postage stamp. The camera was coupled with macro lenses to examine the stamp size 1 cm. For cases that require higher magnification than macro photography, the camera was coupled to a stereomicroscope or microscope to test the objects which were a cross-section taken from painting or pigment particles (80). Cosentino also used MSI in 400-900 nm and transmittance spectroscopy to evaluate the polychrome artworks on translucent support that was reused or covered by new ground preparation. A set of 54 historical pigments were tested to evaluate the feasibility of obtained meaningful transmittance spectra from pigment samples that lay on a prepared canvas and also with a cover of titanium dioxide. The results revealed that 18 of 54 pigments presented characteristic of transmittance spectra even underneath a titanium white layer and the transmitted light MSI can map hidden paint layers (81). In this research, MSI with filter ranges 400-700 nm, band width 10 nm was applied to study multi-spectrum characteristics of paint and primer samples to review how they were affected by light, moisture and heat. Spectro-radiometer also was used to obtain the spectrum reflectance of each sample.

CHAPTER 3

Experiment

These experiments were carried out from January 2015 to March 2018. Primers and paints preparation were done in the Department of Imaging and Printing Technology, while antibacterial property testing was performed in the Department of Botany, Faculty of Science, Chulalongkorn University. Brush testing and artists' satisfaction were conducted at the Ten Division of the Traditional Thai Crafts, the Fine Art Department Ministry of Culture, Thailand. Multi-spectrum Imaging was performed at the Laboratoire Hubert Curien, Faculty of Science and Technology, Jean Monnet University, Saint Etienne, France.

3.1 Materials

3.1.1 Materials for traditional primer

1. Marl (white clay) (from Lopburi province)
2. Tamarind seeds (from Petchaboon province)
3. Senna leaves (from Nakhon Sri Thammarat province)
4. Turmeric
5. Distilled water (prepared in the laboratory)

3.1.2 Materials for novel primer

1. Pigment: Titanium dioxide (Duponts Grade R902, see detail of specification in Appendix A)
2. Filler: Aluminium silicate (Satintone 5HB, BASF Corporation)
3. Binder: Acrylic/Styrene co-polymer (PRIMAL, Dow Chemical Company)
4. Distilled water (prepared in the laboratory)
5. Additives:

   AgNPs particle size 20-50 nm (Prime Nano Co., Ltd, Thailand)

   Ceramic microsphere (Grade W410 - 3M)

Defoaming agent (Antifoam HTD from Thai Innovation Chemical Co., Ltd)

Thickener (Thickener TP-150, from Sathorn Chem Co., Ltd)

Emulsifier (EMULNOL 862 EKO, Sathorn Chem Co., Ltd)

Solvent (Solvent 3040)

Biocide- in can preservative, Skybio B20 (SK Chemical, Korea)

Biocide - on film preservative, Rocima 640 (Dow Chemical Company)

3.1.3 Materials for acrylic paints

1. Pigments

A series of prepared organic pigment supplied by Clariant selected to prepare acrylic paints were as follows: Colanyl Orange HL 100-TH, Flexonyl Yellow WF 013, Colanyl Oxide Yellow R-TH, Colanyl Yellow H3G 500, Flexonyl Black PR100, Flexonyl Violet RL-LA-TH, Flexonyl Blue WF 153-CN, Colanyl Green GG 131-TH, Colanyl Oxide Red B 131-TH, Hostatint Red D3GD 500 and Colanyl Pink E-WD 500.

2. Binder: Acrylic/Styrene emulsion (PRIMAL, Dow Chemical Company).

3. Extender: Aluminium silicate (Satintone 5HB, BASF Corporation)

4. Additives:

Defoaming agent (Antifoam HTD from Thai Innovation Chemical Co., Ltd)

Biocide- in can preservative (Skybio B20, SK Chemical, Korea)

Biocide - on film preservative (Rocima 640, Dow Chemical)

3.1.4 Materials for Pastel

1. Pigments:

A series of powder pigment supplied by Clariant were selected to prepare the pastel; Hostoperm Blue BX, Hostoperm Pink E M25, Hostoperm Green GNX, Hstoperm Orange GR, Hostoperm Permanent Rubine, Hostoperm Violet RLS-EF, Hostoperm Brown HFR01, Hostoperm Permanent Yellow, and two pigments from local company, Carbon Black and Chrome Green.

2. Extender: Calcium carbonate, commercial grade (see detail of specification in appendix A).

3. Binder: Gum tragacanth (Texture CX55 from Ingredient Flavor Co., Ltd Thailand)

4. Gum Arabic as a media for applying the pastel on the substrate.

6. Distilled water was prepared in the laboratory.

3.1.5 Substrates

Concrete slabs,

Canvas (NL brand)

Leneta black and white card - Form 2A Opacity Charts

Paper, Fabriano 300 g/m^2

Filler, Al_2SIO_5 that was used for novel primer and acrylic paints was selected by pre-testing. We brought $CaCO_3$, Talcum and Al_2SiO_5 to mix with the pigment and binder before each of the mixture was evaluated. We found that Al_2SIO_5 gave the best opacity, it therefore was selected to use in the experiment.

3.2 Experiment

3.2.1 Traditional Primer

3.2.1.1 Extracted Senna solution preparation

In this experiment, extracted Senna solution was used to rinse the concrete wall surface before it was applied with the traditional primer. Senna leaves were cleaned by water. After they were left to dry completely at room temperature, they were crushed by the grinder. The weight ratio of Senna leaves to distilled water was 1:3. Speed and time were not considered for grinding. The grinder was stopped when the leaves were fine enough for manually extraction by hands. The ground leaves were extracted and the solution was filtered with a white fabric filter. The pH of the Senna solution was checked by the pH meter. Figure 3.1 showed the Senna leaves and its extracted solution during the grinding process.

Figure 3.1 Senna leaves (left), ground leaves (middle) and decocting and its solution (right).

3.2.1.2 Tamarind glue preparation

The tamarind seeds were roasted until the color of their shells turned black. The light brown seeds inside were brought to boil in distilled water until they were soft, melted, and changed to sticky glue (4) as shown in Figure 3.2. Viscosity of the glue were checked using the Brookfield viscometer- model RVT. The solid content was evaluated by drying the glue in the oven chamber at 110 ^{O}C for 1 hour, the solid content was calculated.

Figure 3.2 Tamarind seeds before roasting (left), light brown seeds before boiling and (middle) Tamarind Glue (right).

3.2.1.3 Traditional Primer preparation

The white clay, tamarind glue and distilled water were mixed together. The ratio of each component in the mixture were designed using simplex centroid mixture design. The minimum, medium and maximum weights of each component were 20-30-40 for clay, 20-30-40 for tamarind glue and 5-10-15 for distilled water. Seven formulas were provided and they were repeated twice. The random order of mixtures is shown in Table 3.1.

The white clay was firstly mixed with water at low speed of 500 rpm in 1-inch blade mixer for 15 minutes. Tamarind glue was added into the mixture; the speed of the mixer was increased gradually when the viscosity increased. Finally, the speed reached 1500 rpm and maintained at this speed for 40 minutes. Figure 3.3 showed the appearance of the clay before and after mixing with water and glue.

Figure 3.3 The white clay (left) and the mixture (right)

The mixture samples were carried out to evaluate viscosity, sagging, leveling and opacity. The results were taken into account for mixture optimization by using the Minitab software. The optimized formula and its model were selected as a guideline which was subsequently tested by mixing the predicted formula and testing the responses. The formulation of the optimized mixture was further adjusted by adding silver nanoparticle for antimicrobial property.

Table 3.1 Mixture design component and weight ratio of the traditional primer.

Run-order	Component Ratio			Component Weight (g)		
	Clay	H_2O	Glue	Clay	H_2O	Glue
1	0	0	1	20	5	40
2	0	0.5	0.5	20	10	30
3	0.5	0	0.5	30	5	30
4	0	1	0	20	15	20
5	0.5	0.5	0	30	10	20
6	0.5	0.5	0	30	10	20
7	1	0	0	40	5	20
8	0	0	1	20	5	40
9	1.0	0	0	40	5	20
10	0	1	0	20	15	20
11	0.33	0.33	0.33	30	10	30
12	0.5	0	0.5	30	5	30
13	0.33	0.33	0.33	30	10	30
14	0	0.5	0.5	20	10	30

3.2.2 Novel primer

Primer preparation

Titanium Dioxide, TiO_2, a commercial grade white pigment, Aluminum Silicate, Al_2SiO_5, acrylic/stylrene emulsion and distilled water were mixed following the ratio designed by the mixture design as shown in the Table 3.2. The ranges of each component weight are minimum, medium and maximum at 20-30-40 for TiO_2, 20-30-40 for Al_2SiO_5 and 20-30-40 for acrylate/styrene emulsion. Distilled water was fixed at 40 mL for all formulas. Component ratios of each mixture were shown in Table 3.2

First, TiO_2 was slowly added into the distilled water and mixed at a low speed of 700 rpm with a 1-inch blade mixer in a 400 mL beaker for 20 minutes. The acrylic/styrene binder was added into the mixture of water and TiO_2 while the mixer was running and the mixture was continually stirred for 20 minutes. At the end, the Al_2SiO_5 was slowly added into the mixture. Once all components were added, the speed of the mixer was increased in order to pull the powder into the solution efficiently as the viscosity increased. The speed of the mixer was turned up to speed of 1500 rpm and it continued for at least 40 minutes.

Again the mixture samples were carried out to evaluate viscosity, sagging, leveling and opacity the same as traditional primer. The formulation of the optimized mixture was further adjusted by adding additives as need to enhance other properties including wash resistance and antimicrobial.

Table 3.2 Mixture design components and weight ratios of the novel primer.

Mixture Design	**Component Ratio**			**Component Weight (g)**		
Run-order	**TiO2**	**Si_2AlO5**	**Acrylic/ Styrene**	**TiO_2**	**Si_2AlO_5**	**Acrylic/ Styrene**
1	0	0	1	20	20	40
2	0	0.5	0.5	20	30	30
3	0.5	0	0.5	30	20	30
4	0	1	0	20	40	20
5	0.5	0.5	0	30	30	20
6	0.5	0.5	0	30	30	20
7	1	0	0	40	20	20
8	0	0	1	20	20	40
9	1.0	0	0	40	20	20
10	0	1	0	20	40	20
11	0.33	0.33	0.33	30	30	30
12	0.5	0	0.5	30	20	30
13	0.33	0.33	0.33	30	30	30
14	0	0.5	0.5	20	30	30

3.2.3 Primers' evaluation

3.2.3.1 Physical properties

Viscosity

The viscosity of the samples was checked using the Brookfield viscometer- model RVT

Leveling and sagging

The primer samples were applied on the Leneta (black and white card) - Form 2A Opacity Charts using leveling/sagging applicator. The leveling and sagging were evaluated using leveling/sagging tester (Sheen 1118). Sagging evaluation was performed in the same manner as SH1108 Sag Index Applicator (samples were placed in and along the length of the chamber) 10 gap sizes were provided ranging from 75 - 300 microns with 25 micron increments. Leveling tests was carried out by applying 5 pairs of coating stripes ranging from 0.1, 0.2, 0.5 and 1.0 mm; after drying the coating was observed to rate the separation of merging of the corresponding pairs.

Opacity: The samples were applied on the Leneta (black and white card) - Form 2A Opacity Charts using automatic K-bar coater at a thickness of 60 microns, which were able to hide the substrate surface. After drying completely, the opacity of the coating was evaluated using Technidyne, geometry d/0, D65/10.

CIE L*a*b*: CIE L*a*b* (D65/2) of the wet samples was measured by colorimeter-Konica Minolta CR-400, 5 repeated measurements were performed.

Washability evaluation: The washability was done following the ASTM D4828-92. The test method covers the removal of a specific soilant from a surface by scrubbing with sponge soaked with soap water. The greater the ease of soil removal with a minimum of film erosion, the greater the washability. The primer samples were applied on glass panels by using the film applicator with the thickness of 100 μm. The films were left to dry at the room temperature (27$\pm$2^{o}C, 65$\pm$5 %RH) for 4 days then left in the oven chamber at 60$\pm$2^{o}C for 24 hours. The specific soilant was applied on the dried films by using the film applicator at the thickness of 75±5 μm. It was left at the room temperature for 30 minutes then left in the oven chamber at temperature of 105±2°C for 30 minutes before scrubbing with damped sponge.

Scrub resistance: The primers were applied on the black plastic panels by using the film applicator with the thickness of 150 μm. The films were left to dry at room temperature (25 ±1°C, 50±5 %RH) for 1 day in horizontal position and 6 days in vertical direction. The dried films were scrubbed by the wet abrasion Scrub Tester (ASTM D2486 Method A: Standard Test Methods for Scrub Resistance of Wall Paints). The weight loss technique is used to report as the film erosion rates.

3.2.3.2 Brush testing and artist satisfaction

To evaluate the brush testing for primers, the concrete slabs were constructed of brick and mortar. Its size was 21x15 cm. After it was left to completely dry, the humidity of the concrete surface was checked by the MMD4E Digital Moisture Tester before it was applied by the primer.

The concrete surface was rinsed with Senna's extracted solution. Tumeric was drawn on the surface as an indicator to check the surface's pH by mean of tumeric's color changing. Once the surface was ready to be used, the primer was applied on the surface of concrete slab using the painted brush.

The thickness of both primers was considered until it covered the concrete surface perfectly.

Samples were taken to 5 artists at the Fine Art department in the ministry of Culture, for paint testing. The acrylic paint "Flashe" brand that was regularly used by artists for their Thai style painting, was used in the testing. The artists' satisfaction questionnaire with a Likert scale 7 scales (82) was prepared. Provided questions were based on artists' suggestions according to their experiences. The questionnaire was presented in Figure A3-A4 in Appendix A.

3.2.3.3 Antimicrobial evaluation for primers

Samples and site description

Microorganism samples for the studying were taken from different areas of the mural painting of the Somanas Rajavaravihara temple (Figure 3.4). According to non-destructive concern, the biological samples were taken by sterile cotton swap (15).

Isolation and identification of bacteria on painted surface

The samples were used as an inoculum for bacterial isolation enrichment culture method. Cultures were grown in 100 ml of 1/5 strength Luria-Bertani (LB) agar supplemented with 100 mg/ml Rose Bengal by shaking at room temperature, 150 rpm for 3 days. The cultured medium solutions were then serially diluted and spread on LB agar. Colonies were selected and further purified by repeatedly streaking to yield a single colony on fresh LB.

Identification

Identification of each bacterial isolate was based on 16s rRNA gene sequences. Genomic DNA of each bacterium was isolated following the protocol described by Sambrook et al. (83). The 16S rRNA gene was amplified using the universal primer set 27F (5′-AGA GTT TGA TCM TGG CTC AG-3′ (M=C: A) and 1525R (5′-AAG GAG GTG WTC CAR CC-3′ (W=A: T; R=A: G) (84). DNA amplification was conducted by predenaturation at 94 °C for 3 min, and was followed by a melting step at 94 °C for 1 min, an annealing step at 52 °C for 1 min, and an extension step at 72 °C for 2 min. The reaction was repeated for 30 cycles and followed by a final extension for 15 min. The PCR product was purified using the QIAquick PCR Purification kit (Qiagen, Valencia, CA), and subsequently sequenced by Macrogen, Seoul, Korea. The full sequences so obtained were compared with the sequences in the GenBank database using the Basic Local

Alignment Search Tool (BLAST) algorithm and the percentage of similarity was recorded.

Antibacterial assay

Test tube contained 5 ml LB broth were seeded with purified bacterial isolate and cultured for 18-24 hours to obtain turbidity. Optical density (OD_{600}) of the seed cultures was adjusted to be 0.1 in LB and 100 µl, adjusted cultures were spread on LB agar. Wells were cut with cork borer and 20 µl of the primers or 0.1% (w/v) Chloramphenicol were added. The plates were then incubated at room temperature for 24 hours.

The antimicrobial activity was evaluated and the diameter of inhibition zones was measured. The experiment was carried out in triplicate and the averages diameter of zone of inhibition was recorded. The antibacterial activity was classified as highly active (>10 mm), mildly active (7-10 mm) and slightly active (6-7 mm); and less than 6 mm was taken as inactive (15). Chloramphenicol was used as a positive control.

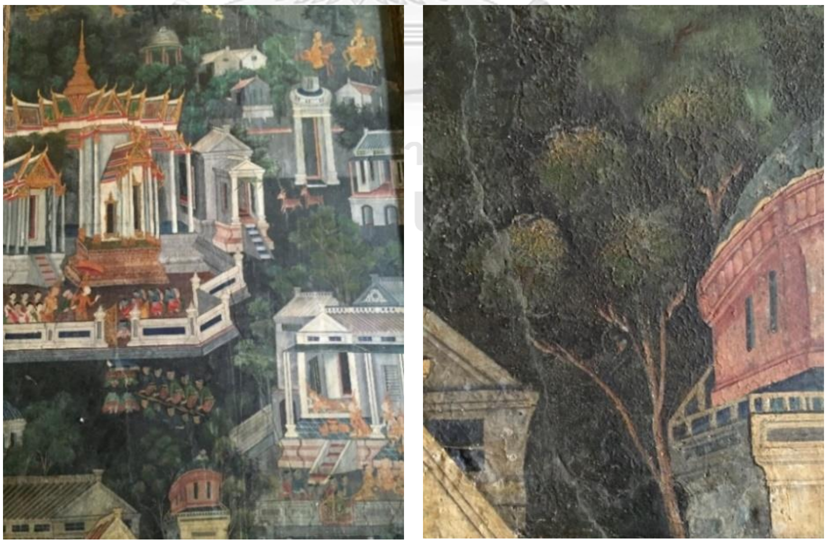


Figure 3.4 Mural painting and the areas where the swab samples were taken at Somanas Rajavaravihara temple.

3.2.4 Acrylic Paints

3.2.4.1 Primary color preparation

To prepare the primary color of acrylic paint, the preparation pigment, Colanyl Pink E-WD 500 (Quinacridone, PR122) was selected as a representative pigment to explain here. Acrylate/styrene emulsion served as a binder and aluminium silicate as a filler. The ratio of each component were designed using the mixture design with simplex centroid method. The ranges of each component weight were minimum, medium and maximum at 100-120-140 for pigment, 20-30-40 for acrylic/styrene emulsion and 10-20-30 for aluminium silicate. Three components were mixed together by the mixer (Eurostar - Ika Labortechnik) at the speed of 1500 rpm for 60 minutes.

The properties of the mixture including viscosity, opacity and drying were conducted and taken into account for optimization by using the Minitab software. The optimized formula and its model was selected and tested to check the error of model. The optimized formula and the responses were used as a guideline. The formulation of this optimized mixture was further used for all pigments.

3.2.4.2 Primary acrylic paint evaluation

Viscosity: The viscosity of the sample was checked using the Brookfield coating viscometer- model RVT.

Opacity: The sample was applied on the *Leneta (black and white card) - Form 2A Opacity Charts* using automatic K-bar coater at the thickness of 40 microns, which was able to hide the substrate surface. After drying completely, the opacity of the coating was evaluated using Technidyne, geometry d/0, D65/10.

Drying evaluation: Following the ASTM D1640/D1640M-14, test method A, *Set-To-Touch Time* procedure (85). The drying test was conducted with an air temperature of 23 ± 2 ^{o}C and 50 ± 5% RH. The sample was applied on the clean glass panels at the thickness of 40 micrometers. The test film sample was lightly touched with the tip of a finger (clean and free of grease) and immediately placed the fingertip against a piece of clean, clear glass. The transferred coating was observed if any of them was transferred to the glass. The time interval was recorded.

Table 3.3 Mixture design components and weight ratios of the acrylic paint.

	Factor Level			Component weight (g)		
Formulation	Pigment	Binder	Filler	Pigment	Binder	Filler
1	0	0	1	100	20	30
2	0	0.5	0.5	100	30	20
3	0.5	0	0.5	120	20	20
4	0	1	0	100	40	10
5	0.5	0.5	0	120	30	10
6	0.5	0.5	0	120	30	10
7	1	0	0	140	20	10
8	0	0	1	100	20	40
9	1	0	0	140	20	10
10	0	1	0	100	40	10
11	0.33	0.33	0.33	120	30	20
12	0.5	0	0.5	120	20	20
13	0.33	0.33	0.33	120	30	20
14	0	0.5	0.5	100	30	10

3.2.4.3 Database building

Paint Calibration: The optimized primary acrylic paint was diluted into 11 concentrations (99.99, 75.00, 50.00, 25.00, 12.50, 5.00, 2.50, 1.25, 0.625, 0.315 and, 0.156 %) by mixing with medium, as shown in the Table 3.4. Eleven shades of each color were applied on the Leneta (black and white card) - Form 2A Opacity Chart at constant thickness of 40 μm which was able to hide the substrate's surface. The reflectance spectrum of all panels were stored and the relationship between the concentrations and K/S coefficients were determined.

Targets: Spectral reflectance of each color shade was measured at the wavelength of 400-700 nm with 10 nm increment. The spectral reflectance of 147 physical munsell and NCS standard color patches that match traditional Thai color names were used as targets or standards (5).

Table 3.4 Concentration of painted calibration primary color.

No.	Primary Color (%)	Medium (%)
1	99.99	0.00
2	75.00	25.00
3	50.00	50.00
4	25.00	75.00
5	12.50	87.50
6	5.00	95.00
7	2.50	97.50
8	1.25	98.75
9	0.625	99.37
10	0.315	99.68
11	0.1563	99.84

3.2.4.4 Thai style color match prediction

The formulation of Thai color was predicted using the optical properties, K/S of each concentration, of the stored database. The color difference, ΔE_{00} (D65/2 SPEX) between the target and the predicted one was given. The predicted formulation then was mixed and the color difference between the predicted and the mixed ones was calculated. The required ΔE_{00} considering as a good match was less than 3 (3). The correction was carried out using the formulation software if the ΔE_{00} was greater than 3. The final corrected formula then was recorded. Sixty-six Thai colors were carried out according to these steps.

3.2.4.5 Brush testing and artist satisfaction:

Twenty samples of Thai style colors were taken to artists at the Fine Art Department, Ministry of Culture. Five artists who experienced in Thai mural painting involved in testing. Feedback was provided through the given questionnaire which was written by us with consulting with artists who expertise in acrylic painting. Flashe acrylic paints were used as benchmark for artists' feedback. The questionnaire was presented in Figure A5 in Appendix A.

3.2.5 Pastel

3.2.5.1 Materials' preparation

Gum tragacanth

Gum tragacanth powder (Texture CX55) was weighted and mixed with the distilled water at a ratio 1:60. The mixture was stirred occasionally. This paste state of the gum tragacanth was used as binder.

Gum Arabic

The Arabic or acacia gum was used as a media for painted calibration and painting test. The solid state of this gum was weight at 6.8837 g to mix with 50 ml of warm water at 90^{o} C. The mixture was stirred until the gum was completely melted. The thin fabric was used to filter all grime and to obtain a clean and clear solution. Figure 3.5 showed the gum Arabic and its solution.

Figure 3.5 Solid state of the gum Arabic (left) and its solution (right).

3.2.5.2 Primary colors' formulation and optimization

The mixture design simplex centroid method was employed to design the mixture of the primary pastel. Three components were pigment, gum tragacanth and $CaCO_3$. Seven runs of the mixtures were designed with ratio of each component was

0-1. The ranges of each component weight are minimum, medium and maximum at 0.3-0.5-0.7 for pigment, 3-5-7 for gum tragacanth and 7-10-13 for $CaCO_3$.

Figure 3.6 Hostoperm Permanent Rubine L4B (left), CaCO3 (middle), and gum tragacanth powder (right).

As shown in the Figure 3.6, The Hostoperm Permanent Rubine L4B pigment, which was selected to optimize the formulation. First, the pigment and $CaCO_3$ were weighted and gently mixed together. The gum tragacanth paste was weighted and gradually poured into the mixture of $CaCO_3$ and the pigment. The components were slowly incorporated until it turned to paste and became clay-like dough. Subsequently, it was kneaded and rolled into 5 cm in diameter. Figure 3.7 presented the method to prepare the pastel stick. This pastel was left to dry completely at room temperature. Properties of the pastel including hardness and artist satisfaction were conducted and taken into account for optimization. The optimized formula, with the predicted properties, was selected and formulated. Its properties were then tested for error of prediction. The formulation of the optimized mixture was further applied for 12 pigments. These 12 pastel sticks were used as primary colors for producing calibration panels in color matching prediction process. Forty colors as defined in the traditional Thai color dictionary then were matched (5). Table 3.5 presented the mixture design component and weight ratio of the pastel.

Medium preparation

Medium was used for diluting the primaries (In the acrylic paint, we used standard base which was white paint). With regard to the formula of the optimized pastel, the medium was prepared by substituting the ratio of pigment with the filler ($CaCO_3$).

Table 3.5 Mixture design component and weight ratio of the pastel.

Run-order	Component Ratio			Component Weight (g)		
	Pigment	$CaCO_3$	Gum solution	Pigment	$CaCO_3$	Gum solution
1	0	0	1	0.3	7	7
2	0	0.5	0.5	0.3	10	5
3	0.5	0	0.5	0.5	7	5
4	0	1	0	0.3	13	3
5	0.5	0.5	0	0.5	10	3
6	0.5	0.5	0	0.5	10	3
7	1	0	0	0.7	7	3
8	0	0	1	0.3	7	7
9	1	0	0	0.7	7	3
10	0	1	0	0.3	13	3
11	0.33	0.33	0.33	0.5	10	5
12	0.5	0	0.5	0.5	7	5
13	0.33	0.33	0.33	0.5	10	5
14	0	0.5	0.5	0.3	10	5

Figure 3.7 Process to prepare the pastel stick, $CaCO_3$ and Hostoperm Permanent Rubine L4B (top left), the mixture of two components (top right), gum tragacanth adding (bottom left), the clay light dough (bottom middle) and the stick pastel (bottom right) stick pastel (bottom right)

3.2.5.3 Pastel primary colors' evaluation

Pastel hardness testing:

Pastel does not have any specifications for the hardness testing. Benchmarking with the market brand, Rembrandt, was therefore conducted to insure that the pastel stick could be held for drawing. The durometer was used to check the sample hardness.

Drawing and painting test:

The pastel stick samples were taken to the expert for drawing test. The substrate was the Renaissance Art Master Drawing paper. A questionnaire was provided to the artist to for drawing and painting test. Likert scale was referred in preparing the questionnaire (82). The questionnaire was provided in Figure A6 in Appendix A.

3.2.5.4 Database building

Paint Calibration: Each primary color of the pastel stick was ground to fine powder by using the mortar. The fine powder was diluted to eight concentrations (1.25, 2.5, 5, 12.5, 25, 50, 75, and 99.99%) by mixing with the medium. Each concentration was mixed with the gum arabic solution at constant ratio and applied on a canvas at thickness of 80 micrometers by using the K-coater. After they were left to dry completely, spectral reflectance of each color shade were measured. Spectral reflectances of 147 colors in the Thai color dictionary were used as standards. Table 3.6 presented the concentration of each color shade of primary color. Spectral reflectances of calibration panels were measured at the wavelength of 400-700 nm with 10 nm increment using the X-Rite SP62 spectrophotometer, (D65/2, SPEX). The corresponding K/S were calculated and stored as database for color match prediction.

Table 3.6 concentration of painted calibration primary clour.

No.	Primary Color (%)	Vehicle (%)
1	99.99	0.00
2	75.00	25.00
3	50.00	50.00
4	25.00	75.00
5	12.50	87.50
6	5.00	95.00
7	2.50	97.50
8	1.25	98.75

3.2.5.5 Thai style color match prediction

The process of color match prediction of pastel was similar to that of acylic paint in section 3.2.4.4.

3.2.5.6 Brush testing and artist satisfaction

Forty samples of Thai color style pastel were taken to the artists at the Fine Art Department, Ministry of Culture. With regard to the traditional painting method and requests of artists, the substrate for painting was coated by traditional primer. Five artists involved in paint testing were allowed to select as many as colors they wanted to test. Traditional tempera and Rembrandt soft pastel were used as benchmarks for their satisfaction feedback. Questionnaire related to satisfaction and suggestions were given them. The questionnaire was shown in Figure A6 of Appendix A.

3.2.6 Color tolerance and Thai artists' acceptation

1) According to the Thai color dictionary, two of Thai style colors were chosen from each category; R, YR, Y, GY, G, BG, B, PB, P, and RP (5). Twenty colors were listed as target including Dang Sen, Hong Din, Din Lueang, Nam-tan, It, Lueang Rong, Lueam Lueang, Mek Sonthaya, Khiao Katn Tong, Khiao Luk Samo, Khiao Bai Kae, Nam Lai, Khiao Khram, Khiao Khap, Khap, Khromtha, Mo Mek, Dok Tabaek, Luk Wa, Dok Maiyarap and Banyen. These colors were matched with Munsell and NCS colors (5).

2) Four samples deviated from the target in valule or lightness direction up, and 4 samples down were produced and applied on canvas with the thickness of 80 μm. The same was done for chroma direction, as shown in the Figure 3.8.

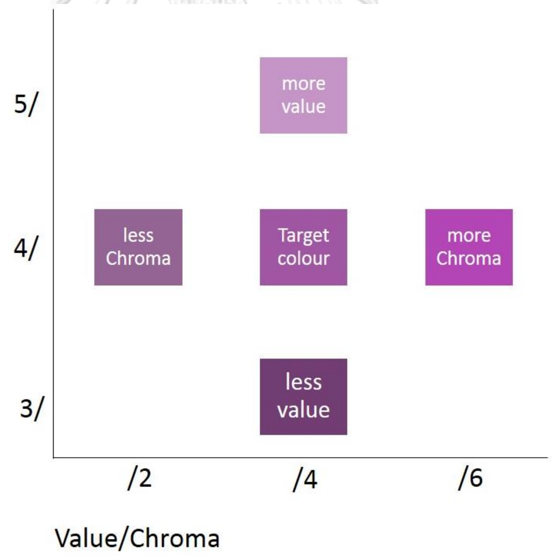


Figure 3.8 Target color and its tolerance in value and chroma.

3) The tolerance samples including the target were cut to 4.5x4.5 cm and the color charts were made. Neutral gray paper was used as a background. Figure 3.9 left, showed the target in the middle and 8 variations of lightness around them. Figure 3.9 right, showed the target in the middle and 8 variations of Chroma around them.

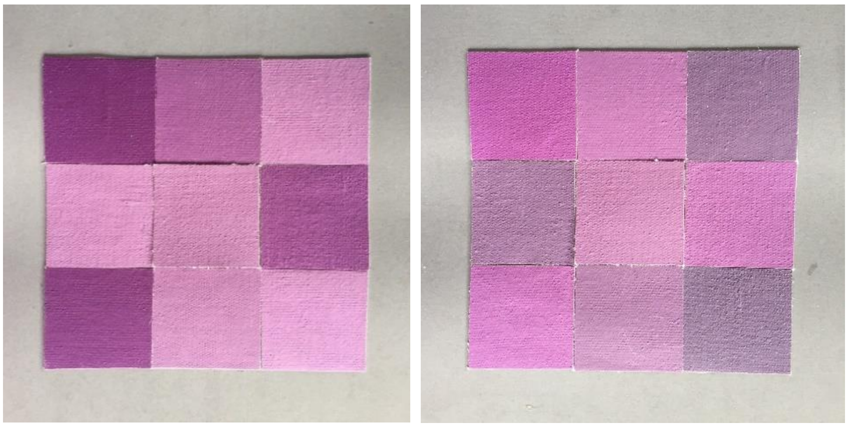


Figure 3.9 The color tolerance chart, different in value (left) and chroma (right).

4) Ten artists at the Fine Art Department chose the acceptable colors according to the target and Thai color name. The observations were conducted under daylight 6500K of the portable light booth and viewing geometry was 45/0. Figure 3.10 presented the artists observing the color tolerance. The artists stated the Thai color names from observing the target in the left Figure and then judged the acceptable color shown in the right Figure.

Figure 3.10 Two of 10 artists were observing Thai style color and its tolerances under a controlled condition, D65 and 45/0.

3.2.7 Multi-Spectrum Characterization of primers and paints

In this session, effect of light, heat and humidity on multi-spectrum characteristic of paints and primers were studied. A list of selected acrylic paints, pastels and primers was presented in the Table 3.7.

Table 3.7 List of samples chosen for aging acceleration.

Type	Light Exposed Test	Heat - Humidity Test
Acrylic-primary	Colanyl Green GG 131	Colanyl Green GG 131
Acrylic-primary	Colanyl Pink E	Colanyl Pink E
Acrylic-Thai	Khiao Khram	Khiao Khram
Pastel-primary	Red D3G70	Red D3G70
Pastel-primary	Violet RLS-EF	Violet RLS-EF
Pastel-Thai	Dang Sen	Dang Sen
Novel Primer	NTA-Ag	NTA-Ag
Novel Primer	NA-Ag	NA-Ag
Traditional Primer	T	T

3.2.7.1 Sample preparation for MSI

Influence of moist heat

Samples were applied on canvas substrate. Acrylic paints were applied directly while the pastel samples were applied with the gum Arabic as homogeneous layer at the thickness of 40 μm. After 1 month drying period, the aging was performed in a climatic chamber simulating as a total of 40 days, at 50° C and 60% RH.

Influence of ultraviolet radiation

Samples were applied on substrates including a cellulose and cotton paper, acids and lignin free. This paper is not treated with optical brightener and commercialized by “Fabriano”, 300 gr/m^2. Acrylic paints were applied directly while the pastel samples were applied with the gum Arabic as homogeneous layer at the thickness of 40 μm. After 1 month drying period, the experimental swatches were exposed inside the Q-Sun Xenon Test Chamber Xe-1 with Xenon Arc Lamp. Test conditions were 0.80 W/m^2 in the visible range at 420 nm. The average temperature was 50 °C for total 1000 hours.

3.2.7.2 Multi-spectral imaging

Multispectral Imaging Devices

1. Imaging devices: The MSI of Light exposed set was acquired with a Sony XCD-X71. The moisture set experiment was acquired with Thorcam camera.

2. Filters: The filters chosen for use were from Lot-Oriel France, 31 bandwidth of 10 nm covered from 400-700 nm.

3. Lighting: D65 ILLUM 4000, Eurosep Instrument

4. Calibration: White patch, PRC Krochmann GmbH

5. Additional devices

The spectroradiometer, Konica Minolta CS-1000 equipped with Macro lens, 50 mm (1:2.8) 32 was also used to measure the spectrum reflectance of each color sample under D65 light booth, geometry 45/0.

TCA software was used to evaluate the color difference.

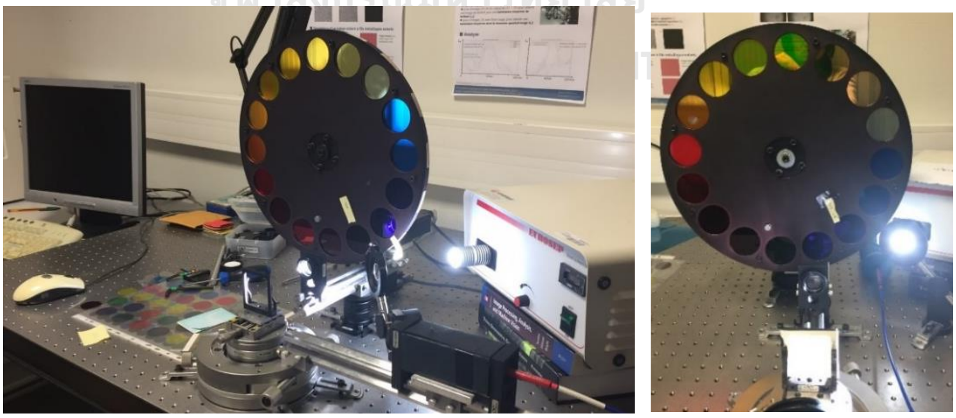


Figure 3.11 Multi-spectrum imaging devices.

CHAPTER 4
Results and Discussion - Primers

4.1 Traditional Primer

4.1.1 Materials' characterization

Tamarind Glue

Figure 4.1 showed appearance of the tamarind glue used in the experiment. It was sticky and light brown color, CIE L* = 90.86, CIE a* = -0.27 and CIE b*= 8.25 (D65/10-Colorimeter-Konica Minolta CR-400). The viscosity was 7,200 ± 50.00 mPa.s (Brookfield with spindle no. 3 at 6 rpm) and the solid content after water was dried completely was 4.23 ± 0.04 %. In this experiment, we produced the tamarind glue according to the traditional method suggested by Thai artists at the Fine art department and by referring the traditional knowledge (4). Tamarind seeds were roasted and boiled manually. Color of seeds was possibly inconsistent, therefore consistency of color and viscosity may be changed slightly in each time of making.

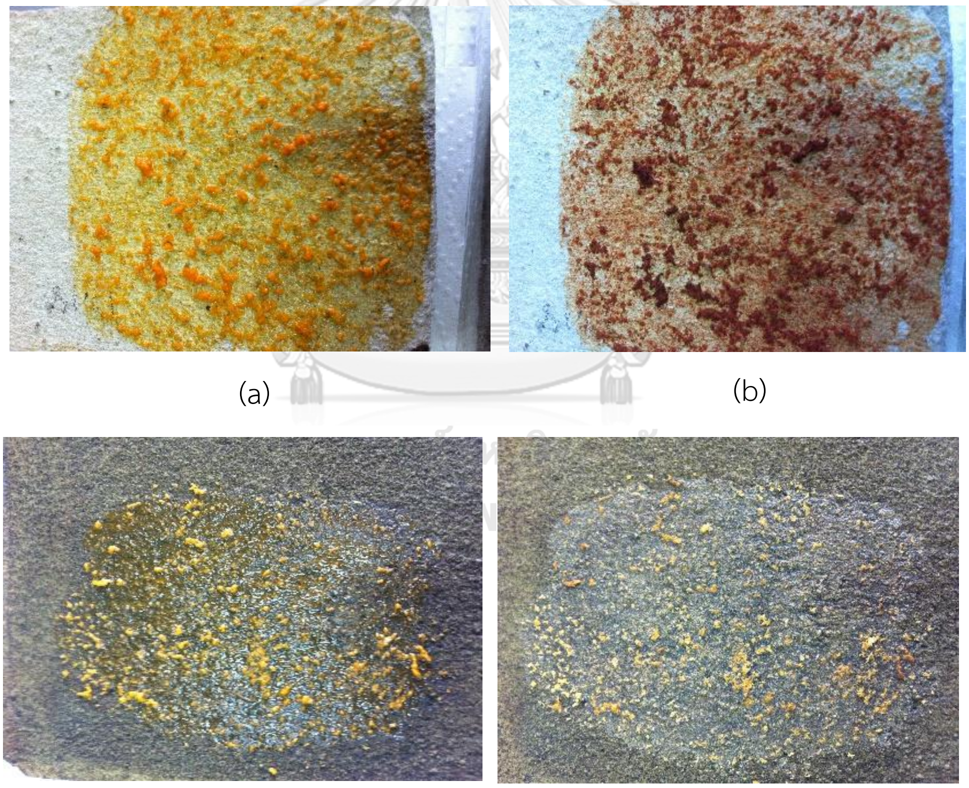
Marl or white clay

White clay used in traditional primer is yellowish white as shown in Figure 4.1. The test report provided by the Department of Science Service (ASTM C25-201) informed that it contained 93.00 % Calcium Carbonate ($CaCO_3$). The reported detail was shown in Figure A1 (Appendix A).

Figure 4.1 Appearance of the white clay and tamarind glue.

Senna leaves and extracted solution

According to the ancient wisdom, we followed the process of preparing a concrete surface that used Senna leave solution for washing away alkali of the surface and checking pH of the surface using turmeric. The Senna leaves solution, appeared dark green, having pH of 4.5 was rinsed on the clean and dried concrete slab surface and the pH of the rinsed Senna solution increased to 5.1. The process was repeated until alkalinity of the surface was reduced. The pH of the Senna leave after the third rinsing was 4.7. The pH of the wall was tested after each rinsing by applying turmeric on the surface. If the yellow applied turmeric turned red, the surface was still in alkali state (Figure 4.2 (a) and (b)). The rinsing process was repeated until color of turmeric did not change (Figure 4.2 (c) and (d)).



(a) (b)

(c) (d)

Figure 4.2 Concrete wall surface after applying turmeric without rinsing of Senna leaves' solution, color of turmeric turned from yellow (a) to dark red (b); after rinsing and applying turmeric (c) and after leaving for a while (d).

4.1.2 Effect of mixture components on the responses

Table 4.1 presented proportions of clay, water and tamarind glue as well as related properties: opacity, viscosity, sagging and leveling, used for optimizing the mixture. Table 4.2 and 4.3 presented the estimated regression coefficients and the regression model of each property, respectively.

The results showed that clay, water and tamarind glue significantly affected the opacity, viscosity, sagging and leveling ($p \leq 0.05$). Opacity, viscosity and sag index were increased when the amount of clay increased. Increasing of water and glue increased leveling but decreased viscosity. The R^2 of the relationship of predictor components and 4 properties were greater than 0.98. The regression models of these properties (Table 4.3) were taken to generate the contour plots of each properties as shown in the Figure 4.3. After overlapping contour plots and gave the ranges of acceptable values of 4 properties, the optimized mixtures were obtained. In general, high opacity was preferred for primer because of its hiding power. However, for this particular type of primer, we concerned that the high amount of clay might cause the dust after drying on the substrate surface. We therefore set up the range of opacity between 40-65%, the viscosity between 3,500-10,000 mPa.S, anti-sag index between 8-12 (86) and leveling between 1-5. The white area seen in Figure 4.4 showed the optimized mixtures in proportion given acceptable properties. One of the optimized mixture proportion that was selected consisted of 0.216 clay, 0.105 water and 0.679 tamarind glue. Following this proportion, predicted opacity, viscosity, sagging and leveling were 45.37%, 5584.37 mPa.S, 8.11, and 1.66 respectively. By using this ratio, the percentage of each component was calculated and presented as follows: clay = 38.03%, water = 9.47%, and Tamarind Glue = 52.50 %.

Table 4.1 Opacity, viscosity, sagging and leveling values obtained from 14 mixtures.

Formulation	Factor Levels X_1	X_2	X_3	Attributes Opacity (%)	Viscosity (mPa.S)	Sagging	Leveling
1	0.00	0.00	1.00	39.79±0.45	5,500	12	2
2	0.00	0.50	0.50	54.20±0.65	3,500	12	2
3	0.50	0.00	0.50	45.00±0.41	8,200	8	2
4	0.00	1.00	0.00	38.00±0.35	1,500	4	2
5	0.50	0.50	0.00	59.15± 0.67	4,400	4	2
6	0.50	0.50	0.00	58.00±0.95	4,500	4	1
7	1.00	0.00	0.00	63.53±0.62	12,200	12	1
8	0.00	0.00	1.00	40.00±0.49	5,700	12	2
9	1.00	0.00	0.00	64.00±0.63	12,400	12	1
10	0.00	1.00	0.00	38.60±0.39	1,500	4	2
11	0.33	0.33	0.33	52.78±0.55	3,500	4	1
12	0.50	0.00	0.50	44.00±0.33	8,300	8	2
13	0.33	0.33	0.33	54.00±0.40	4,800	4	1
14	0.00	0.50	0.50	56.00±0.58	3,300	12	2

X_1 = Clay, X_2 = Water, X_3 = Tamarind Glue

Table 4.2 Estimated Regression Coefficients for traditional primer property.

Term	Coef	SE Coef	P	R-Sq (adj)
Opacity				99.37%
Clay	63.77	0.5236	*	
Water	38.30	0.5236	*	
Glue	39.90	0.5236	*	
Clay*Water	30.17	2.5650	0.000	
Clay*Glue	-29.32	2.5650	0.000	
Water*Glue	64.01	2.5650	0.000	
Clay*Water*Glue	-30.69	18.0465	0.133	
Viscosity				98.90%
Clay	12300	255.7	*	
Water	1500	255.7	*	
Glue	5600	255.7	*	
Clay*Water	-9800	1252.4	0	
Clay*Glue	-2800	1252.4	0.060	
Water*Glue	-600	1252.4	0.646	
Clay*Water*Glue	-22950	8811.6	0.035	
Sagging				100%
Clay	12.00	0.000000	*	
Water	4.00	0.000000	*	
Glue	12.00	0.000000	*	
Clay*Water	-16.00	0.000000	*	
Clay*Glue	-16.00	0.000000	*	
Water*Glue	16.00	0.000000	*	
Clay*Water*Glue	-96.00	0.000000	*	
Leveling				100%
Clay	1.00	0.000000	*	
Water	2.00	0.000000	*	
Glue	2.00	0.000000	*	
Clay*Water	2.00	0.000000	*	
Clay*Glue	2.00	0.000000	*	
Water*Glue	0.00	0.000000	*	
Clay*Water*Glue	-30.00	0.000000	*	

Table 4.3 The predictive regression models of physical property evaluation in Mixture design experiment of traditional primer.

Dependent Variable; Y	Predictive Model	R^2
Opacity	$Y = 63.77X_1+38.30X_2+39.90X_3+30.17X_1X_2-29.32X_1X_3+64.01X_2X_3-30.69X_1X_2X_3$	99.37
Viscosity	$Y = 12300X_1+1500X_2+5600X_3-9800X_1X_2-2800X_1X_3-600X_2X_3-22950X_1X_2X_3$	98.90
Sagging	$Y = 12X_1+4X_2+12X_3-16X_1X_2-16X_2X_3+16X_2X_3 -96X_1X_2X_3$	100
Leveling	$X_1+2X_2+2X_3+2X_1X_2+2X_1X_3 - 30X_1X_2X_3$	100

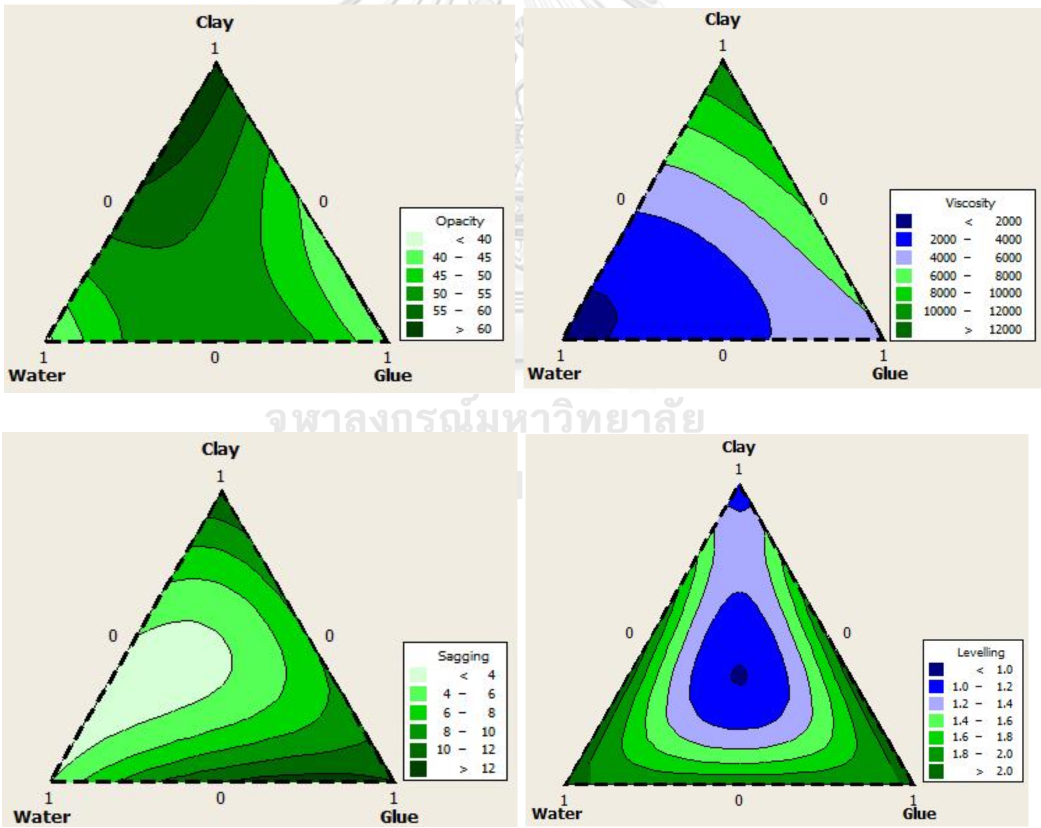


Figure 4.3 Contour plots of traditional primer that presented the opacity, viscosity, sagging, and leveling.

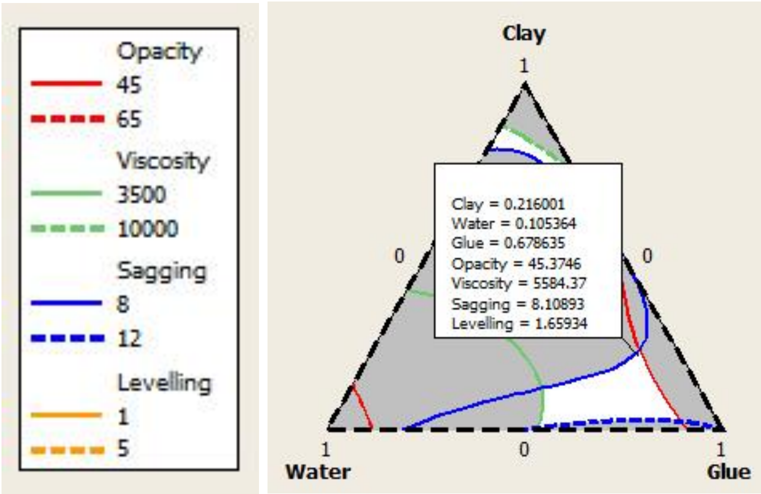


Figure 4.4 Contour plot of traditional primer that presented the overlaid opacity, viscosity, sagging, and leveling.

4.1.3 Artist satisfaction on the optimized formulation

In practical, standard requirement of traditional primer were not documented scientifically. There were no quantitative data of opacity, viscosity or any other properties. Artists' experiences were only source of knowledge and reference. Therefore, to ensure that the predictive formulation was well optimized and satisfied by artists, it was taken to artists for their brush testing before AgNPs was added. Figure 4.5 showed artists Kiettisak Suwannapong and Niphon Baobabdee painting on the concrete slabs coated by the optimized traditional primer. Art works of five artists who involved in the testing were shown in the Figure 4.6.

Figure 4.5 Two artists were painting on concrete slabs that were coated by traditional primer.

Figure 4.7 showed the results of artists' satisfaction on the optimized traditional primer. Scores given by artists were summarized that artists satisfied 88.57% on (A) primer's viscosity, 94.29 % on (B) fineness, 97.14% on (C) flow or leveling while applying it on the substrate with painting brush, 85.71 % on (D) drying, 97.17% on (E) color of primer after coating and drying, 97.14% (F) on hiding power, 91.43 % on (G) effect of primer on paints absorbance over primer, 97.14 % on (H) paints appearance on primer after the paints was dried completely and 94.29 % on (I) overall satisfaction.

Figure 4.6 The art works painted on concrete slabs that were coated the traditional primer. Name of artists for the piece of (a), (b), (c), (d), and (e) were Niphon Baobabdee, Jeerasak Songprasom, Wicien Saechai, Cheep Dissaro, and Kiettisak Suwannapong, respectively.

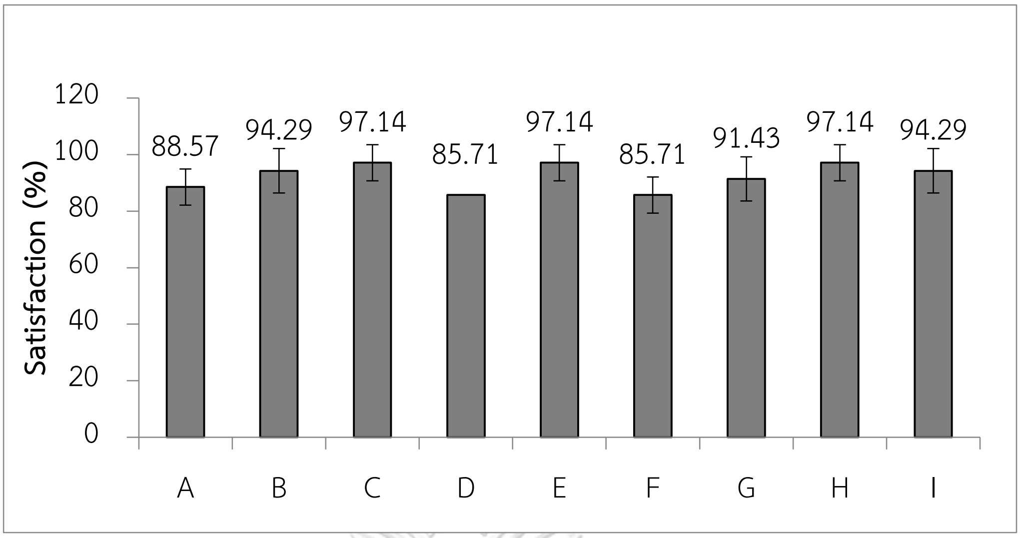


Figure 4.7 Percentage of artists' satisfaction on the model traditional primer.

A = satisfaction on viscosity.

B = satisfaction on primers' fineness.

C = satisfaction on applying (flow or leveling) it on the substrate with painting brush?

D = satisfaction on primer drying.

E = satisfaction on color of primer after coating and drying.

F = satisfaction on hiding power.

G = effect of primer on paints absorbance over primer.

H = effect of primer on paints appearance after the paints dry completely.

I = Overall satisfaction.

Formulation of traditional primer added Ag NPs

Table 4.4 showed formulation of the traditional primer that was added the AgNPs in this experiment.

Table 4.4 Suggested traditional primer formulation

Component	%
Clay	37.00
H2O	9.50
Tamarind Glue	52.00
AgNPs	1.50

4.2 Novel Primer

4.2.1 Effect of mixture components on the responses

Table 4.5 presented the mixture design of 3 components, TiO_2, Al_2SiO_5 and styrene/acrylic copolymer. The amount of distilled water as vehicle was constant for all formulas. The results showed that TiO_2, Al_2SiO_5 and styrene/acrylic copolymer significantly affected ($p \leq 0.05$) the opacity, viscosity, sagging and leveling. The contour plots of the attributes were shown in Figure 4.8. All contour plots were overlapped in order to find the optimized area for the optimized formula with the acceptable range of each property. The opacity was between 90-95%. Viscosity of all formulas was very low, we therefore tolerated the range from 50 to 200 mPa.S. Viscosity was later adjusted by adding the thickener. The range of sagging and leveling were 3-5 and 4-5 respectively. Figure 4.9 showed overlapping of contour plots. The white intersected area was the optimized mixtures. As we mentioned before, the mixture design would be used as a guideline for final formulation. The proportion that we selected was 0.278 pigment, 0.358 filler and 0.364 binder. Following this proportion, the predictive opacity was 94.72%, viscosity was 105.80 mPa.S, sagging was 3.09 and leveling was 4.05.

Regarding the selected proportion, weight of each component was calculated and found that pigment: filler: binder was 25.57g: 27.16g: 27.28g. The distilled water in the mixture was fixed at 40g. This model was further optimized by adding additives to adjust particular properties.

Table 4.5 Opacity, viscosity, sagging and leveling values obtained from 14 mixtures.

	Factor Level			Property			
Formulation	X_1	X_2	X_3	Opacity (%)	Viscosity (mPa.S)	Sagging	Leveling
1	0.00	0.00	1.00	87.05±0.53	150	3	5
2	0.00	0.50	0.50	92.80±0.70	75	5	4
3	0.50	0.00	0.50	92.07±0.48	50	3	4
4	0.00	1.00	0.00	-	-	-	-
5	0.50	0.50	0.00	95.04±0.44	200	3	3
6	0.50	0.50	0.00	62.93±0.28	200	6	1
7	1.00	0.00	0.00	87.79±0.20	200	3	2
8	0.00	0.00	1.00	82.58±0.79	150	3	5
9	1.00	0.00	0.00	87.54±0.45	200	4	3
10	0.00	1.00	0.00	-	-	-	-
11	0.33	0.33	0.33	94.04±0.25	150	3	4
12	0.50	0.00	0.50	94.38±0.83	50	3	5
13	0.33	0.33	0.33	95.21±0.78	125	3	4
14	0.00	0.50	0.50	93.61±0.54	75	3	4

X1 pigment, X2 filler, X3 binder

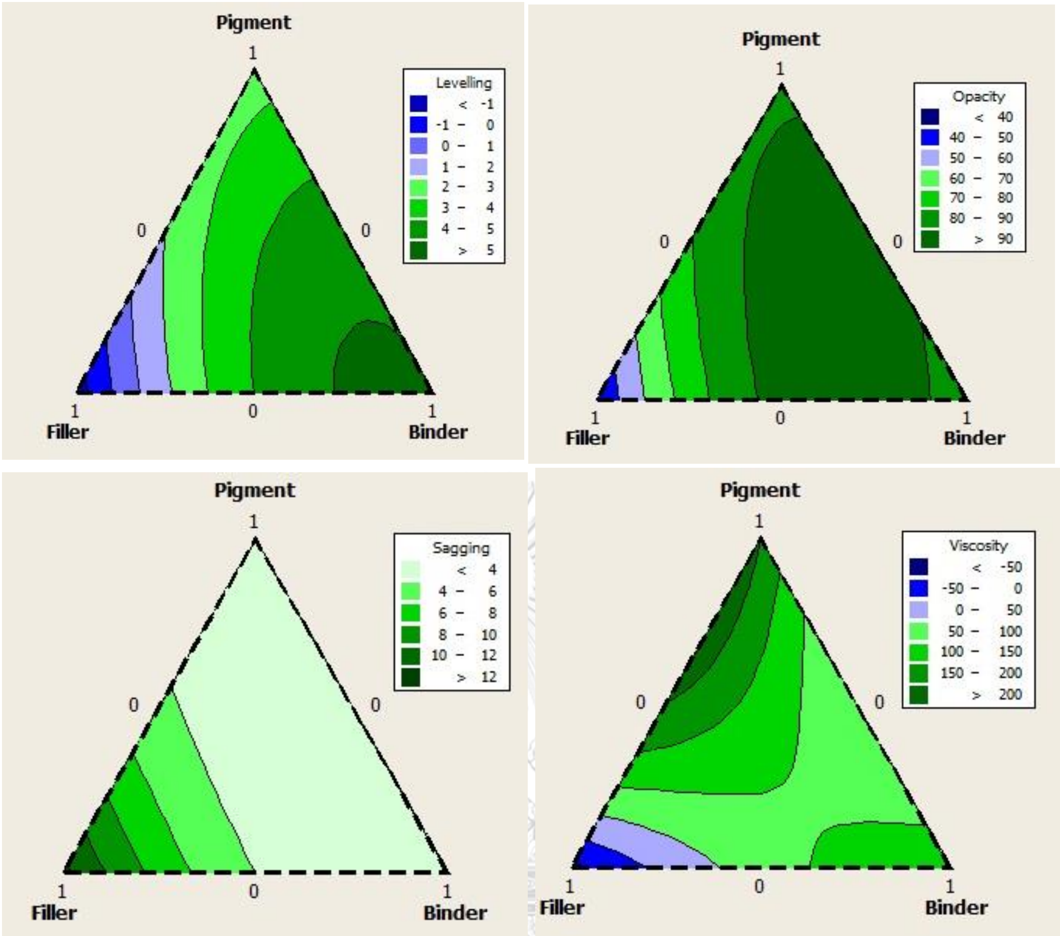


Figure 4.8 Contour plots of novel primer that presented the opacity, viscosity, sagging, and leveling.

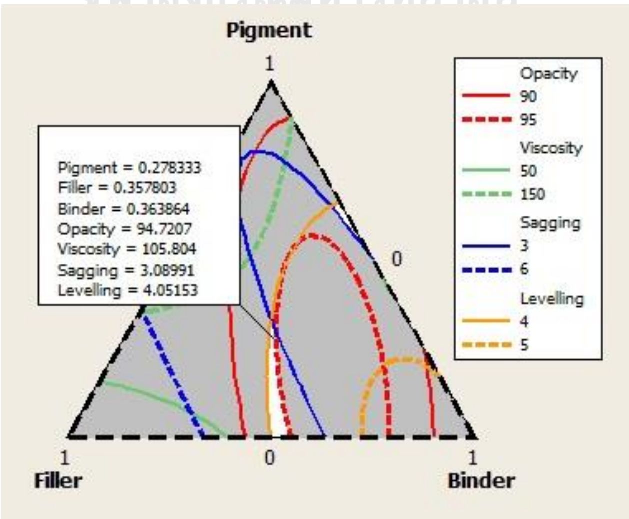


Figure 4.9 Overlapping of contour plot of opacity, viscosity, sagging and leveling of the novel primer, mixture design.

4.2.2 Optimized formulation of the novel primer

The predicted formulation was further optimize by adding the additives as shown in Table 4.6. Two formulations were formulated and optimized. NTA-Ag was based on the predicted proportion of the mixture design results. NA-Ag was additionally formulated in order to study the antibacterial activity of the primer when it did not consist TiO_2 (14-17) in the system. Figure 4.10 showed similar appearance of NTA-Ag and NA-Ag. The CIE L*a*b* values of the former and the latter were 93.77, -0.78, 6.98 and 94.44, -0.87, 5.66 respectively, measured with Technidyne, geometry d/0, D65/10. ΔE_{00} of these two primers was calculated and presented as 1.12.

Table 4.6 Component (%) of novel primers, NTA-Ag and NA-Ag.

Components	NTA-Ag	NA-Ag
Titanium Dioxide	18.30	0.00
Aluminium silicate	17.30	35.70
Distilled water	32.60	32.60
binder	16.50	16.50
Deformer	5.20	5.20
Ceramic microsphere	4.90	4.90
Solvent	2.00	2.00
Silver nanoparticle	1.50	1.50
Emulsifier	1.00	1.00
Thickener	0.30	0.30
Biocide – in can	0.20	0.20
Biocide – on film	0.20	0.20

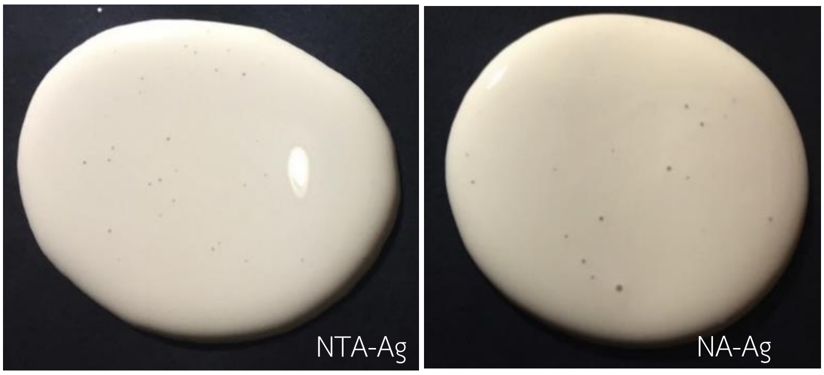


Figure 4.10 Appearance of novel primers, NTA-Ag and NA-Ag.

4.4 Results of washability of traditional and novel primers

Figure 4.11 showed washability results of NTA-Ag, NA-Ag and traditional (T) primers. The results revealed that the traditional primer film was erode by water easily, both soilant materials and primer film were removed. The result of NTA-Ag showed that the soilant was moderate changed from black to slightly visible and left the stain over the primer film resulted in darker primer film. There was no erosion of the primer film. The soilant on NA-Ag was considerably changed from black to barely visible. There was no soilant stain left on the primer and no erosion of the film.

Gloss of the unwashed areas of NTA-Ag and NA-Ag were not changed visually but the measured data (Micro-Tri – gloss meter (BYK) at 60O) showed slightly change of gloss on NTA-Ag that increased from 2.4 ± 0.0 to 2.8 ± 0.1, and on NA-Ag that decreased from 3.8 ± 0.1 to 2.6± 0.0.

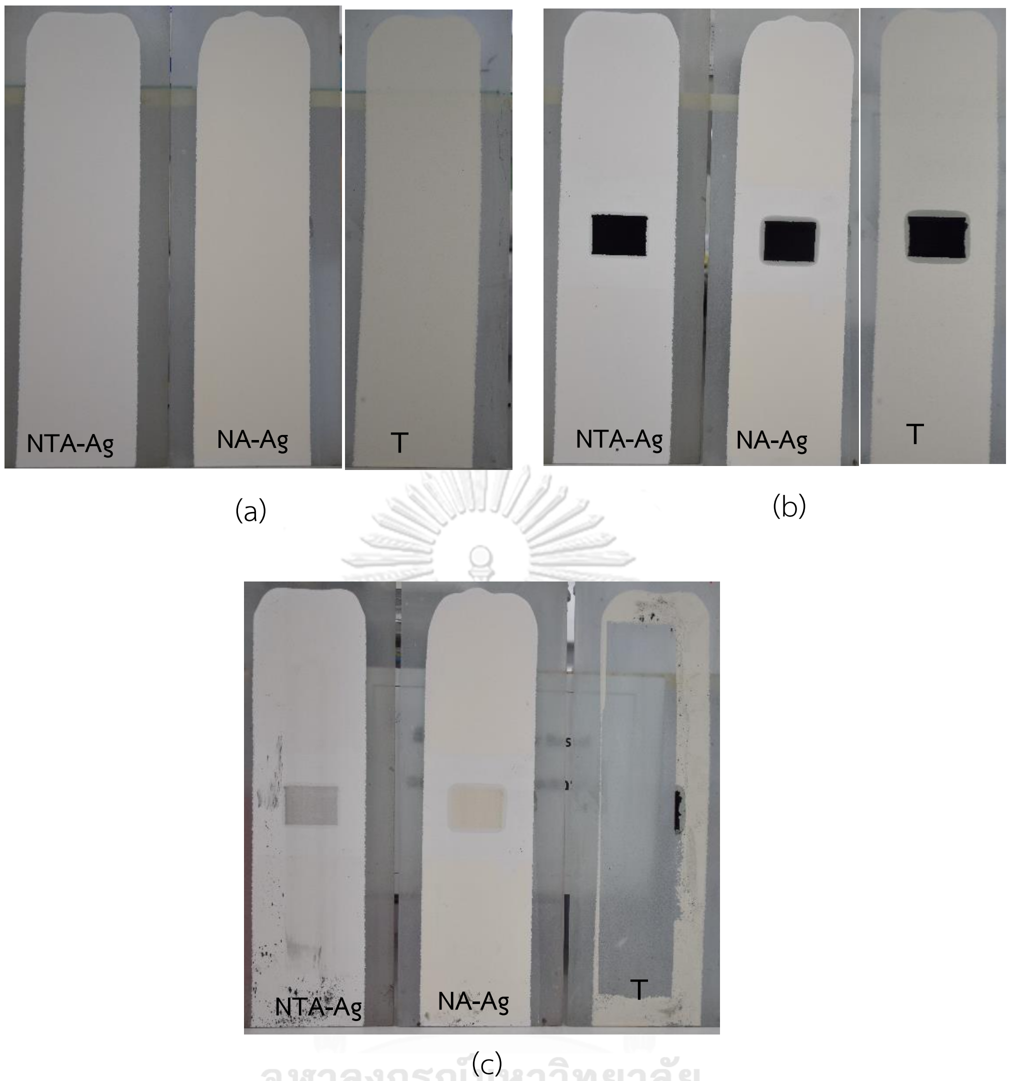


Figure 4.11 Washability results of primers (a) primer film before applying the soilant medium, (b) Soilant medium on primers film and (c) after washability testing.

4.5 Results of scrub Resistance of traditional and novel primers

Figure 4.12 showed the appearance of primer film before and after scrub resistance testing. The results revealed that the traditional primer drawn down film was immediately damaged when the nylon brush and abrasion scrub media touched its surface. The film was 100% removed with only 5 cycles.

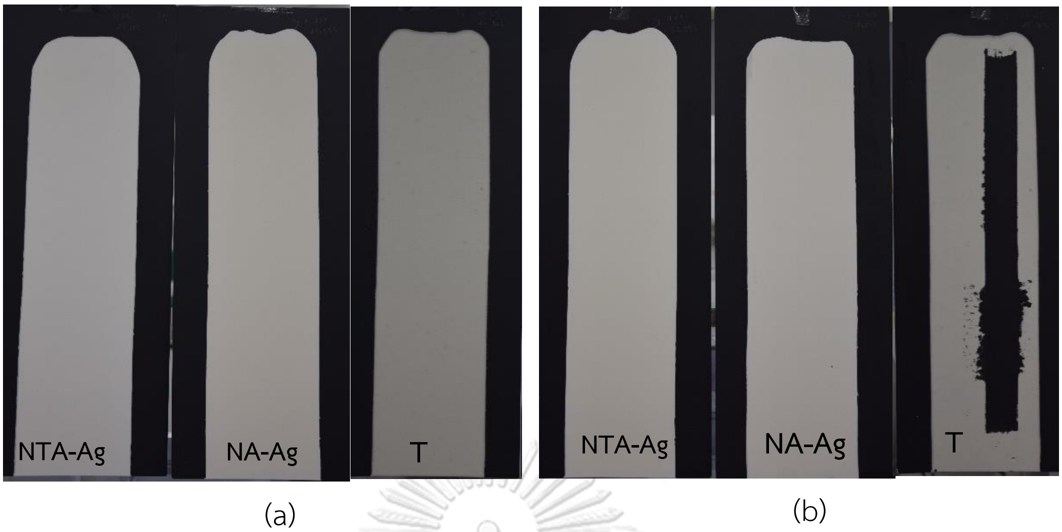


Figure 4.12 Appearance of primers film NTA-Ag, NA-Ag, and T (a) before scrub resistance testing, and (b) after scrub resistance testing

NTA and NA were scrubbed for 3000 cycles, and there were no erosion lines. The erosion rate, C, of each primer sample was calculated using equation 4.1.

$$C = \frac{(W_B - W_A)}{N_C} \times 100,$$

Equation 4.1

where W_B is weight of primer film before scrub, W_A is weight of primer film after scrub and N_C is number of cycles.

The results showed that the erosion rate of NTA-Ag, NA-Ag, and T were 0.00038 ± 0.00028, 0.00059 ± 0.00015 and 6.75600 ± 0.44972 respectively. Three thousand cycles are a criterion for weather resistance emulsion paint (Thai Standard Industrial no.2321). Therefore, tested results showed that novel primers were high resistance to weather.

NTA-Ag and NA-Ag consisted of styrene/acrylic emulsion and ceramic microsphere. The styrene/acrylic emulsion has been widely used in the field of the architectural paints for its prominent properties: high resistance to UV light, to oxygen, to water and to various types of solvents as well as excellent durability (87). Adding ceramic microsphere can increase burnish and abrasion. It can also give the anticorrosive of the paint (21, 66).

4.6 Antibacterial property of primers

4.6.1 Identification of bacterial isolates

As shown in the Table 4.7, 5 isolates of bacteria were identified as four species. The results showed that B14 and C3 isolates were *Bacillus subtilis,* C1 *was Bacillus cereus*, D3 was *Bacillus mycoides,* and IM5 was *Leclercia adecarboxylata.* The similarity percentages of identification were also presented. 16s rDNA sequences of these bacteria were presented in Appendix A.

Table 4.7 Bacteria identification and similarity percentage.

Strain	Compared strains in GenBank	GenBank Accession	Similarity %
B14	*Bacillus subtilis* strain zw50	MH337962.1	100
C1	*Bacillus cereus* strain ATA1	MH368128.1	100
C3	*Bacillus subtilis* strain BS1	MH368068.1	100
D3	*Bacillus mycoides* strain LZH-X41	KY049894.1	99
IM5	*Leclercia adecarboxylata* strain EGTM31	MG890203.1	99

The bacteria isolates that were found in our study related with other previous researches. The genus *Bacillus* has frequently been found on the deteriorated mural and rock paintings (88, 89). Gorbushina et al reported that the isolation of bacteria from mural paintings of the St. Martin's church in Germany were belonged to *Bacillus* and *Bacillus*-related genera (90). They also mentioned that *Bacillus* sp. were found as one of the bio-deterioration problem in the mural paintings (90). Furthermore, Capodicasa et al. *also* stated that *B. subtilis* was found on the deteriorated canvas of 16^{th} century painting named *"Madonna col Bambino in gloria tra S. Caterina, il B. Riniero e S. Lucia"* painted in 1598 by Denys Calvaert and displayed in the medieval church of San Giacomo Maggiore in Bologna, Italy (91).

4.6.2 Evaluation of antibacterial activity of the primers

Table 4.8 depicted the diameters of clear zone of inhibition. Comparison of different primers that affected bacterial inhibition zone were presented in the Figure 4.13. We also presented effect of primers on the growth of each bacterial strains in the Figure 4.14 to 4.17. T and T-Ag are traditional primer without AgNPs and with 150 ppm AgNPs respectively. NTA and NTA-Ag indicated novel primer NTA without AgNPs and with 150 ppm AgNPs respectively. NA and NA-Ag were novel primer NA without AgNPs and with 150 ppm AgNPs respectively.

Table 4.8 Antibacterial activity results of primers.

Strains	Diameter of Clear Zone (cm)						
	control	T	T-Ag	NTA	NTA-Ag	NA	NA-Ag
Bacillus cereus	3.27±0.15	NC	NC	1.00±0.17	1.43±0.06	NC	NC
Bacillus subtilis	4.13±0.06	NC	NC	1.37±0.06	1.57±0.06	NC	NC
Bacillus mycoides	3.45±0.06	NC	NC	1.47±0.06	1.73±0.06	NC	0.77±0.06
Leclercia adecarboxylata	3.70±0.10	NC	NC	2.53±0.06	2.47±0.06	1.67±0.06	1.53±0.06

NC = No clear zone

Mean ± one standard deviation derived from three replicates (N=3)

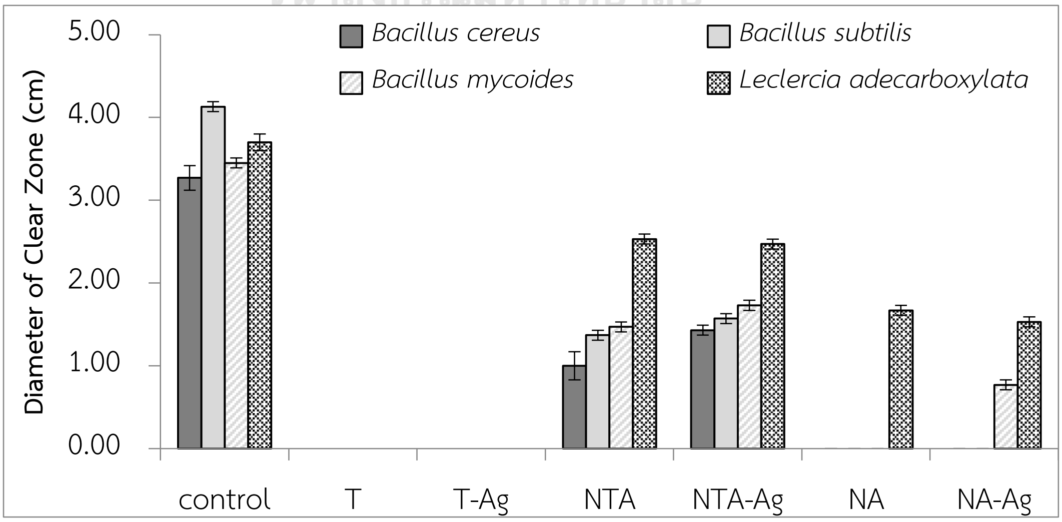


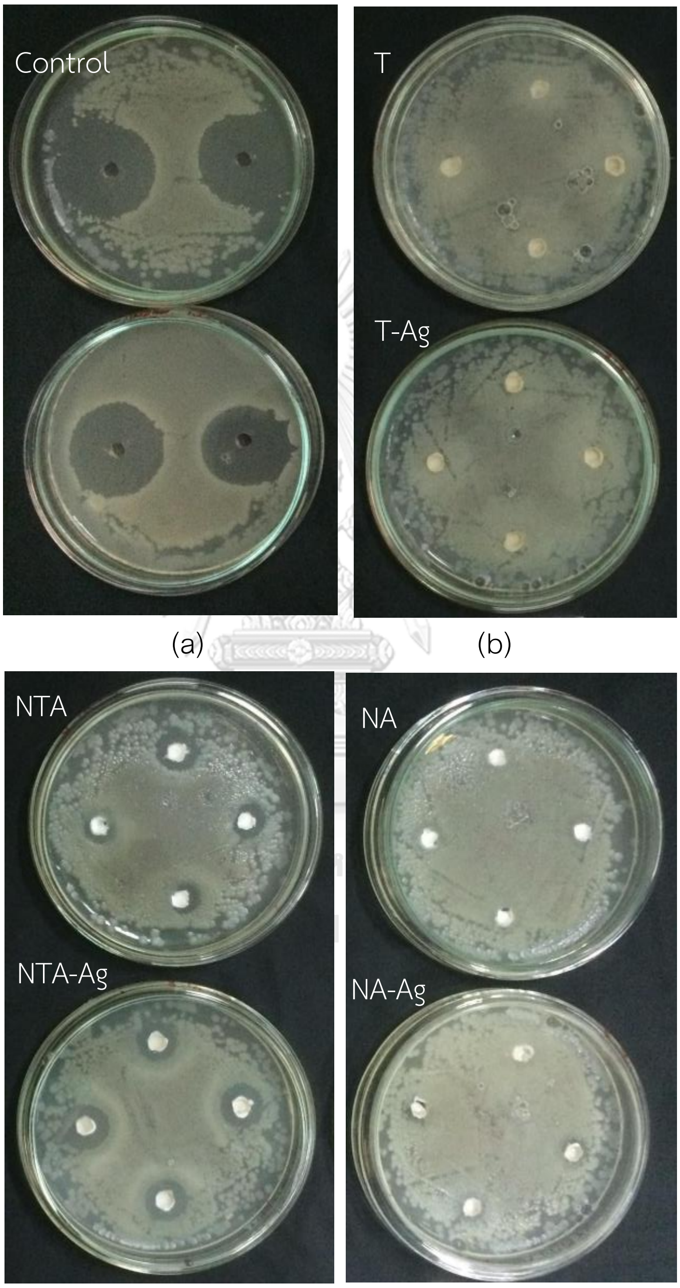
Figure 4.13 Effect of different primers on bacterial inhibition zone.

The results indicated that neither the traditional primers with AgNPs nor the one without showed clear zone against all bacteria strains. The novel primer, NTA showed zone of inhibition of 1.00±0.17 cm against *B. cereus,* 1.37±0.06 cm against *B. subtilis,* 1.47±0.06 cm against *B. mycoides* and 2.53±0.06 cm against *L. adecarboxylata*. The novel primer NTA-Ag showed clear zone of inhibition of 1.43±0.06 cm against *B. cereus,* 1.57±0.06 cm against *B. subtilis*, 1.73±0.06 cm against *B. mycoides*, and 2.47±0.06 cm against *L. adecarboxylata*. The novel primer NA only showed inhibition zone of 1.67±0.06 cm against *L. adecarboxylata*. The novel primer NA-Ag showed inhibition zone of 0.77±0.06 cm against *B. mycoides* and 1.53±0.06 cm against *L. adecarboxylata*.

The results clearly revealed that the Thai traditional primer with AgNPs was not able to inhibit the growth of bacteria. Adding AgNPs does not show effect of inhibition against these 4 isolates of bacteria. The traditional primer was a mixture of clay and tamarind glue. The natural clay is closed to soil which is normally the source of microorganism (92). *Bacillus cereus* and *Bacillus subtilis* are normally found in nature and frequently isolated from soil. In addition, *Bacillus Subtilis* which is a *Saccharolytic bacteria* has the ability to generate energy by metabolizing carbohydrates (93). The tamarind glue consists polysaccharide (51), it therefore can support the growth of bacteria.

The novel primer that consisted of TiO_2 and Al_2SiO_5, without AgNPs, in the formulation showed high active inhibition against all 4 bacterial strains, while the novel primer NTA-Ag that consisted of TiO_2, Al_2SiO_5 and AgNPs showed the highest active inhibition. TiO_2, itself had a strong effect against all 4 isolates of bacteria. Adding AgNPs of 150 ppm in the formulation slightly increased the inhibition effect for 3 isolates of bacteria, except for Leclercia adecarboxylata, the most increase found for Bacillus cereus.

The novel primer contained only Al_2SiO_5 as pigment showed inhibition against one strain of Leclercia adecarboxylata. Adding 150 ppm of AgNPs help inhibition against one more strain of Bacillus mycoides. We may suggest, from the results, that the novel primer NA-Ag can be alternative one if the deterioration of paint layers is of concern. The formulation containing TiO_2, Al_2SiO_5 and AgNPs seems to give the best results but TiO_2 may cause discoloration of paint layers.



(c) (d)

Figure 4.14 Inhibition zone of antibacterial activity of primers on *Bacillus cereus*: (a) control, (b) T and T-Ag, (c) NTA and NTA-Ag and (d) NA and NA-Ag.

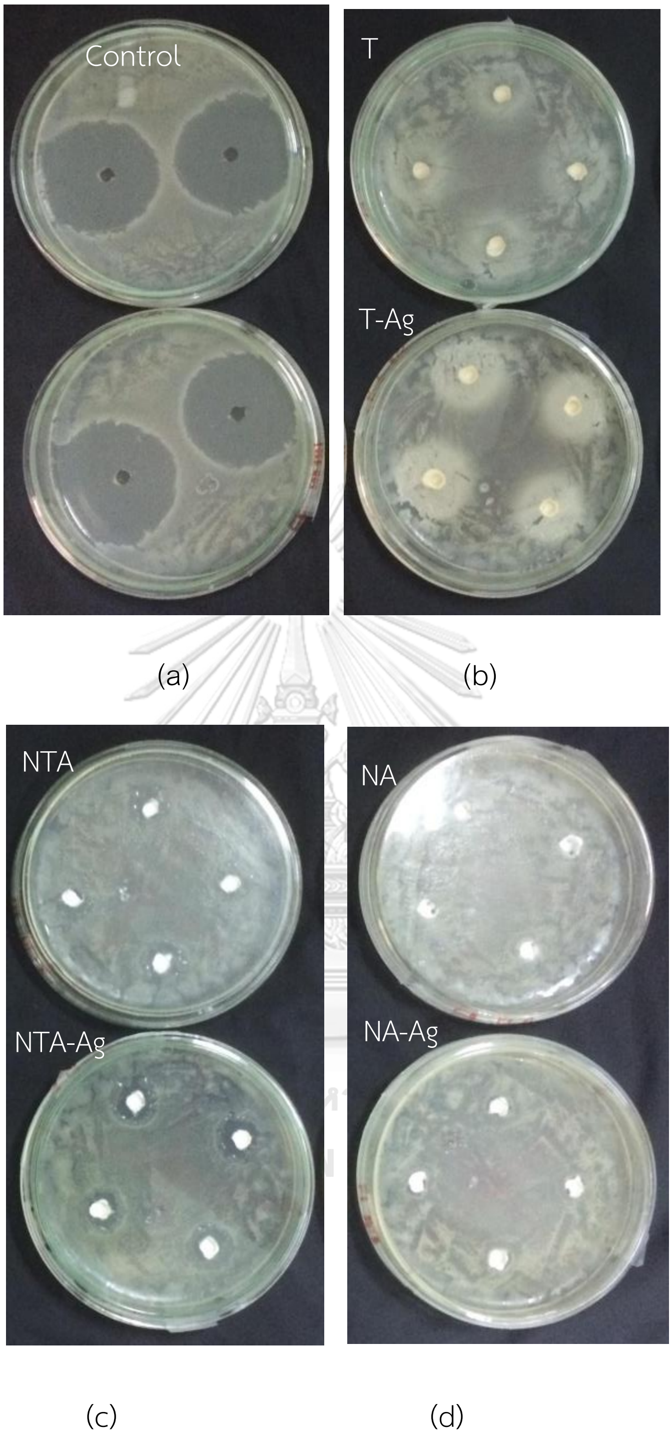
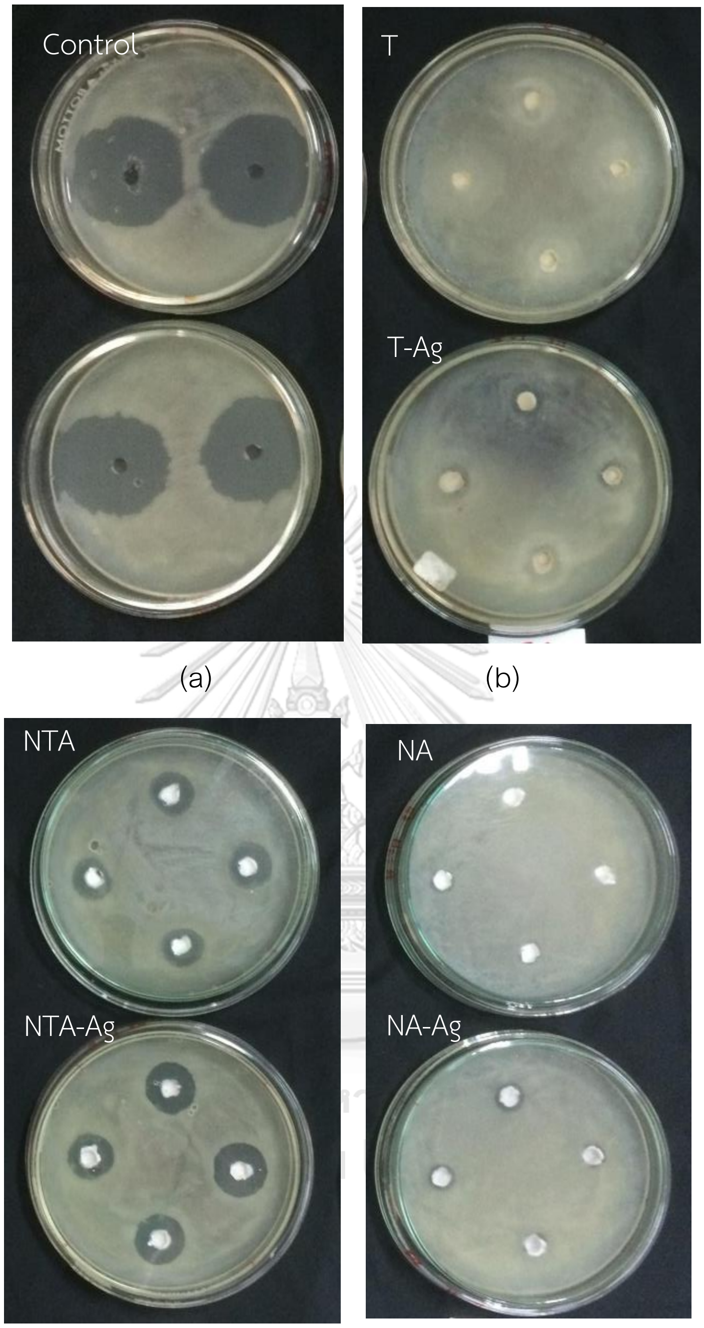
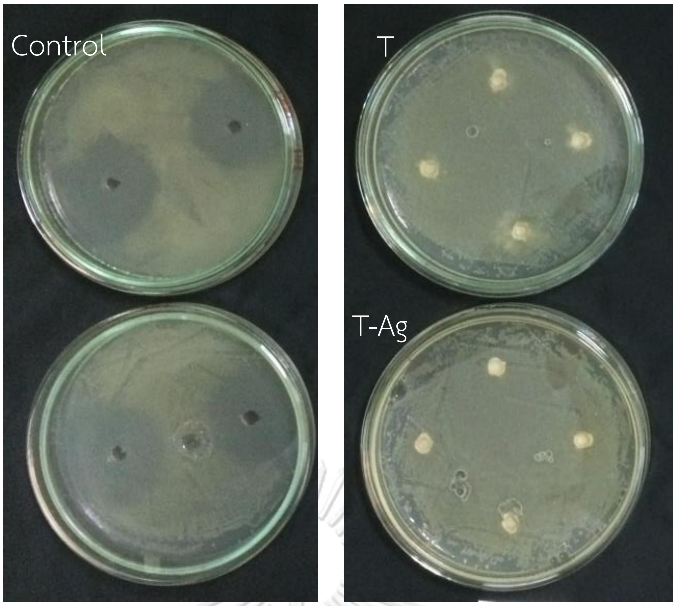


Figure 4.15 Inhibition zone of antibacterial activity of primers on *Bacillus subtilis*: (a) control, (b) T and T-Ag, (c) NTA and NTA-Ag and (d) NA and NA-Ag.

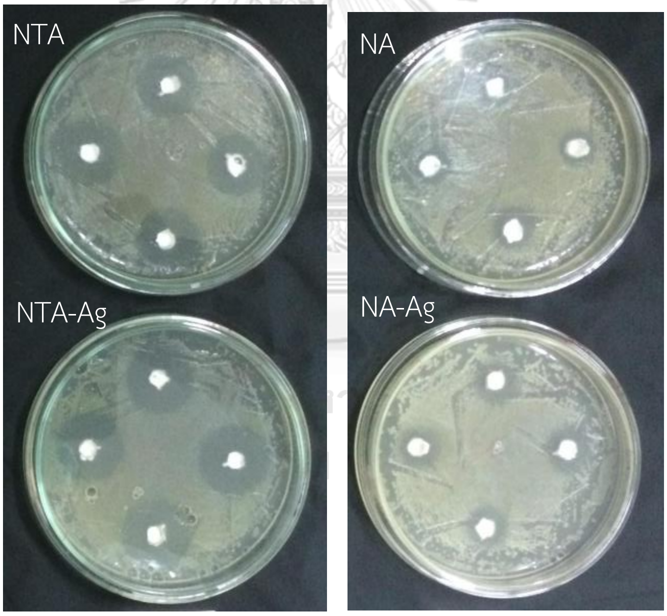


(c) (d)

Figure 4.16 Inhibition zone of antibacterial activity of primers on *Bacillus mycoides*: (a) control, (b) T and T-Ag, (c) NTA and NTA-Ag and (d) NA and NA-Ag.



(a) (b)



(c) (d)

Figure 4.17 Inhibition zone of antibacterial activity of primers on *Leclercia adecarboxylata*: (a) control, (b) T and T-Ag, (c) NTA and NTA-Ag and (d) NA and NA-Ag.

Effect of TiO2 and Ag nanoparticle on microbial growth

TiO_2 is a well-known photocatalytic that can deactivate the growth of microorganisms (14-17). Its effectiveness can be explained on the basis of the oxygen species released on the surface of TiO_2, which cause fatal damage to microorganisms (94). The generation of highly reactive species such as OH−, H_2O_2 and O_2− is also explained. Since TiO_2 can be activated by both UV and visible light, electron-hole pairs (e−h+) can be created. The holes split H_2O molecule (from the suspension of TiO_2) into OH−and H+. Dissolved oxygen molecules are transformed to superoxide radical anions (•O−2), which in turn react with H+ to generate (HO_2•) radicals, which upon subsequent collision with electrons produce hydrogen peroxide anions (HO_2−). They then react with hydrogen ions to produce molecules of H_2O_2. The generated H_2O_2 can penetrate the cell membrane and kill the bacteria (95). Although the mechanism of AgNPs to inhibit the growth of microorganism is not fully understood but there were reports explained that AgNPs can attach to the cell membrane and penetrates inside the bacteria. This is possible because the low dimension of the particles; the smaller and higher surface area, is the most aggressive for the cell membrane. They attack, preferably, the respiratory chain, leading ultimately to cell's death (96, 97). In addition, the positive charge on the Ag^+ is crucial for its antimicrobial activity through the electrostatic attraction between negative charged cell membrane of microorganism and positive charged nanoparticles (19). It is known that DNA of microorganism loses its replication ability and cellular proteins become inactivated on Ag^+ treatment (65). Size of nanoparticles is very small which is 250 times smaller than a bacterium, therefore, the antimicrobial ability of silver nanoparticle might be referred to their small size , which makes them easier to adhere with the cell wall of the microorganisms and also possible to penetrate inside the bacteria causing its destruction and cell death ultimately (96).

In combination of TiO_2 and AgNPs in the novel primer NTA-Ag showed more effective clear zone inhibition.

The inhibited zone of NA against the *Leclercia adecarboxylata* was unexpected. The NA did not consist of TiO_2 and AgNPs while the aluminium silicate framework also did not contribute to bacteria death (98). We assumed that this was possibly explained by the difference of the Gram. *Leclercia adecarboxylata* is a Gram-negative (99) While the *Bacillus subtilis*, *B. mycoides, and B. cereus* are gram-positive (100-102). Gram-positive and Gram-negative cells differ markedly in their cell walls. Obviously, the peptidoglycan (PG) in the cell walls of Gram-positive cells is much thicker than that in the Gram-negative ones, and it is attached to echoic acids that strengthen and are unique to the Gram-positive cell wall only. While Gram-negative cell walls is more structurally and chemically complex. It comprises a thin PG layer and contains an outer membrane, which covers the surface membrane. The PG layer of Gram negative is about 1/10 of the Gram positive and had no echoic acid bond which , therefore, the cell wall of Gram negative is weaker than the cell wall of the Gram positive (103, 104). However, we suggested that this particular evidence should be taken to study further.

4.7 Artist satisfaction on brush testing of novel primers

Novel primers; NTA-Ag and NA-Ag were taken to five artists for brush testing. Figure 4.18 showed their art works that were painted on concrete slaps coated by NTA-Ag and NA-Ag.

(a)

(b)

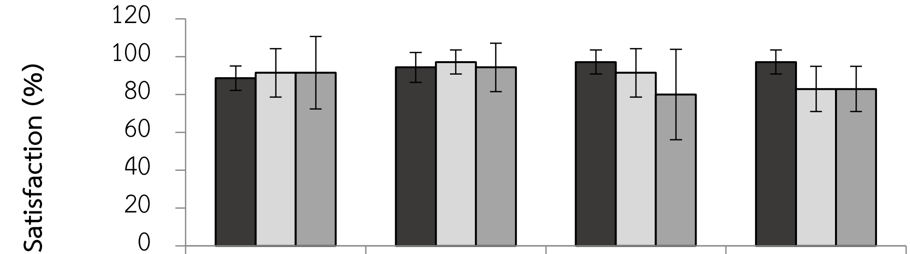
(c)

(d)

(e)

Figure 4.18 Art works painted on concrete slabs that were coated by primer NTA-Ag (left of each picture) and NA-Ag (right of each picture). Name of artist were list as follow; (a) Thammarat Kangwarnkong, (b) Keittisak Suwannapong, (c) Wichien Saechai (d) Panya Phodee and (e) Kan Pisutthibongkoch.

The satisfaction scores on physical properties of novel primers comparing with traditional primer were shown in Figure 4.19. For traditional primer, artist satisfied 88.57% for viscosity, 94.29% for fineness, 97.14% for wet color and 97.14% for odor. Artists satisfied 91.43% on primer's viscosity, 97.14 % on fineness, 91.43 % on wet color and 82.86% on odor, for NTA-Ag, while for NA-Ag, the satisfaction scores of viscosity, fineness, wet color and odor were 91.43%, 94.29%, 80% and 82.86% respectively.

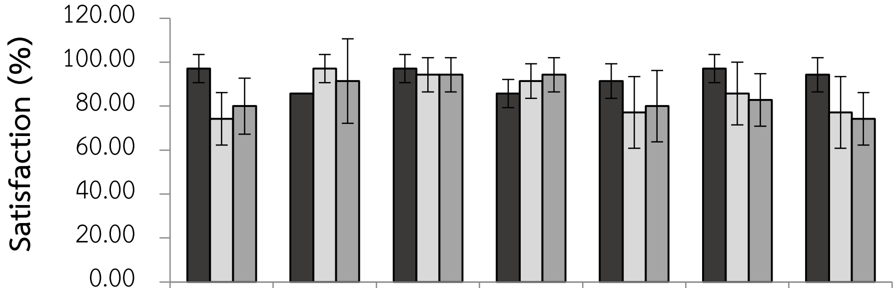


	viscosity	fineness	wet color	odor
Traditional Primer	88.57	94.29	97.14	97.14
NTA-Ag	91.43	97.14	91.43	82.86
NA-Ag	91.43	94.29	80.00	82.86

Figure 4.19 Artists 'satisfaction physical properties of primers including traditional primer and novel primer: NTA-Ag and NA-Ag

We also compared in Figure 4.20 the satisfaction scores of traditional and novel primers when they were applied on concrete surface. As it can be seen that artists satisfied on (A) a convenience of applying primer on the substrate with painting brush (flow and leveling) at 97.14%, 74.29% and 80% for traditional primer, NTA-Ag and NA-Ag respectively. Satisfaction on (B) drying time of primer were 85.71%, 97.15% and 91.43% for traditional primer, NTA-Ag and NA-Ag respectively. Satisfaction on (C) shade of primer after coating and drying was 97.14% for traditional primer and 94.29 % for both novel primers. (D) Hiding power of traditional primer, NTA-Ag and NA-Ag was satisfied by 85.71, 91.43% and 94.29% respectively. Effect of primer on (E) painting, paints absorbance and paint drying, and was satisfied by 91.42%, 77.14% and 80% for traditional primer, NTA-Ag and NA-Ag.

Moreover, satisfaction on (F) effect of primer on paints appearance after completely drying were 97.14%, 85.71% and 82.86% for traditional primer, NTA-Ag and NA-Ag respectively. Lastly, overall satisfaction (G) given for traditional primer, NTA-Ag and NA-Ag were 94.29%, 77.14% and 74.29% respectively.



	A	B	C	D	E	F	G
Traditional Primer	97.14	85.71	97.14	85.71	91.43	97.14	94.29
NTA-Ag	74.29	97.15	94.29	91.43	77.14	85.71	77.14
NA-Ag	80.00	91.43	94.29	94.29	80.00	82.86	74.29

Figure 4.20 Artists' satisfaction on traditional primer, novel primer NTA-Ag and NA-Ag that were applied on concrete surface.

CHAPTER 5
Results and Discussion – Pastel and Acrylic Paints

In this chapter the optimized mixtures of pastel and acrylic paint were presented. In addition, the formulations of pastel and acrylic paint that matched the CIELAB values of Thai color dictionary were suggested. Moreover, the color tolerance of 20 of Thai colors made by pastel were determined.

5.1 Pastel

The 3-components mixture design with simplex centroid was also applied to optimized pastel formulation. The process was the same as optimizing primer formulations. We then would omit showing the 14 mixtures and its responses. The contour plots and the optimized formula would be presented. The responses data of the mixtures of Permanent Rubine Red (PR57:1), gum tragacanth and $CaCO_3$ were hardness and paint testing. Our aim for making ready-to-use pastel was grinding and mix with binder to obtain Thai color for mural painting.

5.1.1 Effect of mixture components on the responses

Hardness was normally influenced by amount of binder. Excessive binder resulted in very hard pastel stick which could not draw line on substrate; in contrast, the pastel stick crumbled with less binder (72). Regarding our aim of the pastel stick, the pastel stick should be stable and easy to grind. Considering the contour plot of hardness (Figure 5.1), it presented the similar result reported by other researchers/artists that increase of proportion of binder would increase hardness.

Score of paint satisfaction increased with increasing of pigment. Combination of pigment and filler with very less amount of binder gave low score of satisfaction. This assumed that because it was nearly to crumble. Fillers was not necessary for pastels if the cost was not concerned. However, it provided smoother blends and gradations from the purest to the highly luminous (69, 105).

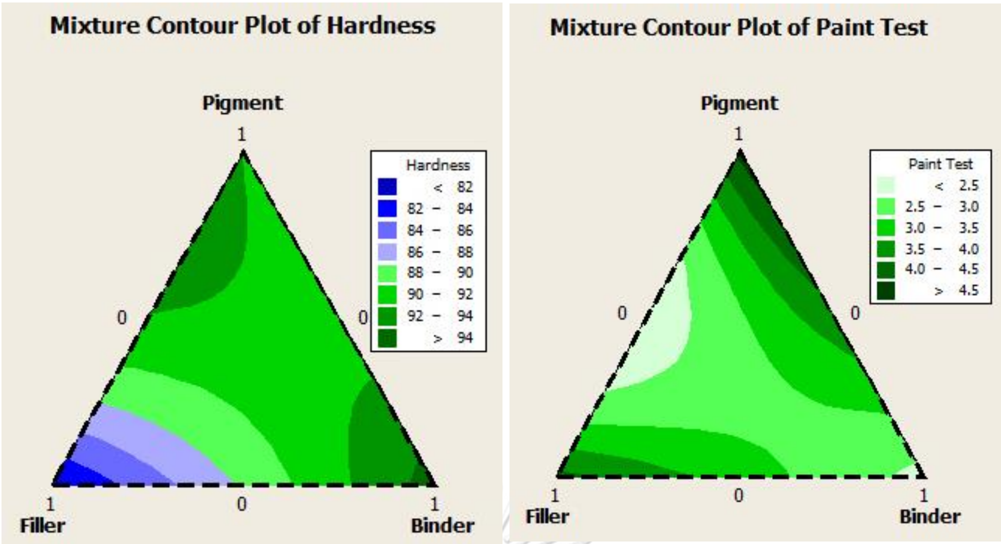


Figure 5.1 Contour plots of different combinations of pigment (Permanent Rubine Red), filler ($CaCO_3$) and Binder (Gum Tragacanth) on apparent hardness and painting test scores.

Formulations optimization

Mapping contour plots to generate the optimum proportion to meet the expectations of the responses, we selected the optimum proportion of 0.966 part of pigment, 0.008 part of filler and 0.026 part of binder giving hardness of 91.8 and painting satisfaction score of 4.8 out of 5. By using this ratio, the percentage of each component was calculated and presented as shown in the Table 5.1.

PR57:1 Permanent Rubine Red pastel stick and its painting appearance were presented in the Figure 5.2.

Figure 5.2 Pastel stick of the model Permanent Rubine Red (PR57:1).

Table 5.1 Suggested formulation of pastel

Component	%
Pigment	6.33
Binder	28.65
Filler	65.02

5.1.2 Primary color formulation

Figure 5.3 showed the pastel sticks of all primary colors. These primary color pastel sticks were ground and mixed with the gum acacia before they were coated on the canvas at the thickness of 80 microns. Figure 5.4 showed spectrum reflectance of all primary colors and Table 5.2 showed the CIELAB values (D65/2°). Permanent Rubine Red was not presented Figure 5.4 because it was not taken to further conduct calibration process due to it light fastness was rated as poor, as mentioned previously.

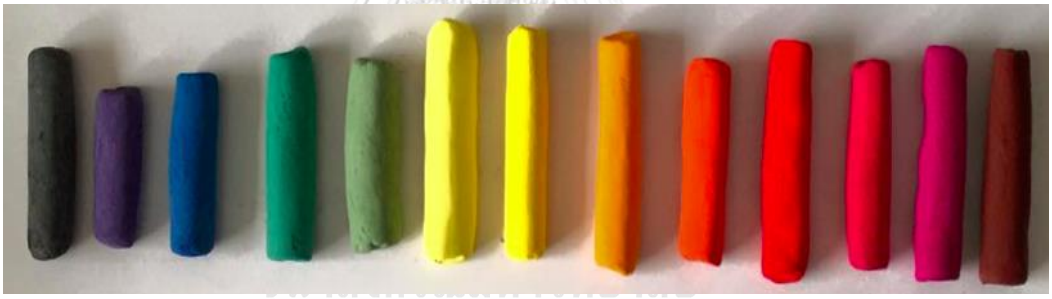


Figure 5.3 Sticks of pastel primary color (from let to right): Carbon Black, Violet RLS-EF, Blue-BX, Green GNX, Chrome Green, Oxide Yellow –BV02, Yellow F2G, Yellow M2R 70, Orange GR, Red D3G 70 Permanent Rubine Red, Pink EM25, and Brown HFR01.

Table 5.2 Pastel primary colors, visual and quantitative observation (D65/2 SPEX, X-Rite SP62)

	Blue BX	Carbon Black	Violet	Green GNX	Chrome Green	Oxide Yellow
L*	29.17	20.8	21.48	38.00	49.27	88.31
a*	1.96	0.10	6.13	-31.61	-20.93	-12.91
b*	-31.54	0.67	-5.65	2.08	17.98	81.67
C*	31.60	0.68	8.33	31.68	27.59	82.68
h°	273.55	81.25	317.33	176.23	139.33	98.98

	Yellow F2G	Yellow M2R70	Orange	Red D3G	Pink	Brown
L*	83.17	70.66	53.49	41.42	30.68	22.81
a*	-0.62	33.97	56.12	59.38	44.26	13.46
b*	95.35	79.82	57.00	39.94	8.79	11.71
C*	95.36	86.75	79.99	71.56	45.13	17.84
h°	90.37	66.95	45.45	33.92	11.23	41.04

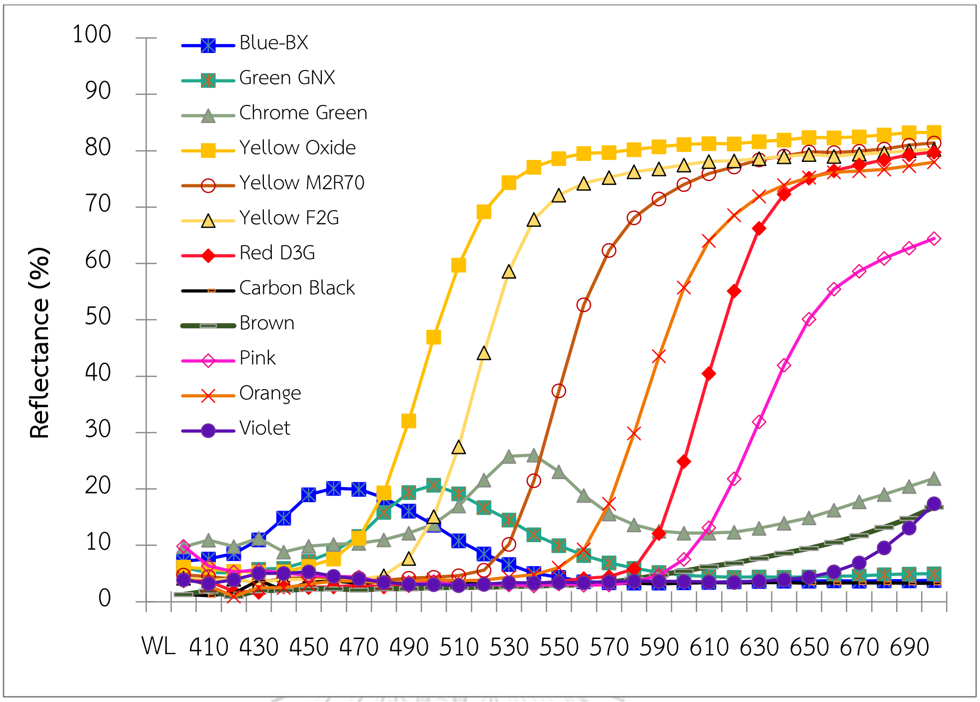


Figure 5.4 Reflectance curves of pastel primary color: Carbon Black, Violet RLS-EF, Blue-BX, Green GNX, Chrome Green, Oxide Yellow –BV02, Yellow F2G, Yellow M2R 70, Orange GR, Red D3G 70, Pink EM25 and Brown HFR01.

5.1.3 Database and calibration

Figure 5.5 showed the sticks of the Blue BX and the calibration panels at different concentrations: 99.99, 75.00, 50.00, 25.00, 12.50, 5.00, 2.50 and 1.25 %. Figure 5.6 presented the spectrum reflectance of all concentrations.

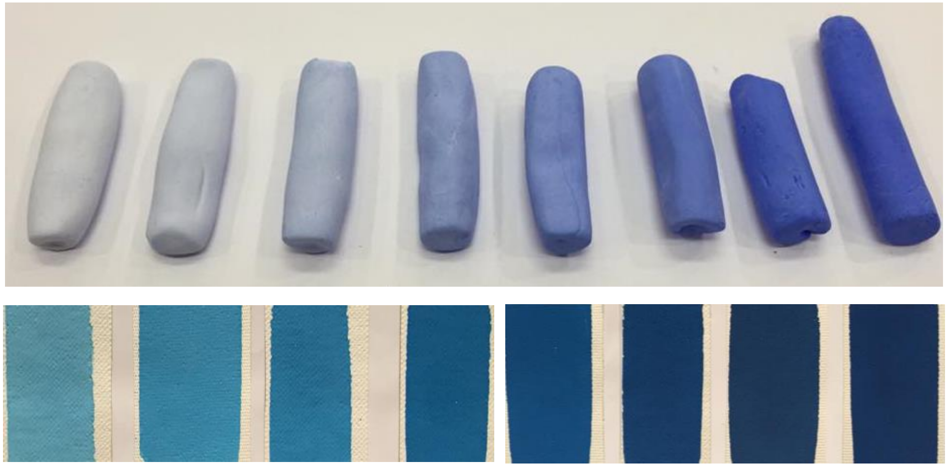


Figure 5.5 Sticks of blue-BX at different concentrations (top) and its color swatches (bottom), from left to right 1.25, 2.50, 5.00, 12.50, 25.00, 50.00, 75.00, and 99.99 %.

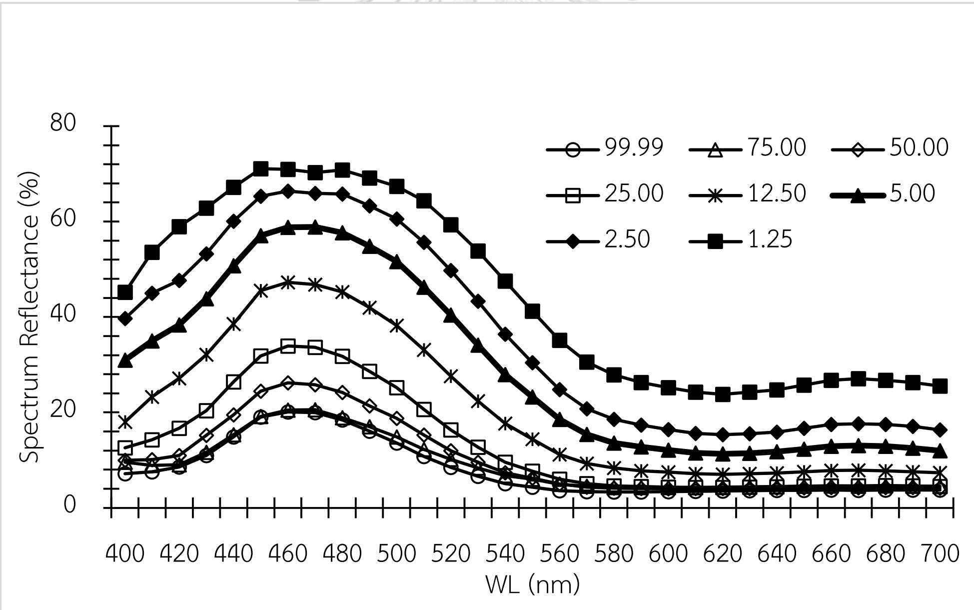


Figure 5.6 Percentage of spectrum reflectance of Blue BX calibrated panels for 8 concentrations, X-Rite SP62, illuminant/observers: D65/2, SPEX.

In addition to this Blue BX, calibration panels and spectrum reflectance of all primary color; Green GNX, Chrome Green, Yellow F2G, Oxide Yellow, Yellow M2R70, Orange, Red D3G 70, Pink EM25, Violet, Brown and Black were presented in Appendix-B.

5.1.4 Match prediction of the traditional Thai style color

After storing the reflectance spectrum of calibration panels to the database of color match prediction software, the K/S were calculated and the predicted formulations of traditional Thai style color were carried out. By selecting the colorants in the stored database, the specified traditional Thai style colors that were listed in the Thai color dictionary were formulated. Number of colorants was considered between 2 to 5 (77). The maximum number of colorants were 3 for pastels. Color difference CIEDE2000 (ΔE_{00}) < 3 was used as a criterion to accept as a good match (3). The formulation software can generate multiple formulations, each formulation predicted different color data including the ΔE_{00} and metameric index. We selected the best predicted formulation by mean of ΔE_{00} < 3 and minimum number of selected colorants. Since Thai color dictionary classified traditional Thai style colors into 11 categories; R, YR. Y, GY, G, BG, B, PB, P, RP, and Neutral (5), we therefore presented them based on each category.

R Category

Table 5.3 contained the CIELAB data of traditional Thai style colors in the R category. The first column indicated the Thai color name, the next three columns showed CIE L*, a* and b* values according to the Thai color dictionary. The next four columns indicated CIE L*, a*, b* and ΔE_{00} R category contained 25 colors. 20 colors showed that most of their predicted ΔE_{00} < 1.00. “Chompu” color could not be formulated.

Predicted formulation of 5 colors that included “Dang Sen”, “Hong Din”, “Din Tut”, “Dang Tubtim” and “Kulap” were taken to make “trial” samples as shown in the Table 5.14. Composition including percentage of each colorant and vehicle was presented. In addition, CIELAB values of predicted and “trial” samples were shown. ΔE_{00} of “Dang Sen”, “Hong Din”, “Din Tut”, “Dand Tub Tim”, “Dang Tubtim” and “Kulap” were 3.06, 1.55, 1.47, 2.28 and 1.31.

YR Category

Thai style colors in YR category were shown in the Table 5.4, almost of 14 colors were well matched. There was only “Nam Rak” could not have predicted ΔE_{00} that < 1.00, the best predicted formulation had ΔE_{00} 1.32. We brought this predicted formula of “Nam Rak” to make the “trial” sample and it was found that the obtained ΔE_{00} was 2.15 which was accepted.

Beside “Nam Rak”, five colors were also made: “Din Lueang”, “Nam-tan”, “It”, “Sanim Thong Dang” and “Hong Sabat”. ΔE_{00} of these colors were 2.69, 2.54, 2.81, 3.04 and 2.98 respectively. Other information including their composition, CIELAB values of standard, predicted and trial were also shown in the Table 5.14.

Table 5.3 List of Thai style color names in R category, CIELAB values according to Thai color dictionary and predicted data (using the stored database and formulation software; X-Rite SP62, illuminant/observers D65/2, SPEX).

Color Name	Dictionary			Database Prediction			
	L*	a*	b*	L	a*	b*	ΔE_{00}
Dang Chad	52.17	53.03	21.45	Presented separately. See table 5.15			
Dang Sen	51.43	52.19	26.83	51.19	52.59	27.40	0.35
Kulap	41.44	54.47	15.81	41.15	54.97	16.28	0.35
Dang Luead Nok	41.44	54.47	15.81	41.15	54.97	16.28	0.35
Dang Dok Chaba	52.17	53.03	21.45	Presented separately. See table 5.15			
Dang Tubtim	41.76	45.69	14.20	41.81	46.14	13.04	0.72
Dang Luead	41.31	44.86	21.50	41.36	46.61	21.45	0.68
Dang Tubtim (Rubi)	41.04	38.60	12.21	41.20	39.48	11.55	0.61
Dang Luead Moo	40.86	36.28	18.52	41.10	36.61	19.32	0.48
Dang Linchi	36.19	33.38	13.98	Presented separately. See table 5.15			
Dang Dok Kamut	61.44	32.93	17.07	61.51	32.81	16.66	0.25
Dang Dok Bua Dang	61.44	32.93	17.07	61.51	32.81	16.66	0.25
Hong Din	40.58	28.03	18.54	40.81	29.05	19.57	0.63
Hong Din Klang	41.03	20.00	12.85	41.20	20.66	13.45	0.47
Hong Din On	80.34	15.70	11.99	80.75	15.12	12.46	0.70
Hong Din Kae	31.58	11.32	6.29	31.80	12.01	6.74	0.63
Hong Din Tut	41.30	10.54	6.51	42.39	45.38	31.83	0.30
Thong Dang	41.06	25.04	21.17	41.37	24.08	22.20	1.09
Thong Dang Kae	41.15	18.91	15.03	41.46	19.24	16.12	0.72
Thong Dang Mon	51.16	16.61	15.11	51.29	16.67	15.66	0.38
Din Tut	31.36	5.98	4.17	31.25	6.78	4.52	0.86
Khao Pun	90.77	3.20	4.43	91.10	2.79	4.66	0.63
Khao Mo	82.69	0.95	1.52	Presented separately. See table 5.15			
Chompu	71.18	42.94	16.11	CAN NOT BE FORMULATED			
Chompu Klang	71.23	24.72	9.19	71.42	24.50	9.50	0.31

Table 5.4 List of Thai style color names in YR category, CIELAB values according to Thai color dictionary and predicted data (using the stored database and formulation software; X-Rite SP62, illuminant/observers D65/2, SPEX).

Color Name	Dictionary			Database Prediction			
	L*	a*	b*	L	a*	b*	ΔE_{00}
Lueang Champa	81.56	14.29	63.33	81.22	14.05	62.39	0.43
Samrit	41.26	0.98	8.65	42.02	0.68	7.88	0.98
Sen	57.11	55.8	51.37	Presented separately. See table 5.15			
Sen Kae	59.69	44.04	39.15	Presented separately. See table 5.15			
Sen On	67.87	40.26	35.32	Presented separately. See table 5.15			
Hong Sen	76.75	28.11	26.05	Presented separately. See table 5.15			
Hong Sen On	81.45	20.79	21.25	Presented separately. See table 5.15			
Fa Lap	90.97	5.67	7.43	89.90	5.16	6.88	0.91
Nam-tan	61.49	9.51	22.37	61.64	9.32	23.1	0.49
Nam Rak	25.67	2.69	4.70	25.15	1.89	5.28	1.32
Din On	55.72	14.59	9.07	Presented separately. See table 5.15			
Khao Kabang	80.35	1.71	13.17	80.4	1.95	12.9	0.39
Lueang Nang Kho	82.95	1.12	36.50	Presented separately. See table 5.15			
Kho Lueang Tong	71.76	10.85	32.33	Presented separately. See table 5.15			
Lueang Thong-urai	81.56	14.29	63.33	81.22	14.05	62.4	0.34
Din Lueang	71.47	12.75	51.54	71.78	12.43	51.78	0.34
It	61.36	27.30	35.01	61.92	26.78	36.30	1.00
It Kae	51.52	26.93	36.09	52.18	27.74	36.46	0.76
It On	80.92	20.36	26.88	80.86	19.74	27.29	0.57
Mo Mai	67.8	32.13	44.24	Presented separately. See table 5.15			
Sanim Thongdang	40.89	6.77	10.64	41.4	7.11	11	0.61
Mak Suk	68.23	37.41	52.25	Presented separately. See table 5.15			
Hong Sabat	71.11	38.72	55.66	70.82	36.62	52.86	0.61
Sat	59.85	52.44	49.98	Presented separately. See table 5.15			
Kaki	71.76	10.85	32.33	Presented separately. See table 5.15			
Noppakao	60.53	7.10	8.26	Presented separately. See table 5.15			
Din Dang	45.46	27.84	16.11	Presented separately. See table 5.15			
Din Dang Kae	31.37	19.67	11.27	Presented separately. See table 5.15			
Din Dang Thet	50.22	41.3	23.30	Presented separately. See table 5.15			
Dang Dok Seng	61.39	39.47	53.78	61.95	39.05	54.52	0.68
Nam Mak	38.4	35.27	23.24	Presented separately. See table 5.15			

Table 5.5 List of Thai style color names in Y category, CIELAB values according to Thai color dictionary and predicted data (using the stored database and formulation software; X-Rite SP62, illuminant/observers D65/2, SPEX).

color name	Dictionary			Prediction			
	L*	a*	b*	L	a*	b*	ΔE_{00}
Lueang Thong	81.93	7.29	81.46	82.08	7.76	78.35	0.81
Lueang Nuan Chan	85.81	3.81	54.66	85.17	4.02	52.58	0.77
Lueang Manao	85.65	-14.75	72.91	85.64	-13.37	70.82	0.75
Lueang Rong	80.68	-1.93	70.59	80.71	-1.50	69.87	0.30
Nga Chang	90.25	-1.67	17.12	90.73	-1.59	15.89	0.73
Nuan Thae	91.16	-0.02	16.82	90.82	-0.2	16.30	0.43
Nuan	90.25	-1.67	17.12	90.73	-1.59	15.89	0.73
Lueang Sot	85.89	-2.2	67.73	85.76	-2.00	69.39	0.41
Lueang On	86.13	-2.32	56.13	86.08	-1.41	55.92	0.79
Mek Sonthaya	80.43	11.49	51.97	81.18	-11.5	57.40	0.27
Khao Kralok	85.75	-4.48	16.92	85.92	-4.11	16.77	0.4
Khao Nga Khao	91.29	-4.17	18.66	91.4	-3.57	18.37	0.62
Khao Nuan	90.71	-1.27	9.22	90.89	-1.12	8.97	0.28
Sang	93.7	-1.31	6.18	Presented separately. See table 5.15			
Lueam Lueang	81.22	4.58	54.19	81.21	4.45	53.99	0.10
Lueam Prapasson	81	8.24	44.9	Presented separately. See table 5.15			
Lueang Horadan	86.13	-2.32	56.13	86.08	-1.41	55.92	0.79
Lueang Luk Chan	85.81	3.81	54.66	85.18	4.14	52.88	0.67

"Lueang Rong," "Lueang Manao," "Lueang Sot," and "Lueam Lueang" were made and their information were shown in Table 5.14.

GY Category

Table 5.6 showed **GY category** information. Two colors were shown in this table. Predicted ΔE_{00} of "Khiao Luk Samo" and "Khiao Karn Tong" were the same, 0.46. These 2 colors were made and their compositions and color data were presented in the Table 5.14.

Table 5.6 of Thai style color names in GY category, CIELAB values according to Thai color dictionary and predicted data (using the stored database and formulation software; X-Rite SP62, illuminant/observers D65/2, SPEX).

Sample	Dictionary			Prediction			
	L*	a*	b*	L	a*	b*	ΔE_{00}
Khiao Farang	78.74	-21.86	44.74	Presented separately. See table 5.15			
Khiao Tong On	70.73	-17.63	34.22	Presented separately. See table 5.15			
Khiao Kan Mali	89	-16.36	31.58	Presented separately. See table 5.15			
Khiao Luk Samo	71.81	-11.38	28.79	71.94	-12.09	29.20	0.46
Khiao Karn Tong	60.82	-14.92	26.55	61.07	-13.93	25.69	0.46
Khiao Bai Mai	60.28	-23.48	24.23	Presented separately. See table 5.15			
Khiao Nuan	79.93	-21.61	17.47	Presented separately. See table 5.15			
Khiao Tang Sea	76.98	-30.46	16.96	Presented separately. See table 5.15			
Bai Tong Kae	50.94	-12.76	12.26	Presented separately. See table 5.15			
Khiao Pun Dam	39.32	-4.78	8.06	Presented separately. See table 5.15			
Dam Nin	31.24	-0.16	3.05	Presented separately. See table 5.15			
Dam Muad	29.82	-1.27	1.84	Presented separately. See table 5.15			

G Category

Table 5.7 showed the data of G category. Predicted ΔE_{00} of 10 out of eleven colors were less than 1. Only Khiao Sot that its predicted ΔE_{00} was 2.94.

"Nam Lai" "Khiao Om Dum" and "Khiao" were taken to make trial sample. Their information were shown in the Table 5.14. It can be seen that the colors were good matching as ΔE_{00} obtained were 1.99, 2.19 and 2.37, respectively.

Table 5.7 List of Thai style color names in G category, CIELAB values according to Thai color dictionary and predicted data (using the stored database and formulation software; X-Rite SP62, illuminant/observers D65/2, SPEX).

Sample	Dictionary			Prediction			
	L*	a*	b*	L	a*	b*	ΔE_{00}
Khiao Sot	51.79	-54.34	24.44	52.75	-46.04	24.76	2.94
Khiao	51.24	-41.78	18.47	51.58	-41.61	19.12	0.48
Khiao Klang	51.56	-30.93	15.31	51.63	-31.72	16.18	0.50
Khiao Thae	38.39	-30.26	12.85	39.07	-30.40	14.11	0.92
Khiao Kae	31.17	-18.60	8.01	30.98	-20.24	8.74	1.02
Khiao Bai Kae	51.37	-20.41	9.59	52.01	-20.92	9.83	0.70
Khiao Kampu	51.37	-20.41	9.59	52.01	-20.92	9.83	0.70
Khiao Mo	51.32	-17.25	19.96	51.55	-17.22	19.41	0.38
Khiao Om Dam	41.29	-10.27	5.70	42.24	-10.52	5.47	0.90
Nam Lai	71.42	-23.64	11.58	71.88	-24.42	12.13	0.57
Khiao Hin	80.58	-12.93	2.70	81.01	-12.87	2.50	0.33

BG Category

Table 5.8 contained BG category which had only 5 colors, "Nam Talay" was presented separately in the table 5.15. Predicted ΔE_{00} of "Khiao Khram" "Khiao Khram Kae," "Khiao Khap" and "Mo Mued" were well achieved 0.51, 0.99, 0.6 and 1.08 respectively.

"Khiao Khap" was selected to make the sample. As it can be seen in the Table 5.14 that the ΔE_{00} of this color was very small at 1.86.

Table 5.8 List of Thai style color names in BG category, CIELAB values according to Thai color dictionary and predicted data (using the stored database and formulation software, X-Rite SP62, illuminant/observers D65/2, SPEX).

Sample	Dictionary			Prediction			
	L*	a*	b*	L	a*	b*	ΔE_{00}
Khiao Khram	51.34	-29.52	-5.52	51.00	-30.20	-4.87	0.51
Khiao Khram Kae	40.69	-10.85	-9.5	41.57	-11.30	-0.92	0.99
Khiao Khap	41.48	-17.61	-9.5	41.78	-18.55	-9.23	0.6
Nam Talay	38.34	-7.65	-10.3	Presented separately. See table 5.15			
Mo Mued	41.79	-5.06	-2.61	40.09	-5.15	-1.91	1.08

B Category

Table 5.9 showed B category information. 4 of 6 out of color were well matched with predicted ΔE_{00} <1. ΔE_{00} of "Khram Khap," "Khap" "Khrom Tha," and "Mok" were 1, 0.68, 0.62, and 0.89 respectively. While predicted ΔE_{00} of "Takua tut," and "Fa" were unable to formulate at ΔE_{00} less than 1. They were 1.63 and 3.08 respectively.

Predicted formulation of "Khram Khap," and "Khrom Tha" were taken to make real paste sample, their component and color data were presented in the Table 5.14. Results insisted that the stored database was well able to formulate the Traditional Thai style color in this category.

Table 5.9 List of Thai style color names in B category, CIELAB values according to Thai color dictionary and predicted data (using the stored database and formulation software; X-Rite SP62, illuminant/observers D65/2, SPEX).

Sample	Dictionary			Prediction			
	L*	a*	b*	L	a*	b*	ΔE_{00}
Fa	71.19	-19.62	-26.94	68.09	-20.47	-23.26	3.08
Mo Khram	49.85	-8.12	-17.59	Presented separately. See table 5.15			
Mo Khram Klang	58.18	-7.24	-17.99	Presented separately. See table 5.15			
Mo Khram Kae	31.69	-6.06	-17.04	Presented separately. See table 5.15			
Mo Khram On	80.99	-11.22	-15.3	Presented separately. See table 5.15			
Khram Khap	31.91	-9.66	-16.75	31.68	-10.8	-16.36	1.00
Khap	40.95	-12.76	-14.13	41.5	-13.2	-12.73	0.68
Mek	87.03	-6.47	-7.42	Presented separately. See table 5.15			
Khrom Tha	30.95	-6.33	-6.68	31.25	-4.84	-6.88	0.62
Takua tut	61.57	-2.41	-4.11	61.46	-1.71	-2.47	1.63
Mok	81.08	-2.92	-2.44	81.3	-3.19	-1.59	0.89

PB Category

PB category information was presented in the Table 5.10. “Khram,” “Muang Dok Unchan” “Dok Pak Top” “Muang Khram” and “Muang Khram On” were shown separately in the Table 5.15.

Six colors out of eight colors were well predicted. They showed predicted ΔE_{00} < 1. Only “Mek Khram,” and “Dam Kho Ka” that predicted ΔE_{00} were 1.55 and 2.33, respectively. We selected “Nam Ngern” predicted formula to make real sample, and it was shown that the ΔE_{00} of the sample was very small as 1.01.

Table 5.10 List of Thai style color names in PB category, CIELAB values according to Thai color dictionary and predicted data (using the stored database and formulation software; X-Rite SP62, illuminant/observers D65/2, SPEX).

Sample	Dictionary			Prediction			
	L*	a*	b*	L	a*	b*	ΔE_{00}
Khram	33.67	7.39	-36.13	Presented separately. See table 5.15			
Nam Ngern	31.61	4.04	-35.69	31.96	2.38	-33.55	0.40
Nam Ngern On	50.91	0.96	-32.59	50.66	0.56	-31.44	0.14
Nam-Ngern Kae	30.68	1.54	-18.54	30.43	0.67	-16.51	0.76
Mek Khram	71.17	-0.81	-30.62	69.62	-3.70	-25.76	1.55
Muang Dok Aunchan	42.45	10.84	-29.72	Presented separately. See table 5.15			
Mo Mek	71.49	-3.08	-14.91	71.74	-5.55	-11.75	0.29
Dok Paktop	62.98	6.35	-12.33	Presented separately. See table 5.15			
Thao mek	71.49	-3.08	-14.91	71.88	-3.60	-13.82	0.95
Kwan Buri	80.8	-0.73	-5.86	80.88	-1.01	-4.87	0.91
Dam Kho Ka	25.3	-0.24	-4.86	24.74	-0.44	-5.75	2.33
Muang Khram	41.23	18.26	-24.92	Presented separately. See table 5.15			
Muang Khram On	47.95	12.4	-20.18	Presented separately. See table 5.15			

P Category

P category was presented in the Table 5.11. This category included 4 colors, Dok Tabaek and Luk Wa were well predicted with ΔE_{00} 0.26 and 0.6 respectively. These two colors were made and their compositions and color data were presented in the Table 5.14. Results expressed that the stored database well supposed these colors' formulation.

"Pleaug Munkut," and "Muang Med Maprang" were shown separately in the Table 5.15.

Table 5.11 List of Thai style color names in P category, CIELAB values according to Thai color dictionary and predicted data (using the stored database and formulation software; X-Rite SP62, illuminant/observers D65/2, SPEX).

Sample	Dictionary			Prediction			
	L*	a*	b*	L	a*	b*	ΔE_{00}
Dok Tabeak	61.08	26.78	-16.64	61.22	26.94	-17.08	0.26
Luk Wa	41.02	21.23	-15.47	40.88	22.31	-15.6	0.6
Pleag Mankut	38.88	19.18	-9.16	Presented separately. See table 5.15			
Mueang Med Maprang	48.32	46.87	-8.21	Presented separately. See table 5.15			

RP Category

RP category was shown in the Table 5.12, "Muang Chad", "Muang Chad Klang" "Muang Chad On", "Muang Chad Kae" and "Banyen" were well predicted with ΔE_{00} < 1. "Muang Chad," and "Dok Maiyarap" formulation were taken to make real pastel sample. Their composition and color data were presented in the Table 5.14. Both "Muang Chad" and "Dok Maiyarap" were well matched with ΔE_{00} 2.04 and 2.09 respectively.

Table 5.12 List of Thai style color names in RP category, CIELAB values according to Thai color dictionary and predicted data (using the stored database and formulation software; X-Rite SP62, illuminant/observers D65/2, SPEX).

Sample	Dictionary			Prediction			
	L*	a*	b*	L	a*	b*	ΔE_{00}
Muang Chad	40.58	45.87	0.7	40.73	46.24	0.65	0.18
Muang Chad Klang	50.6	36.04	2.57	50.61	36.97	2.03	0.49
Muang Chad On	61.35	33.51	2.69	61.45	33.33	3.35	0.42
Muang Chad Kae	40.32	28.38	1.65	40.33	26.55	0.25	0.87
Banyen	50.96	43.32	-3.75	51.09	43.59	-3.47	0.22
Dok Maiyarap	60.11	31.21	-8.02	60.31	31.29	-7.95	0.18
Bua Roi	56.74	22.61	-1.09	Presented separately. See table 5.15			

Neutral Category

Table 5.13 showed information of Neutral category. 10 colors were categorized in this category. 7 colors out of 10 were properly formulated with ΔE_{00} almost at 1 and less < 1. "Khao Phong" "Hong" and "Khao Fun" which were all white shade color were not able to formulate with low predicted ΔE_{00}.

"Kamao," and "Nok Phirap" were selected to make the pastel sample, Table 5.14 showed component and color data of these two colors. Color tolerance of Kamao is 2.04, and 3.01 for Nok Phirap.

Table 5.13 List of Thai style color names in Neutral category, CIELAB values according to Thai color dictionary and predicted data (using the stored database and formulation software; X-Rite SP62, illuminant/observers D65/2, SPEX).

Sample	Dictionary			Prediction			
	L*	a*	b*	L	a*	b*	ΔE_{00}
Kamao	25.10	0.74	-1.24	24.24	0.66	-2.23	1.13
Dam Muek	25.10	0.74	-1.24	24.24	0.66	-2.23	1.13
Din Mo	28.48	0.29	-0.99	27.60	-0.01	-1.00	0.80
Mo Muek Kae	35.94	-1.46	0.36	35.67	-1.41	-0.16	0.56
Nok Phirap	57.04	-0.37	-0.77	57.21	-0.25	-0.58	0.30
Mo Muek	64.23	-1.16	-0.32	64.41	-1.08	-0.23	0.21
Mo Muek On	80.91	-0.79	-0.31	81.38	-0.54	-0.55	0.54
Khao Phong	96.28	-0.65	1.74	92.71	-0.43	3.08	2.49
Hong	96.28	-0.65	1.74	92.71	-0.43	3.08	2.49
Khao Fun	96.28	-0.65	1.74	92.71	-0.43	3.08	2.49

Table 5.14 showed traditional Thai style color pastel formulations, CIELAB values of predicted and trial samples. We selected representative samples from each category in Table 5.3 to 5.13 to make stick pastels. Color values of each sample was evaluated and ΔE_{00} was compared with the CIELAB values in the dictionary.

Table 5.14 List of Thai style color pastel samples, their given formulation, predicted and trial CIELAB / ΔE_{00} data (X-Rite SP62, illuminant/observers D65/2, SPEX).

Color name		CIELAB values		Visual Perception	suggested formulation	
		Predicted	Trialed		Colorant Name	%
Dang Sen	L*	51.19	54.56		Orange	3.23
	a*	52.59	52.26		Red D3G70	4.68
	b*	27.4	27.43		Violet RLS-EF	0.11
	ΔE_{00}	0.35	3.06		Vehicle	91.98
Hong Din	L*	40.81	40.55		Brown HFR 01	13.47
	a*	29.05	31.2		PinkEM250	0.13
	b*	19.57	18.71		Vehicle	86.39
	ΔE_{00}	0.63	1.55			
Din Tut	L*	31.25	31.47		Blue BX	2.502
	a*	6.78	4.69		Brown HFR 01	9.677
	b*	4.52	3.46		Carbon Black	2.666
	ΔE_{00}	0.85	1.47		Vehicle	85.16
Dang Tub Tim	L*	41.81	42.88		Pink EM250	16.76
	a*	46.14	47.31		Violet RLS-EF	0.085
	b*	13.04	10.94		Yellow F2G	4.627
	ΔE_{00}	0.72	2.28		Vehicle	78.53
Kulap	L*	41.15	41.08		Pink EM250	14.1
	a*	54.97	53.79		Red D3G70	5.187
	b*	16.28	13.26		Yellow Oxide	0.148
	ΔE_{00}	0.35	1.31		Vehicle	79.24

Table 5.14 (Continued)

Color name	CIELAB values			Visual Perception	suggested formulation	
		Predicted	Trialed		Colorant Name	%
Din Lueang	L*	71.78	70.73		Brown HFR 01	2.11
	a*	12.43	14.66		Permanent Yellow DHG	2.44
	b*	51.78	47.89		Vehicle	95.44
	ΔE_{00}	0.34	2.69			
Nam-Tan	L*	61.64	63.39		Chrome Green	7.72
	a*	9.32	7.2		Pink EM250	0.85
	b*	23.06	20.8		Yellow M2R 70	1.5
	ΔE_{00}	0.49	2.54		Vehicle	89.93
It	L*	62.01	63.71		Chrome Green	5.128
	a*	26.13	24.66		Orange	2.148
	b*	35.63	39.3		Vehicle	92.72
	ΔE_{00}	1.07	2.81			
Sanim Thong Dang	L*	41.42	44.39		Brown HFR 01	7.174
	a*	7.11	6.51		Green GNX	5.965
	b*	11.02	9.12		Vehicle	86.86
	ΔE_{00}	0.6	3.04			
Hog Sabat	L*	70.81	72.54		Orange	3.38
	a*	36.6	43.95		Yellow M2R	2.515
	b*	52.86	58.78		Vehicle	94.11
	ΔE_{00}	0.91	2.98			
Nam Rak	L*	25.15	27.71		Carbon Black	8.10%
	a*	1.89	1.72		Orange	2.212
	b*	5.28	3.53		Vehicle	89.69
	ΔE_{00}	1.31	2.15			

Table 5.14 (Continued)

Color name		CIELAB values		Visual Perception	suggested formulation	
		Predicted	Trialed		Colorant Name	%
Lueang Rong	L*	80.71	82.68		Red D3G70	0.09
	a*	-1.5	2.38		Yellow F2G	7.14
	b*	69.87	72.75		Vehicle	92.77
	ΔE_{00}	0.3	3.01			
Lueang Manao	L*	85.64	86.47		Violet RLS-EF	0.022
	a*	-13.37	-11.06		Yellow F2G	5.417
	b*	70.82	68.27		Vehicle	94.56
	ΔE_{00}	0.75	2.07			
Lueang Sot	L*	85.89	82.27		Yellow M2R 70	0.597
	a*	-0.83	-3.37		Yellow Oxide	21.55
	b*	67.21	65.43		Vehicle	77.85
	ΔE_{00}	0.84	2.58			
Lueam Lueang	L*	81.21	83.09		Orange	0.34
	a*	4.45	7.95		Yellow F2G	2.33
	b*	53.99	53.48		Vehicle	97.33
	ΔE_{00}	0.09	2.64			
Khiao Karn Tong	L*	61.07	58.11		Carbon Black	0.29
	a*	-13.93	-15.3		Green GNX	3.36
	b*	25.69	25.7		Yellow M2R 70	2.08
	ΔE_{00}	0.67	2.47		Vehicle	94.26
Khiao Luk Samo	L*	71.94	74.17		Carbon Black	0.26
	a*	-12.09	-9.2		Yellow Oxide	6.58
	b*	29.2	30.19		Vehicle	93.17
	ΔE_{00}	0.47	2.56			

Table 5.14 (Continued)

Color name		CIELAB values		Visual Perception	suggested formulation	
		Predicted	Trialed		Colorant Name	%
Nam Lai	L*	71.88	71.46		Brown HFR 01	0.26
	a*	-24.42	-20.25		Green GNX	2.5
	b*	12.13	9.51		Yellow Oxide	2.72
	ΔE_{00}	0.57	1.99		Vehicle	94.52
Khiao Om Dum	L*	42.24	41.78		Brown HFR 01	4.267
	a*	-10.52	-12.43		Green GNX	19.72
	b*	5.47	4.56		Vehicle	76.01
	ΔE_{00}	0.9	2.19			
Khiao	L*	51.58	53.1		Green GNX	19.29
	a*	-41.6	-43.2		Yellow M2R70	0.589
	b*	19.12	21.78		Yellow Oxide	27.93
	ΔE_{00}	0.48	2.37		Vehicle	52.19
Khiao Khap	L*	41.78	42.98		Blue BX	8.14
	a*	-18.55	-18.38		Yellow M2R 70	1.74
	b*	-9.23	-11.47		Vehicle	90.12
	ΔE_{00}	0.74	1.86			
Khram Khap	L*	31.68	29.02		Blue BX	14.41
	a*	-10.81	-9.81		Green GNX	25.48
	b*	-16.36	-14.02		Pink EM250	5.306
	ΔE_{00}	1.00	2.78		Vehicle	54.8
Khrom Tha	L*	31.38	30.46		Green GNX	27.43
	a*	-7	-6.01		PinkEM250	3.84
	b*	-6.58	-7.45		Red D3G70	3.37
	ΔE_{00}	0.85	0.82		Vehicle	65.35

Table 5.14 (Continued)

Color name	CIELAB values			Visual Perception	suggested formulation	
		Predicted	Trialed		Colorant Name	%
Ngam Ngern	L*	31.9	31.17		Blue BX	27.73
	a*	1.6	1.65		Green GNX	2.032
	b*	-33.55	-32.36		Violet RLS-RF	2.046
	ΔE_{00}	0.7	1.01		Vehicle	67.19
Dok Tabaek	L*	61.22	61.05		PinkEM250	1.13
	a*	26.94	30.4		Red D3G70	0.2
	b*	-17.08	-16.12		Violet RLS-EF	0.44
	ΔE_{00}	0.26	1.81		Vehicle	98.23
Luk Wa	L*	40.88	41.31		Blue BX	1.98
	a*	22.31	19.74		Orange	1.32
	b*	-15.6	-13.47		PinkEM250	7.04
	ΔE_{00}	0.59	1.26		Vehicle	89.66
Muang Chad	L*	40.73	42.78		Green GNX	0.453
	a*	46.24	46.95		Pink EM250	17.21
	b*	0.65	0.12		Yellow M2R 70	1.38
	ΔE_{00}	0.18	2.04		Vehicle	80.96
Dok Maiyarap	L*	60.31	60.09		Carbon Black	0.17
	a*	31.29	32.96		Orange	0.25
	b*	-7.95	-4.76		PinkEM250	2.08
	ΔE_{00}	0.18	2.09		Vehicle	97.5
Kamao	L*	24.24	26.72		Blue BX	59.38
	a*	0.66	0.31		Brown HFR 01	13.71
	b*	-2.23	-1.24		Carbon Black	0.39
	ΔE_{00}	1.13	2.04		Vehicle	26.52
Nok Phirap	L*	57.21	54.4		Green GNX	2.12
	a*	-0.25	-1.16		Red D3G70	0.86
	b*	-0.58	0.55		Vehicle	97.01
	ΔE_{00}	0.29	3.01		Green GNX	2.12

Formulations for Thai color names that were matched with NCS color system

Forty-seven colors matching with NCS were formulated and the results were shown in Table 5.15.

Table 5.15 List of traditional Thai color names that their CIELAB data in the color dictionary were matched with NCS color system, CIELAB values according to Thai color dictionary and predicted color data. (X-Rite SP62, illuminant/observers D65/2, SPEX).

Category	Sample	NCS	Standard			Prediction*			
			L*	a*	b*	L	a*	b*	DE_{00}
R	Dang Chad	S1070-R	52.17	53.03	21.45	53.73	51.4	20.12	1.66
	Dang Dok Chaba	S1070-R	52.2	53.03	21.45	52.81	49.75	19.69	1.25
	Dang Linchi	S4050-R	36.19	33.38	13.98	38.42	30.48	11.63	2.45
	Khao Mo	S1502-R	82.7	0.95	1.52	83.3	0.92	2.31	0.84
YR	Sen	S0585-Y20R	57.11	55.8	51.37	58.1	54.36	50.9	1.02
	Sen Kae	S1070-Y70R	59.69	44.04	39.15	60.8	41.66	37.19	1.3
	Sen On	S0560-Y70R	67.87	40.26	35.32	69.08	38.37	34.27	1.24
	Hong Sen	S0540-Y70R	76.75	28.11	26.05	77.46	26.66	26.76	1.22
	Hong Sen On	S0530-Y70R	81.45	20.79	21.25	81.29	19.55	22.13	1.19
	Din On	S4020-Y90R	55.72	14.59	9.07	56.2	13.74	8.78	0.77
	Lueang Nang Kho	S1030-Y10R	82.95	1.12	36.5	84.08	0.8	36.04	0.81
	Lueang Tong Tak	S2030-Y30R	71.76	10.85	32.33	73.03	10.9	32.32	0.96
	Mo Mai	S1060-Y50R	67.8	32.13	44.24	68.45	30.92	43.94	0.79
	Mak Suk	S5070-Y50R	68.23	37.41	52.25	69.18	36.33	50.78	0.88
	Sat	S0580-Y70R	59.85	52.44	49.98	61.29	50.18	45.27	2.04
	Kaki	S2030-Y30R	71.76	10.85	32.33	73.08	10.9	32.38	0.99
	Noppakao	S4010-Y70R	60.53	7.1	8.26	60.77	6.26	9.03	1.27
	Din Dang	S4040-Y90R	45.46	27.84	16.11	56.47	17.9	6.23	13.09
	Din Dang Kae	S6030-Y90R	31.37	19.67	11.27	34.94	19.15	11.89	2.94
	Din Dang Thet	S2060-Y90R	50.22	41.3	23.3	52.12	40.03	22.55	1.95
	Nam Mak	S3560-Y80R	38.4	35.27	23.24	40.14	33.18	21.93	1.75
Y	Sang	S0502-Y	93.7	-1.31	6.18	92.48	-1.58	6.92	0.98
	Lueam Prapasson	S1040-Y20R	81	8.24	44.9	80.99	8.29	44.05	0.31

Table 5.15 (Continued)

Category	Sample	NCS	Standard			Prediction*			
			L*	a*	b*	L	a*	b*	ΔE₀₀
GY	Khiao Farang	S1050-G50Y	78.74	-21.9	44.74	79.24	-20.8	44.2	0.6
	Khiao Tong On	S2040-G50Y	70.73	-17.6	34.22	71.61	-16.8	34.1	0.81
	Khiao Kan Mali	S0530-G50Y	89	-16.4	31.58	89.43	-14.8	30.5	0.93
	Khiao Bai Mai	S3040-G30Y	60.28	-23.5	24.23	61.41	-22.5	24.4	1.12
	Khiao Nuan	S1030-G20Y	79.93	-21.6	17.47	80.47	-19.6	20.8	2.46
	Khiao Tang Sea	S1040-G10Y	76.98	-30.5	16.96	77.66	-28.7	16.4	0.89
	Bai Tong Kae	S5020-G30Y	50.94	-12.8	12.26	50.83	-12.9	12.5	0.02
	Khiao Pun Dam	S7010-G50Y	39.32	-4.78	8.06	41.54	-4.65	7.13	2.08
	Dam Nin	S8005-G80Y	31.24	-0.16	3.05	34.42	-2.11	5.45	4.12
	Dam Muad	S8005-G50Y	29.82	-1.27	1.84	34.65	-3.56	4.56	5.26
BG	Nam Talay	S6020-B10G	38.34	-7.65	-10.3	41.82	-7.16	-8.58	3.25
B	Mo Khram	S4030-B	49.85	-8.12	-17.6	51.64	-7.93	-16.5	1.88
	Mo Khram Klang	S3030-B	58.18	-7.24	-18	59.33	-7.87	-17.3	1.26
	Mo Khram Kae	S6030-B	31.69	-6.06	-17	35.28	-6.32	-16	2.98
	Mo Khram On	S0530-B	80.99	-11.2	-15.3	81.82	-11.5	-13.3	1.41
	Mek	S0515-B	87.03	-6.47	-7.42		NA		
PB	Khram	S4050-R80B	33.67	7.39	-36.1	37.27	5.67	-33.3	3.06
	Muang Dok Aunchan	S4040-R70B	42.45	10.84	-29.7	44.65	9.74	-27.9	2.16
	Dok Paktop	S3020- R60B	62.98	6.35	-12.3	64.21	6.7	-11.7	1.23
	Muang Khram	S4040-R60B	41.23	18.26	-24.9	43.42	17.09	-23.6	2.13
	Muang Khram On	S4030-R60B	47.95	12.4	-20.2	54.51	7.99	-0.37	14.57
P	Pleag Mankut	S5030- R40B	38.88	19.18	-9.16	38.68	20.55	-10.5	1.02
	Mueang Med Maprang	S2060-R30B	48.3	46.87	-8.21	50.55	46	-7.67	2.25
RP	Bua Roi	S3030- R20B	56.74	22.61	-1.09	58.01	21.31	-0.41	1.43

Table 5.16 showed traditional Thai style color pastel formulations, CIELAB values of predicted and trialed samples. We selected representative samples from each category in the Table 5.15 to make stick pastels. Color values of each sample was evaluated and ΔE_{00} was compared with the CIELAB values in the dictionary.

Table 5.16 List of Thai style color pastel sample, their given formulation, predicted and trial CIELAB / ΔE_{00} data (X-Rite SP62, illuminant/observers D65/2, SPEX).

Color name	CIELAB values			**Visual Perception**	**suggested formulation**	
		Predicted	Trial		**Colorant Name**	**%**
Dang Chad	L*	53.73	50.95		Red D3G70	4.3693
	a*	51.4	52.26		Violet RLS-EF	0.0647
	b*	20.12	21.26		Vehicle	95.566
	ΔE_{00}	1.66	1.23			
Dang Linchi	L*	38.42	36.34		Chrome Green	18.422
	a*	30.48	27.9		PinkEM250	13.005
	b*	11.63	11.15		Yellow M2R 70	6.0734
	ΔE_{00}	2.45	2.52		Vehicle	62.5
Hong Sen	L*	77.46	77.71		Orange	2.747
	a*	26.66	28.82		Red D3G70	0.2523
	b*	26.76	28.29		Yellow Oxide	1.7364
	ΔE_{00}	1.22	1.59		Vehicle	95.264
Mak Suk	L*	69.18	71.26		Orange	2.4711
	a*	36.33	34.54		Yellow F2G	1.6783
	b*	50.78	49.7		Vehicle	95.851
	ΔE_{00}	0.88	2.61			
NA						
Khiao Tang Sae	L*	77.66	74.19		Green GNX	1.735
	a*	-28.7	-31.47		Yellow F2G	0.3652
	b*	16.42	14.29		Yellow M2R 70	0.0177
	ΔE_{00}	0.89	2.62		Vehicle	97.882
NA						
NA						
Muang Dok Unchan	L*	44.65	41.12		Blue BX	
	a*	9.74	9.1		Pink EM250	4.231
	b*	-27.9	-30.5		Yellow Oxide	1.0538
	ΔE_{00}	2.16	2.03		Vehicle	90.985

Table 5.16 (Continued)

Color name		CIELAB values		Visual Perception	suggested formulation	
		Predicted	Trial		Colorant Name	%
Dok Paktop	L*	64.21	58.61		Green GNX	1.6428
	a*	6.7	5.85		Pink EM250	1.2416
	b*	-11.73	-13.5		Vehicle	97.116
	ΔE_{00}	1.23	3.96			
Pleag Mankut	L*	38.68	37.43		Brown HFR 01	3.0354
	a*	20.55	18.49		Violet RLS-EF	3.1533
	b*	-10.45	-7.89		Vehicle	93.811
	ΔE_{00}	1.02	1.49			
Bua Roi	L*	58.01	56.69		Carbon Black	0.5485
	a*	21.31	21.09		PinkEM250	1.0687
	b*	-0.41	-0.52		Red D3G70	0.6844
	ΔE_{00}	1.43	0.95		Vehicle	97.698

5.1.5 Artists' satisfaction and brush testing

Table 5.17 contained list of pastel color name, CIELAB data and ΔE_{00}* of 40 colors that were taken to artists for brush testing. ΔE_{00} of all colors < 3.

Table 5.17 List and color data of traditional Thai style color pastel that were taken to artists for the brush testing and artists satisfaction.

Categories	Color Name	L*	a*	b*	ΔE_{00}
R	Dang Chad	50.95	52.26	21.26	1.23
	Dang Sen	53.56	55.32	27.43	2.3
	Kulap	41.08	53.79	13.26	1.27
	Dang Luead Nok	39.68	54.43	19.02	2.24
	Dang Tubtim	42.88	47.31	10.94	2.16
	Dang Linchi	36.34	27.9	11.15	2.71
	Hong Din	40.55	31.2	18.71	1.69
	Din Tut	31.47	4.68	3.46	1.49
YR	Hong Sen	78.8	30.16	31.02	2.72
	Din Lueang	69.36	14.66	46.89	2.94
	Sanim Thongdang	43.39	6.51	9.12	2.51
	Mak Suk	71.26	34.54	49.7	2.61
	Hong Sabat	73.54	43.95	58.78	2.69
Y	Lueang Manao	86.47	-11.06	68.27	2.09
	Lueang Rong	82.11	2.38	72.75	2.81
	Lueang Sot	82.27	-3.37	65.43	2.59
	Lueam Lueang	83.09	7.95	53.48	2.85
GY	Khiao Luk Samo	71.17	-9.2	30.19	2.3
	Khiao Karn Tong	58.11	-15.29	24.7	2.63
	Khiao Tang Sae	74.19	-31.47	14.29	2.59
G	Khiao Bai Kae	53.6	-22.89	11.32	2.73
	Khiao Om Dam	41.78	-12.43	4.56	2.21
	Nam Lai	71.46	-20.25	9.51	2.13
BG	Khiao Khram	49.58	-31.18	-5.45	1.9
	Khiao Khap	42.98	-18.38	-11.47	1.86
B	Khram Khap	29.02	-9.81	-14.02	2.79
	Khap	40.24	-15.47	-15.36	1.98
	Khrom Tha	30.46	-6.01	-7.45	0.82
PB	Nam Ngern	31.17	1.65	-32.36	1.01
	Muang Dok Unchan	41.12	9.1	-30.51	2.03
	Dok Paktop	60.61	5.85	-13.51	2.33
P	Dok Tabeak	61.05	30.4	-16.12	1.82
	Luk Wa	41.31	19.74	-13.47	1.26
	Pleag Mankut	37.43	18.49	-7.89	1.49

Table 5.17 (Continued)

Categories	Color Name	L*	a*	b*	ΔE_{00}
RP	Muang Chad	42.78	46.95	0.12	2.04
	Banyen	48.71	45.36	-2.09	2.52
	Dok Maiyarap	60.09	32.96	-4.76	2.09
	Bua Roi	56.69	21.09	-0.52	0.92
Neutral	Kamao	26.72	0.31	-1.24	1.35
	Nok Phirap	55.4	-1.16	0.55	2.29

Figure 5.7 showed the art works painted by five artists. Colors used in each picture were listed as below:

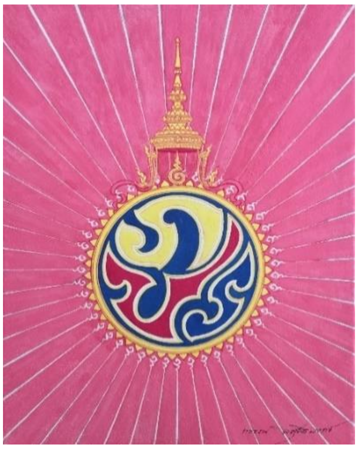
(a) “Nam-ngern”, “Lueang Sod”, “Dang Chad” and “Kulap”

(b) “Lueang Sod”, “Lueang Manao”, “Dang Chad”, “Dang Luead Nok”, “Dang Linchi” “Hong Sen”, “Hong Din” , “Dok Tabaek”, “Pleag Mungkut”, “Khiao Bai Kae”, “Khiao Tang Sae”, “Nam-ngern”, “Kamao” and “Sanim Thongdang”.

(c) “Hong Din”, “Dok Tabaek”, “Dang Linchi”, “Hong Sen”, “Khiao Tang Sae”, “Lueang Sod”, “Mak Suk”, “Nam-ngern”, “Lueang Manao”, “Kamao” and “Dang Chad”

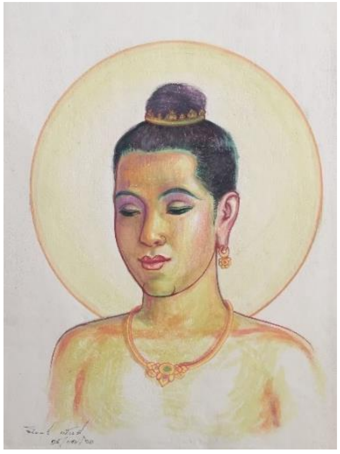
(d) “Lueang Sod”, “Lueang Manao”, “Hong Sen”, “Mark Suk”, “Dok Tabaek”, “Khiao Tang Sae”, “Dang Chad”, “Dang Linchi”, “Kamao” and “Hong Din”.

(e) “Lueang Sod”, “Lueang Manao”, “Dang Luead Nok”, “Dang Linchi”, “Dang Chad”, “Hong Sen”, “Dok Tabaek”, “Pleag Mungkut”, “Khiao Bai Kae”, “Khiao Tang Sae”, “Nam-ngern”, “Sanim Thong Dang”



(a)

(b)



(c)

(d)

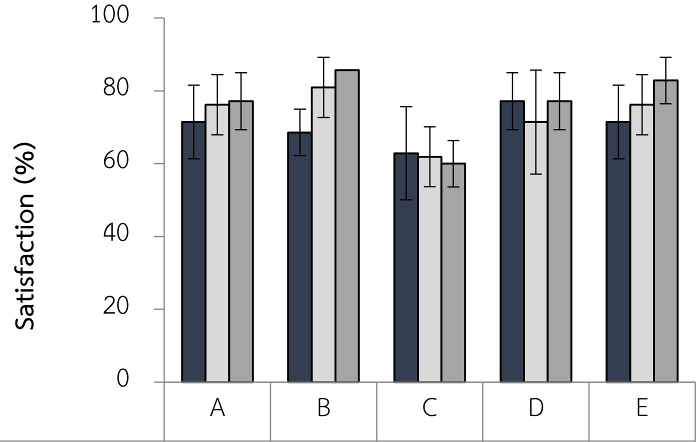
(e)

Figure 5.7 Five art works painted by five artists using the pastel samples. Name of artists were listed as follow; (a) Artist; Kan Pisutthibongkoch, (b) Artist; Pitaksin Sudsang, (c) painted Kamol Kinchagawat, (d) painted by Nipon Boababdee, and (e) painted by Winyapath Phayakkhawong

.

Artists' satisfaction on the traditional style color pastel samples were performed comparing with 1). The traditional tempera and 2). Rembrandt soft pastel. Results were shown in the Figure 5.8. We found that the artist satisfied on (A) tinting strength of color strength at 71.74% for the traditional tempera, 76.19% for Rembrandt soft pastel and 77.14% for our samples. Satisfaction on (B) fineness of pastel powder were 68.57%, 80.95% and 85.71% for the traditional tempera, Rembrandt soft pastel and our pastel samples respectively. Artists' satisfaction on (C) the hiding power were 62.86% for the traditional tempera, 61.90% for Rembrandt soft pastel and 60.00 % for our samples. One artist mentioned that for the watery style or tinting area, our samples were proper. But for solid area, more opacity was recommended. Artists satisfied on (D) color matching with Thai color name at 77.14% for both traditional tempera and our pastel samples, while it was 71.43 for Rembrandt soft pastel. Regarding the color matching with Thai color name, we did additional test and found that these artists knew traditional Thai style color only 20%. The result may not reflect their knowledge how colors were correct per the Thai color name. Even one senior artist who was mentioned as high experience was able to tell Thai color only 20%. Senior artist informed that artist's nowadays may not be well recognize Thai color due to they did not work on them routinely.

However, the result reveled that that artists found useful information from our research. Overall satisfaction given for our samples was 82.86% which meant very satisfied. It was higher than satisfaction scores given for traditional tempera and Rembrandt soft pastel. In addition, since we provided 40 colors for their testing while they picked 15 colors to test. This was reflected that more variation of color that correspondent to Thai color name was able to prepared.



	A	B	C	D	E
Traditional tempera	71.43	68.57	62.86	77.14	71.43
Rembrandt Soft Pastel	76.19	80.95	61.90	71.43	76.19
Pastel Sample	77.14	85.71	60.00	77.14	82.86

Figure 5.8 Artists satisfaction on pastels brush testing.

A. Tinting strength of color

B. Fineness of powder

C. Hiding power for solid painting

D. Color matching with Thai color name

E. Overall satisfaction

5.2 Acrylic Paint

5.2.1 Effect of mixture components on the responses

The mixture contour plots of the responses were depicted in the Figure 5.9 to present the influence of 3 components on viscosity, opacity and drying.

One prominent character of acrylic paint is “quick drying”. In this research, drying of each mixtures’ formulation were studied by mean of “set-to-touch time” method (ASTM D1640/D1640M-14 method A). Increasing of pigment ratio increased the drying time (take long time to dry), while the increasing of binder and filler decreased the drying time. Having this result assumed that increasing of pigment ratio also increased percentage of water due to this prep. Pigment Red 122, Quinacridone

Colanyl Pink E-WD 500 contained 47% of water and 53% of solid content which included 32% of pigment. Drying of the acrylic paint can be learned by the film formation process (Figure 5.10). The first stage is the evaporation of water, it happens until the particles start to interact and pack. The first stage of drying is usually within 10-20 minutes. An enormous rise in viscosity is occurred in this stage. After that in the second stage, the particles will deform and the remaining water will evaporate. In this stage capillary forces play an important role. A few percentage of water remains trapped in the film, and hardly any interface with air will be left. Viscosity is close to infinite depending on the composition of the acrylic binder. In the third stage, the boundaries between the individual acrylic particles will disappear and the polymer chain will entangle across the interface of the particles. In general, thin films can dry within 10-20 minutes while thick films may take from an hour up to several days (106). Artists preferred different levels of drying depended on types of their art works but fast drying is clear advantage when thick layers of paints are being applied (23). In this experiment we set up the required drying time as less as the mixtures could present as 0-5 minutes.

Considering the contour plot of viscosity, it can be seen that increasing of pigment and binder ratio decreased the viscosity of the paint, while increasing of filler ratio increased the viscosity. Among 3 components, only filler was dry powder while pigment consisted of water and an increasing of water decreased the viscosity. Viscosity of acrylic artist paints can be classified as soft body, heavy body and super heavy body. Soft body acrylic paint (medium viscosity of 500-4000 mPa.S) is suitable for painting on canvas or panel and mural ones. Heavy body or high viscosity acrylic paint has a thick consistency which is similar to oil paint. It is suitable for traditional art techniques using brushes or knives, while the super heavy body is excellent for "textural" and "sculptural" technique (106). The soft body ones was our aim in this research. However, the viscosity of all mixtures were between 300 – 740 mPa.S, we therefore set up the required viscosity 500 – 750 mPa.S, for contour plots overlapping. Viscosity was once again adjusted by adding the thickener in the optimized formulation process.

Opacity contour plot showed that at the very high proportion of pigment and binder, the opacity decreased. A combination of pigment, binder and filler can increase the opacity. Filler, aluminium silicate, majorly increased the opcity. Opacity is influenced by the difference of the refractive indices of the pigment and the medium, particle size and dispersion of the pigment, the proportion of pigment in the vehicle (i.e., pigment volume concentration or PVC) and the thickness of the applied film. It is a result of multiple scattering of incident light that have interaction with pigment particles (107). Aluminium silicate is a white cream particles with refractive index as 1.56-1.62 (61). Increasing of pigment and aluminium silicate particles therefore increased the opacity because the interaction with incident light increased thus the possibility of scattering and reflecting increased. The higher opacity, the better cover strength. The range of the opacity of our mixture was approximately between 60-75. We therefore set up the required opacity at 70 – 100% for overlapping contour.

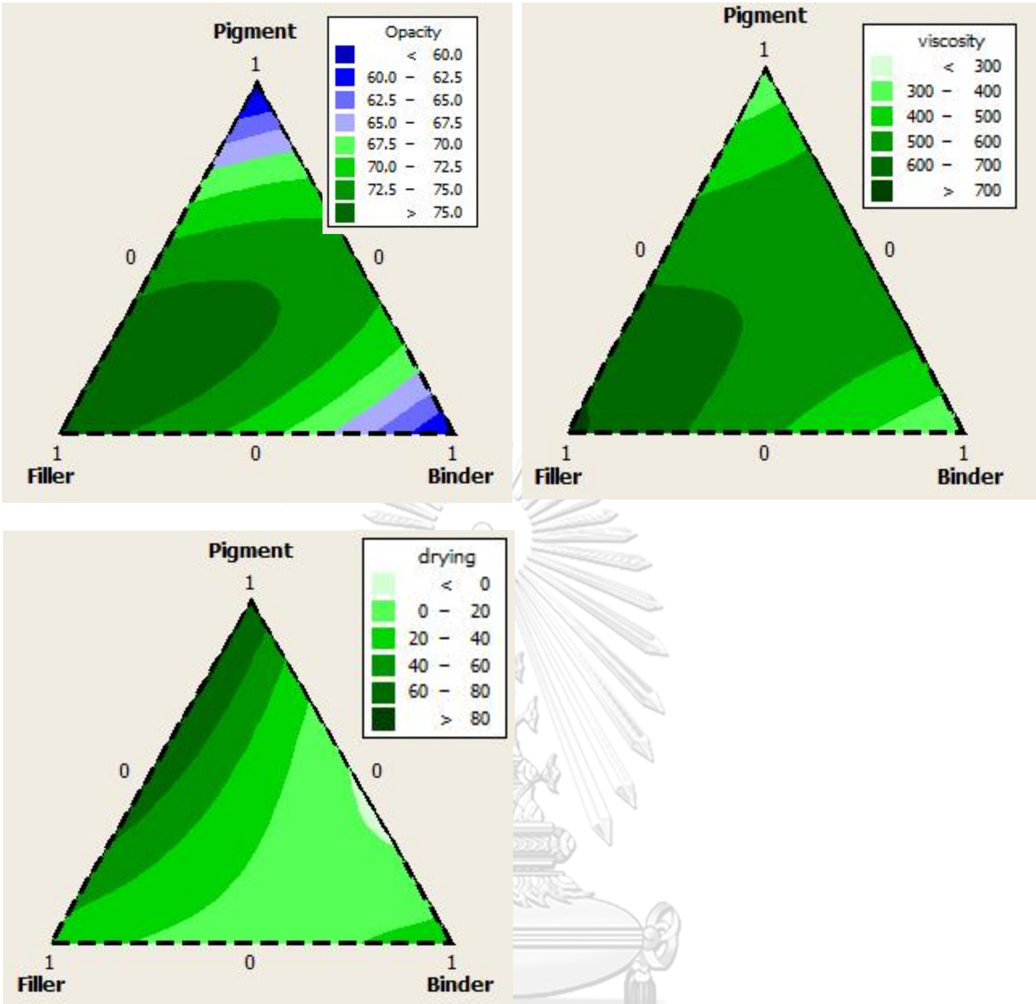
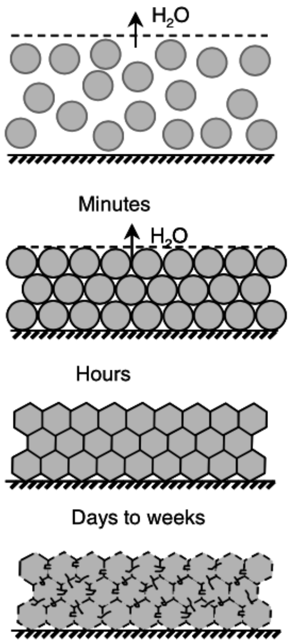


Figure 5.9 Contour plots of different combinations of pigment (Quinacridone Red), filler (Aluminium Silicate) and Binder (Styrene/acrylic co-polymer) on apparent opacity, viscosity and drying.



Acrylic dispersion in water

Stage 1; water evaporates particles get into close contact and start to pack

Stage 2; particles deform, and are packing

Stage 3; coalescence polymer chains entangle across particle boundaries

Figure 5.10 Film formation of water -borne acrylic dispersion

Formulations optimization

Acrylic paint with fast drying time, high opacity and proper viscosity was preferred. The selected optimum proportion was 0.381 part of pigment, 0.084 part of filler and 0.535 part of binder. The predicted responses for drying time, opacity and viscosity were 3.42 minutes, 73.56%, and 573.36 mPa.S respectively.

Weight ratio of each component was further optimized, additional additives that included anti-foaming agent, thickener, and emulsifier, solvent and anti-biocide were added. Optimized formulation of Pink E - PR122 Quinacridone was shown in the Table 5.18.

Table 5.18 suggested formulation

Component	%
Prep. Pigment	68
Binder	18
Filler	7
Deformer	2.5
Thickener	0.6
Emulsifier	1.6
Solvent	1.8
Anti-biocide in can	0.2
Anti-biocide on film	0.2

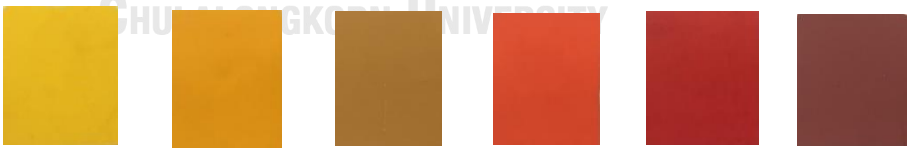
5.2.2 Primary color formulation

Table 5.19 showed CIELAB of the acrylic paint of all primary colors corresponding with pigments that were mentioned in Chapter 3. Figure 5.11 showed spectrum reflectance of all primary colors. These primary colors then were used for making calibration panels for color match prediction. The similar process as we did for pastel. From the reflectance spectrum of the primary we could see that green, blue and violet did not show peaks, we could predict that the color match prediction of green, blue-green and purple might not perform well. As we assumed, the results, of color match prediction of acrylic paint were not as good as the pastel. Except for black, all primaries of pastel show reflectance peak, whereas some primaries of acrylic did not. In this result section of acrylic paint, we then showed only the good match giving $\Delta E_{00} < 3$.

Table 5.19 Primary colors of acrylic paint, visual and quantitative observation (D65/2, SPEX, X-Rite SP62)

	Violet	Blue	Black	Green	Pink
L*	28.91	23.28	22.41	19.73	28.39
a*	3.8	16.31	0.12	2.69	27.03
b*	-0.06	-15.96	1.09	-7.26	9.66
C*	3.8	22.82	1.1	7.74	28.71
h°	359.16	315.62	83.56	290.37	19.66

	Yellow H3G	Yellow WF	Oxide Yellow	Orange	Red D3G	Oxide Red
L*	80.07	74.37	61.8	56.49	38.37	33.08
a*	5.66	17.8	12.79	54.38	55.07	19.64
b*	88.34	77.03	46.9	48.75	30.25	11.8
C*	88.52	79.06	48.62	73.03	62.84	22.91
h°	86.33	76.99	74.75	41.88	28.78	31.01



5.2.3 Database and calibration

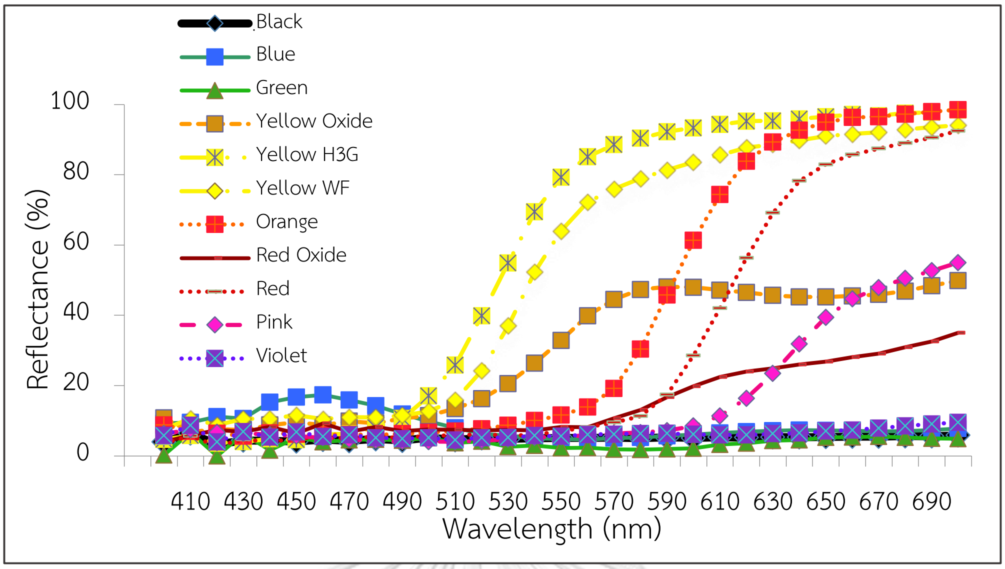


Figure 5.11 Spectrum reflectance of acrylic primary colors.

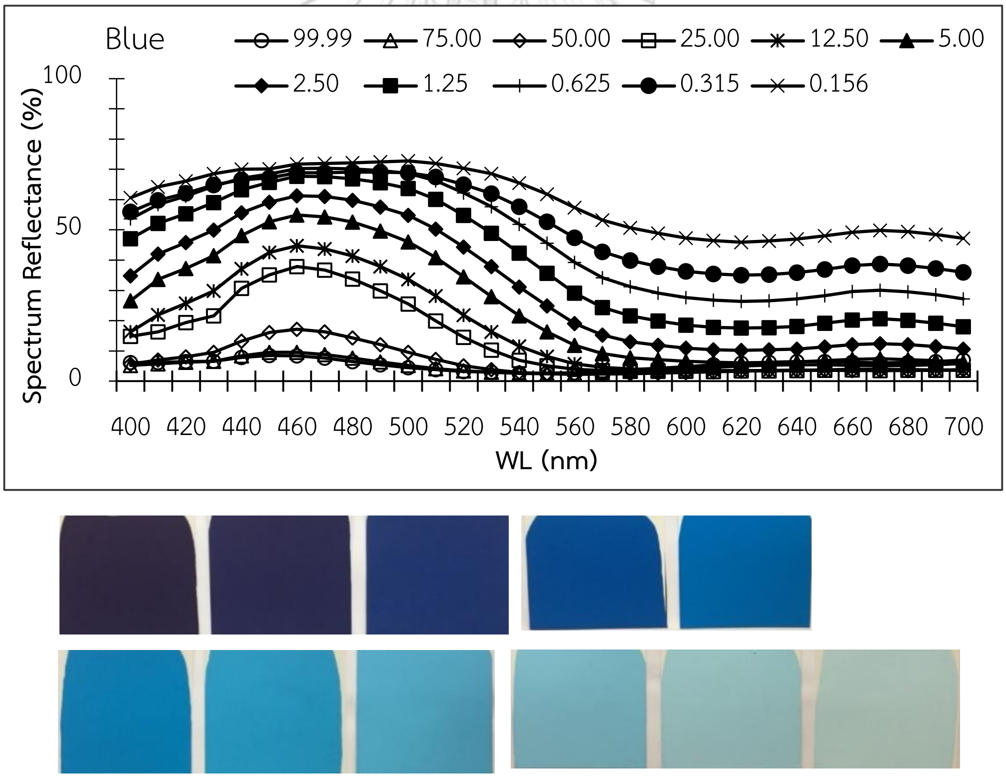


Figure 5.12 Spectrum reflectance (%) and calibrated color panels of Blue at different concentrations. From left to right: 99.99, 75.00, 50.00, 25.00, 12.50 (top), 5.00, 2.50, 1.25, 0.635, 0.315, and 0.156 (bottom).

5.2.4 Match prediction of the traditional Thai style color

In this part, only colors that were matched with Munsell color system in the color dictionary (5) and $\Delta E_{00} < 3$ were presented.

Table 5.20 showed the CIELAB data of traditional Thai style colors in R category which contained 21 colors. Predicted data were not well matched, most of predicted ΔE_{00} were very high. Only 11 colors that gave $\Delta E_{00} < 3$. Six colors: "Hong Din tut," "Hong Din On," "Thong Dang Kae," "Khao Pun," and "Chompu Klang" gave the predicted $\Delta E_{00} < 1$. We selected "Hong Din Tut" to formulate the trial sample as it was presented in Table 5.24. As it can be seen, composition that included percentage of each colorant and vehicle was presented.

Table 5.21 presented the color matching of YR and Y category. Fourteen Thai color names were mentioned in YR category, predicted ΔE_{00} of 3 out of 14 colors were less than 1 which were "Khao Kabang," "Din Lueang," and "It On". Din Lueang was taken to make the sample, its component and color data were presented in Table 5.24.

R Category

Table 5.20 List of Thai style color names in R category, CIELAB values according to Thai color dictionary and predicted data (using the stored database and formulation software; X-Rite SP62, illuminant/observers D65/2, SPEX).

Category	Sample	Standard			Prediction			
		L*	a*	b*	L	a*	b*	ΔE_{00}
R	Dang Luead	41.31	44.86	21.5	40.66	49.56	20.87	2
	Dang Tubtim	41.04	38.6	12.21	40.87	37.95	17	3.00
	Dang Dok Kamut	61.44	32.93	17.07	62.27	33.42	20.28	2.02
	Dang Dok Bua Dang	61.44	32.93	17.07	62.27	33.42	20.28	2.02
	Hong Din On	80.34	15.7	11.99	80.34	15.79	12.27	0.18
	Hong Din Tut	41.3	10.54	6.51	40.38	10.54	6.33	0.85
	Thong Dang Kae	41.15	18.91	15.03	41.46	19.24	16.12	0.72
	Thong Dang Mon	51.16	16.61	15.11	51.71	15.75	18.97	2.98
	Khao Pun	90.77	3.2	4.43	91.47	3.76	4.44	0.83
	Chompu	71.18	42.94	16.11	72.03	36.05	28.3	8.99
	Chompu Klang	71.23	24.72	9.19	71.71	24.32	10.25	0.89

Table 5.21 List of Thai style color names in YR and Y category, CIELAB values according to Thai color dictionary and predicted data (using the stored database and formulation software; X-Rite SP62, illuminant/observers D65/2, SPEX).

Category	Sample	Standard			Prediction			
		L*	a*	b*	L	a*	b*	ΔE_{00}
YR	Fa Lap	90.97	5.67	7.43	89.43	5.32	7.29	1.03
	Nam-tan	61.49	9.51	22.37	63.31	12.16	24	2.54
	Khao Kabang	80.35	1.71	13.17	80.65	1.8	13.92	0.51
	Din Lueang	71.47	12.75	51.54	71.55	12.29	53.9	0.93
	It	61.36	27.3	35.01	61.29	26.54	39.93	2.69
	It Kae	51.52	26.93	36.09	51.68	27.57	42.11	2.63
	It On	80.92	20.36	26.88	80	19.65	26.79	0.77
	Lueang Thong	81.93	7.29	81.46	80.81	3.76	85.68	2.45
	Lueang Nuan Chan	85.81	3.81	54.66	83.08	3.81	52.49	1.92
	Lueang Manao	85.65	-14.75	72.91	86.53	-14.14	61.7	0.43
	Lueang Rong	80.68	-1.93	70.59	80.91	-0.52	70.18	0.86
	Nga Chang	90.25	-1.67	17.12	90.61	-1.4	16.26	0.92
	Nuan Thae	91.16	-0.02	16.82	89.43	5.32	7.29	1.03
Y	Nuan	90.25	-1.67	17.12	90.61	-1.4	16.26	0.92
	Lueang Sot	85.89	-2.2	67.73	85.07	-2.84	70.85	0.53
	Lueang On	86.13	-2.32	56.13	85.61	-1.98	57.24	0.45
	Mek Sonthaya	80.43	11.49	51.97	81.53	-11.58	58.65	0.55
	Khao Kralok	85.75	-4.48	16.92	85.96	-4.53	17.77	0.51
	Khao Nga Khao	91.29	-4.17	18.66	91.46	-4.18	19.18	0.31
	Khao Nuan	90.71	-1.27	9.22	90.68	-0.62	9.05	0.88
	Lueam Lueang	81.22	4.58	54.19	81.29	5.07	55.36	0.43
	Lueang Horadan	86.13	-2.32	56.13	85.61	-1.98	57.24	0.45

Colors in Y category were well matched. ΔE_{00} of 12 colors out of 16 colors were predicted less than 1. While ΔE_{00} of 4 colors that included “Lueang thong,” “Lueang Nuan Chan,” “Nuan Thae” and “Lueang Luk Chan” were 2.45, 1.92, 1.03 and 3.07, respectively. These results showed that Thai colors in Y category were able to formulate almost 100%. If we observer the primaryes we could see that there were vaious shades of yellow and orange resulting in very good match for this category.

Table 5.22 showed prediction data of colors in GY/G/BY and B category. GY category had two colors that were Khiao Luk Samo and Khiao Karn Tong. Predicted ΔE_{00} of these colors were 0.07 and 0.89, respectively. Acrylic paint sample of Khiao Luk Samo was made, its component and color data were presented in Table 5.24.

G category contained 11 colors, predicted ΔE_{00} of 3 colors that included “Khiao Mo”, “Nam Lai” and “Khiao Hin” were well matched at ΔE_{00} 0.89, 0.6 and 0.51, respectively, while ΔE_{00} of “Khiao”, “Khiao Klang”, “Khiao Bai Kae” and “Khiao Kampu” were 2.93, 2.46, 2.3, and 2.3, respectively. We selected “Nam Lai” and “Khiao Bai Kae” to make the sample and their color data showed well matching.

BG and B category results presented that ΔE_{00} of most colors were in between 1-4.

Table 5.22 List of Thai style color names in GY/G/BG/B category, CIELAB values according to Thai color dictionary and predicted data (using the stored database and formulation software; X-Rite SP62, illuminant/observers D65/2, SPEX).

Category	Sample	Standard			Prediction			
		L*	a*	b*	L*	a*	b*	ΔE_{00}
GY	Khiao Luk Samo	71.81	-11.38	28.79	72.04	-11.58	30.27	0.67
	Khiao Karn Tong	60.82	-14.92	26.55	60.89	-13.35	27.47	0.89
G	Khiao	51.24	-41.78	18.47	52.41	-43.76	24.49	2.93
	Khiao Klang	51.56	-30.93	15.31	51.5	-36.82	`8.34	2.46
	Khiao Bai Kae	51.37	-20.41	9.59	51.91	-23.87	12.44	2.3
	Khiao Kampu	51.37	-20.41	9.59	51.91	-23.87	12.44	2.3
	Khiao Mo	51.6	-21.18	4.33	51.66	-17.18	21.44	0.89
	Nam Lai	71.42	-23.64	11.58	71.8	24.2	12.45	0.6
	Khiao Hin	80.58	-12.93	2.7	81.62	-10.93	6.65	0.51
	Khiao Khram	51.34	-29.52	-5.52	52.36	-32.00	-6.5	1.53
BG	Khiao Khram Kae	40.69	-10.85	-9.5	42.13	-11.56	-9.12	1.48
	Khiao Khap	41.48	-17.61	-9.5	43.34	-15.67	-8.98	2.13
	Fa	71.19	-19.62	-26.94	71.99	-18.56	-26.78	1.33
	Khram Khap	31.91	-9.66	-16.75	31.05	-8.88	-17.12	1.86
	Khap	40.95	-12.76	-14.13	43.2	-12.78	-17	2.07
	Khrom Tha	30.95	-6.33	-6.68	28.78	-6.98	-6.23	2.56
	Takut	61.57	-2.41	-4.11	63.23	-2.65	-6.23	2.25
B	Mok	81.08	-2.92	-2.44	78.9	-2.67	-2.78	2.15

Table 5.22 presented matching results of colors in the PB/P/RP and Neutral category. ΔE_{00} of colors in the PB category were in between 0.87-5.84 (in the table we showed only ΔE_{00} < 3). Most of colors in RP category were well matched. Table 5.24 showed the formulation of selected acrylic paints as examples.

For the colors that the predicted ΔE_{00} >5, their ΔL^*, Δa^*, Δb^* were shown in Table 5.25. Δa^* of all colors in R and YR category were high negative showing that these colors were less red than targets, while Δb^* showed high positive presenting more yellow than targets. “Hong Sabat” was also very high at Δa^* of -20.91 (a* of target of 38.72) confirming that primary red in our database was not enough.

"Khiao Sot" in G category showed very high Δa^* of 44.14 (a^* of target of -54.3) indicating that green primary in our database was not enough.

"Muang Chad Kae" in RP category showed very high Δb^* (b^* of target of 1.65) indicating that blue primary in our database was not enough.

Suggestion was that more variety of primaries in red, green and blue shades should be added into the database.

Table 5.23 List of Thai style color names in PB/P/RP/Neutral category, CIELAB values according to Thai color dictionary and predicted data (using the stored database and formulation software; X-Rite SP62, illuminant/observers D65/2, SPEX).

Category	Sample	Standard			Prediction			
		L*	a*	b*	L	a*	b*	ΔE_{00}
PB	Nam Ngern	31.61	4.04	-35.69	32.67	4.09	-35.8	0.87
	Nam-Ngern Kae	30.68	1.54	-18.54	31.88	1.56	-16.78	1.42
	Mek Khram	71.17	-0.81	-30.62	72.92	-0.87	-32.11	1.56
	Kwan Buri	80.8	-0.73	-5.86	79.3	-2.23	-5.23	2.31
P	Dok Tabeak	61.08	26.78	-16.64	60.94	26.91	-16.68	0.13
	Luk Wa	41.02	21.23	-15.47	39.83	22.98	-17.12	1.56
RP	Muang Chad Klang	50.6	36.04	2.57	49.99	37.16	3.31	0.85
	Muang Chad On	61.35	33.51	2.69	60.97	33.67	3.84	0.77
	Banyen	50.96	43.32	-3.75	50.65	43.31	-2.22	0.86
	Dok Maiyarap	60.11	31.21	-8.02	60.28	31.37	-7.41	0.39
Neutral	Mo Muek Kae	35.94	-1.46	0.36	35.12	-2.58	-0.97	2.06
	Nok Phirap	57.04	-0.37	-0.77	56.89	-0.81	0.13	1.11
	Mo Muek	64.23	-1.16	-0.32	64.4	-1.32	0.59	0.92
	Mo Muek On	80.91	-0.79	-0.31	81.3	-0.52	-0.19	0.46
	Khao Phong	96.28	-0.65	1.74	93.3	-0.07	1.93	1.99
	Hong	96.28	-0.65	1.74	93.3	-0.07	1.93	1.99
	Khao Fun	96.28	-0.65	1.74	96.28	-0.07	1.93	1.99

Table 5.24 Formulations of traditional Thai style color acrylic paints.

Category	Color name	CIELAB values			Visual	suggested formulation	
			Predicted	Trialed	Perception	Colorant Name	%
R	Hong Din Tut	L*	40.38	39.24		Oxide Red	6.6589
		a*	10.31	11.46		Pink E	0.7933
		b*	6.33	8.5		Black	1.6591
		ΔE_{00}	0.85	2.37		Vehicle	90.8887
YR	Din Lueang	L*	71.55	68.79		Orange	3.7245
		a*	12.29	12.9		Oxide Yellow	28.5207
		b*	53.9	49.8		Black	0.0137
		ΔE_{00}	0.93	2.16		Vehicle	67.7411
YR	It	L*	61.29	58.52		Orange	36.8187
		a*	26.54	28.65		Oxide Yellow	5.3749
		b*	39.93	35.74		Black	0.124
		ΔE_{00}	2.69	2.57		Vehicle	57.6824
YR	Noppakao	L*	61.23	62.22		Oxide Red	1.139
		a*	6.45	6.2		Oxide Yellow	1.1371
		b*	10.17	8.87		Black	0.4528
		ΔE_{00}	1.23	1.91		Vehicle	29.271
Y	Lueang Rong	L*	80.91	80.28		Green	0.013
		a*	-0.52	1.86		Oxide Yellow	7.5325
		b*	70.18	68.99		Yellow WF	3.52
		ΔE_{00}	0.86	2.35		Vehicle	88.9345
Y	Lueang Horadan	L*	85.31	84.7		Oxide Yellow	3.48
		a*	-0.86	-0.17		Yellow WF	1.3122
		b*	56.12	55.25		Vehicle	95.2038
		ΔE_{00}	0.86	1.5			
	Khao Nuan	L*	90.68	92.28		Green	0.0039
		a*	-0.62	-0.58		Orange	0.1803
		b*	9.05	10.71		Oxide Yellow	0.3052
		ΔE_{00}	0.88	1.74		Vehicle	99.5107
GY	Khiao Luk Samo	L*	72.04	73.67		Green	0.2876
		a*	-11.58	-13.74		Oxide Red	0.6476
		b*	30.27	32.46		Yellow WF	1.2265
		ΔE_{00}	0.67	2.29		Vehicle	97.838

Table 5.24 (Continued)

Category	Color name		CIELAB values		Visual	suggested formulation	
			Predicted	Trialed	Perception	Colorant Name	%
G	Khiao Bai Kae	L*	51.91	51.24		Green	2.0161
		a*	-23.87	-22.5		Black	0.9799
		b*	12.44	11.7		Yellow WF	1.3478
		ΔE_{00}	2.3	**1.53**		Vehicle	95.6564
G	Nam Lai	L*	71.99	73.62		Green	0.5288
		a*	-24.18	-24.3		Yellow H3G	3.038
		b*	13.31	12.52		Black	0.1384
		ΔE_{00}	1.08	1.75		Vehicle	96.2948
BG	Khiao Khap	L*	41.14	39.88		Pink E	2.164
		a*	-15.78	-18.2		Blue	4.158
		b*	-9.95	-6.41		Yellow WF	1.9138
		ΔE_{00}	2.02	2.22		Vehicle	91.764
BG	Khiao Khram	L*	51.65	51.77		Green	3.6871
		a*	-29.53	-29.3		Pink E	1.4201
		b*	-0.9	-3.77		Yellow H3G	4.0322
		ΔE_{00}	2.3	0.85		Vehicle	90.861
B	Mo Khram	L*	51.2	51.1		Black	0.5858
		a*	-8.74	-6.81		Blue	1.5204
		b*	-16.87	-16.8		Violet	0.241
		ΔE_{00}	0.94	1.62		Vehicle	97.6528
PB	Dok paktop	L*	63.93	64.4		Black	0.2593
		a*	6.24	6.26		Blue	0.1196
		b*	-12.19	-12.8		Violet	0.2615
		ΔE_{00}	0.46	0.83		Vehicle	99.3596
P	Dok Tabeak	L*	61.2	61.2		Pink E	1.3087
		a*	26.82	28.31		Yellow H3G	1.1597
		b*	-15.81	-16.7		Violet	0.404
		ΔE_{00}	0.87	0.65		Vehicle	97.128

Table 5.24 (Continued)

Category	Color name	CIELAB values	Predicted	Trialed	Visual Perception	suggested formulation Colorant Name	%
P	Dok Tabeak	L*	61.2	61.2		Pink E	1.3087
		a*	26.82	28.31		Yellow H3G	1.1597
		b*	-15.81	-16.7		Violet	0.404
		ΔE_{00}	0.87	0.65		Vehicle	97.128
P	Luk Wa	L*	39.83	39.13		Blue	0.5859
		a*	22.62	21.15		Violet	2.0272
		b*	-14.82	-14.5		Red	2.8893
		ΔE_{00}	1.38	1.76		Vehicle	94.498
RP	Banyen	L*	50.65	51.23		Pink	5.2575
		a*	43.31	40.15		Violet	0.116
		b*	-2.22	-3.14		Yellow WF	0.6244
		ΔE_{00}	0.86	1.16		Vehicle	94.0022
RP	Dok Maiyarap	L*	60.28	60.21		Orange	4.1066
		a*	31.37	32.82		Pink	1.6948
		b*	-7.41	-7.58		Violet	0.2618
		ΔE_{00}	0.39	0.76		Vehicle	93.937
Neutral	Nok Phirap	L*	56.89	57.05		Green	0.4909
		a*	-0.81	-0.23		Black	0.5709
		b*	0.13	-0.51		Red	0.8499
		ΔE_{00}	1.11	0.32		Vehicle	98.0889
Neutral	Mo Muek	L*	64.47	65.05		Green	0.0138
		a*	-1.64	-2.24		Pink E	0.0992
		b*	0.32	0.5		Black	0.4957
		ΔE_{00}	0.93	1.78		Vehicle	99.267

Table 5.25 List of Thai style color names that had predicted ΔE_{00} > 5, ΔL^*, Δa^*, and Δb^* (using the stored database and formulation software; X-Rite SP62, illuminant/observers D65/2, SPEX).

Category	Sample	Color Difference			
		ΔE_{00}	ΔL^*	Δa^*	Δb^*
R	Kulap	6.25	1.9	-5.78	9.12
	Dang Luead Nok	6.25	1.9	-5.78	9.12
	Dang Tubtim	6.39	3.5	-6.79	6.64
	Dang Luead Moo	15.57	10.3	-7.07	16.71
	Hong Din Klang	10.94	-1.5	-8.04	10.3
	Thong Dang	14.07	7.35	-8.78	15.05
	Chompu	8.99	0.85	-6.89	12.19
YR	Nam Rak	6.25	-1.06	-0.4	8.19
	Hong Sabat	11.28	-4.43	-20.91	-7.17
G	Khiao Sot	19.5	-3.85	44.14	-1.57
	Khiao Thae	25.03	9.91	28.6	24.46
	Khiao Kae	18.27	7.98	15.75	15.46
PB	Mo Mek	5.74	3.09	-1.04	-0.32
	Thao mek	5.74	3.09	-1.04	-0.32
RP	Muang Chad Kae	22.99	11.41	-12.28	24.47
Neutral	Kamao	8	-8.06	3.55	-4.52
	Dam Muek	8	-8.06	3.55	-4.52
	Din Mo	6.5	-4.47	-4.17	0.55

5.2.5 Artists' satisfaction and brush testing

Twenty acrylic paint samples that their CIELAB and ΔE_{00} were mentioned in the Table 5.23, were taken to the artist for brush testing. Artists' satisfaction results were shown in the Figure 5.13. Figure 5.14 showed the art works painted by five artists. We also compared the results of artists' satisfaction on the acrylic paint "Flashe" which was used regularly by them. It can be seen that satisfaction scores for (A) viscosity were 80.00% and 71.43 % for Flashe and acrylic paint samples respectively. Artists satisfied 71.43% on (B) odor of Flashe and 82.86% on our sample odor. Satisfaction score for Flashe and acrylic paint sample were 77.14% and 74.29 % respectively for (C) fineness. Satisfaction on (D) tinting strength of color were 74.29% for Flashe and 57.14% for our sample. (E) Drying was satisfied by 80.00% for Flashe and 65.71% for our acrylic paint sample. Artists satisfied on (F) hiding power 74.29% for Flashe and 65.71% for our sample. (G) Matching of color with Thai color name was satisfied by 68.57% for both. (H) Overall satisfaction scores were 77.14% for Flashe and 65.71% for our acrylic paint sample.

Artists overall rated "satisfied" on Thai style color acrylic but comments were given. The tinting strength of color was not satisfied as it was scored at 57.14%, artist commented that pigment volume concentration and formulation should be reconsidered. In addition, some color were different after it was left to dry. This would be proper for the art that is designed the pattern before painting but would create a problem for artists who have less experience.

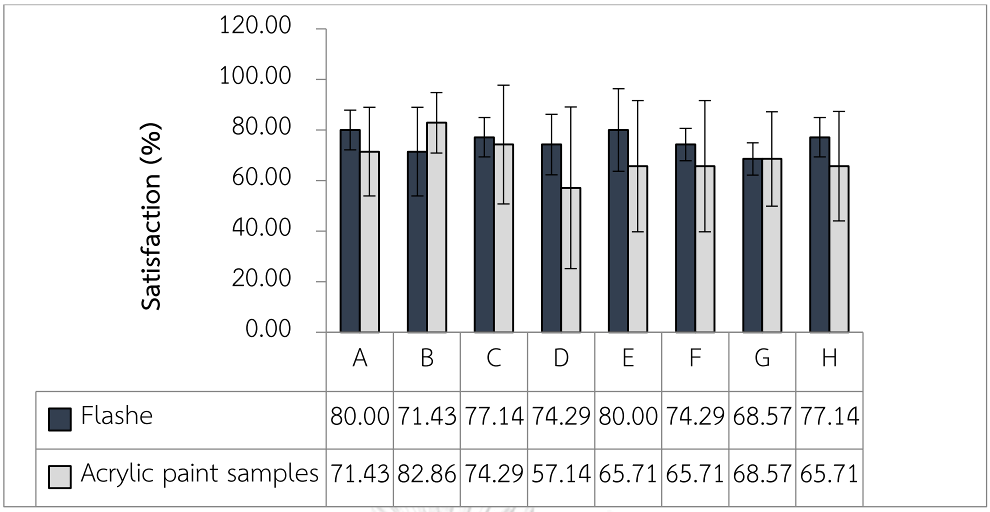


Figure 5.13 Artists ‘satisfaction on traditional Thai style color acrylic paint.

Where;

A	satisfaction on viscosity
B	satisfaction on odor
C	satisfaction on fineness
D	satisfaction on tinting strength of color
E	satisfaction on drying
F	satisfaction on hiding power
G	satisfaction on matching of the samples’ colors with Thai color name
H	satisfaction on overall satisfaction

(a)

(b)

(c)

(d)

(e)

Figure 5.14 Five art works painted by five artists using the acrylic paint samples. Name of artists were listed as follow; (a) Kiettisak Suwannapong, (b) Thammarat Kangwarnkong, (c) Karn Phisutthibongkot, (d) Wichien Saechai, and (e) Panya Phodee.

5.3 Color tolerance and artist acceptation

We evaluated the tolerance of traditional Thai style colors that using pass-fail color tolerance and 10 observers involved in visual assessment were Thai artists from the department of Fine art, Ministry of Culture. Total color difference; ΔE_{00}, ΔEab^*, lightness difference (ΔL^*), chroma difference (ΔC^*) and hue difference (ΔH^*) were used for determining tolerance. Twenty colors: “Dang Sen”, “Hong Din”, “Din Lueang”, “Nam-tan”, “It”, “Lueang Rong”, “Lueam Lueang”, “Khiao Karn Tong”, “Khiao Luk Samo”, “Khiao Bai Kae”, “Nam Lai”, “Khiao Khram”, “Khiao Khap”, “Khap”, “Khromtha”, “Mo Mek”, “Dok Tabaek”, “Luk Wa”, “Dok Maiyarap” and “Banyen” were selected from 10 categories: R, YR, Y, GY, G, BG, B, PB, P and RP mentioned in the Thai color dictionary to ensure that all range of colors were assessed. These were pastels giving color difference between predicted and target less than 1.

We selected “Hong Din” which its cumulative number of observations showed the lowest accepted $\Delta E_{00,}$ for an exemplification of evaluation.

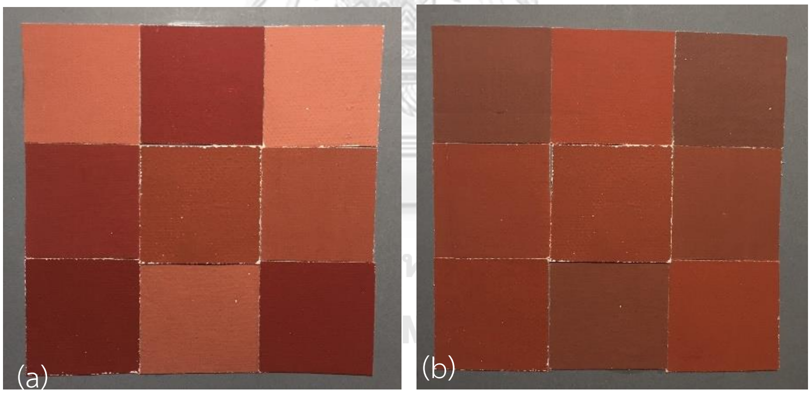


Figure 5.15 color charts of “Hong Din”, (a) 8 shades of color with different CIE L* having similar CIE C* and hue, and (b) 8 shades of with different CIE C* having similar CIE L* and hue. The “Hong Din” target color was the middle one of each chart.

We showed in Figure 5.15 the color of “Hong Din” (the middle piece of each color chart) and its tolerances which were randomly placed on the neutral gray background. Figure 5.15 (a) presented the difference CIE L* having similar CIE C* and hue, while Figure 5.15 (b) showed the similar CIE L* and hue but having different CIE

C*. Table 5.26 contained the color data of these different shades of CIE L* and CIE C* of "Hong Din". First column indicated 8 different shades for lightness (CIE L* shade 1 to shade 8) and 8 different shade for Chroma (CIE C* shade 1 to shade 8). Next five columns presented L*, a*, b*, C* and h of each color shade. In addition, different attributes of all color shades compared with the target color were also presented as ΔL*, ΔC*, ΔH*, ΔE_{00} and ΔEab*. It can be seen that ΔL* of CIE L* shades were various from -8.69 to 12.13, while ΔC* of CIE C* shades were from -14.74 to 3.55. In addition, the ΔH* of each shade was also presented, the smallest hue difference was 0.15, while the biggest hue difference was 13.54. Last two columns presented total color differences: ΔE_{00} and ΔEab*, of each color shade. Results of the visual assessment; the cumulative frequency percentages of pass and fail done by ten artists were shown in the Table 5.27.

Table 5.26 CIELAB values, C* and h of "Hong Din" that has difference CIE L* and CIE C*, ΔL*, ΔC*, ΔH*, ΔE_{00} and ΔEab*, (X-Rite SP62, illuminant/observers D65/2, SPEX).

Color shade	Color samples					Difference				
	L*	a*	b*	C*	h	ΔL*	ΔC*	ΔH*	ΔE00*	ΔEab*
CIE L* shade 1	42.4	28.96	19.61	34.97	34.11	1.85	-1.41	1.96	2.09	3.04
CIE L* shade 2	46.04	28.37	18.74	34	33.44	5.49	-2.38	1.53	5.27	6.18
CIE L* shade 3	49.07	28.16	19.4	34.19	34.56	8.52	-2.19	2.22	8.24	9.07
CIE L* shade 4	52.68	26.04	18.49	31.94	35.38	12.13	-4.44	2.64	12.1	13.18
CIE L* shade 5	36.01	33.52	17.29	37.72	27.29	-4.54	1.34	2.37	4.26	5.29
CIE L* shade 6	33.44	44.67	16.83	37.61	26.58	-7.11	1.23	13.54	8.66	15.34
CIE L* shade 7	32.54	33.03	17.35	37.31	27.72	-8.01	0.93	2.08	6.88	8.33
CIE L* shade 8	31.86	32.68	17.79	37.21	28.57	-8.69	0.83	1.53	7.34	8.86
CIE C* shade 1	40.24	25.83	17.57	31.24	34.22	-0.31	-5.14	1.93	2.51	5.49
CIE C* shade 2	40.2	22.54	15.58	27.4	34.65	-0.35	-8.98	2.04	4.06	9.21
CIE C* shade 3	39.34	19.78	14.27	24.39	35.8	-1.21	-11.99	2.52	5.62	12.31
CIE C* shade 4	37.99	17.79	12.32	21.64	34.71	-2.56	-14.74	1.84	7.08	15.07
CIE C* shade 5	40.36	30.73	21.23	37.35	34.63	-0.19	0.97	2.37	1.71	2.57
CIE C* shade 6	40.5	31.39	21.84	38.67	34.39	-0.05	2.29	2.14	1.89	3.14
CIE C* shade 7	39.88	32.37	23.13	39.79	35.55	-0.67	3.41	3.05	2.53	4.62
CIE C* shade 8	38.39	32.32	23.45	39.93	35.96	-2.16	3.55	3.33	3.26	5.33

Remark: Hong Din target color data: L 40.55, a* 31.20, b* 18.71, C 36.38, h 30.96

Table 5.27 cumulative frequency of pass and fail for “Hong Din” assessed by ten artists under condition 6500K, 45/0.

Color shade	observation results done by ten artists										Sum	
	artist 1	artist 2	artist 3	artist 4	artist 5	artist 6	artist 7	artist 8	artist 9	artist 10	P*	F*
CIE L* shade 1	P	P	P	P	P	P	P	P	P	P	10	0
CIE L* shade 2	F	P	p	F	P	P	P	P	F	F	6	4
CIE L* shade 3	F	P	p	F	F	F	P	F	F	F	3	7
CIE L* shade 4	F	P	p	F	F	F	P	F	F	F	3	7
CIE L* shade 5	F	F	F	F	F	F	F	F	F	F	0	10
CIE L* shade 6	F	F	F	F	F	F	F	F	F	F	0	10
CIE L* shade 7	F	F	F	F	F	F	F	F	F	F	0	10
CIE L* shade 8	F	F	F	F	F	F	F	F	F	F	0	10
CIE C* shade 1	F	P	P	F	P	F	P	P	P	P	7	3
CIE C* shade 2	F	F	F	F	F	F	P	P	F	F	0	10
CIE C* shade 3	F	F	F	F	F	F	P	F	F	F	0	10
CIE C* shade 4	F	F	F	F	F	F	P	F	F	F	0	10
CIE C* shade 5	F	P	P	P	P	P	F	F	F	F	8	2
CIE C* shade 6	F	P	F	P	F	F	F	F	F	F	2	8
CIE C* shade 7	F	P	F	F	F	F	F	F	F	F	1	9
CIE C* shade 8	F	P	F	F	F	F	F	F	F	F	1	9

*P = passed; *F = failed

Figure 5.16 presented the relation of cumulative number of observations and color difference defined as ΔE_{00}*, ΔEab*, ΔL*, ΔC* and ΔH* of “Hong Din”. As shown in the graphs, series 1 was cumulative frequency of observers who rated the color as “pass”, while series 2 was cumulative frequency of observers who rated the color as “fail”. The crossed point of series 1 and 2 is the maximum tolerance that the observers accepted. It can be seen that the tolerance of ΔE_{00}, ΔEab*, ΔL*, ΔC* and ΔH* that artists as the target color for “Hong Din” were 2.20, 5.50, 3.90, 1.80 and 2.20 respectively.

We employed this process to analyze an additional 19 colors as mentioned previously. Table 5.28 contained the data of attributes, ΔE_{00}, ΔEab*, ΔL*, ΔC*, and ΔH* of all colors. It can be seen that artists accepted color tolerance (ΔE_{00}) up to 5.6

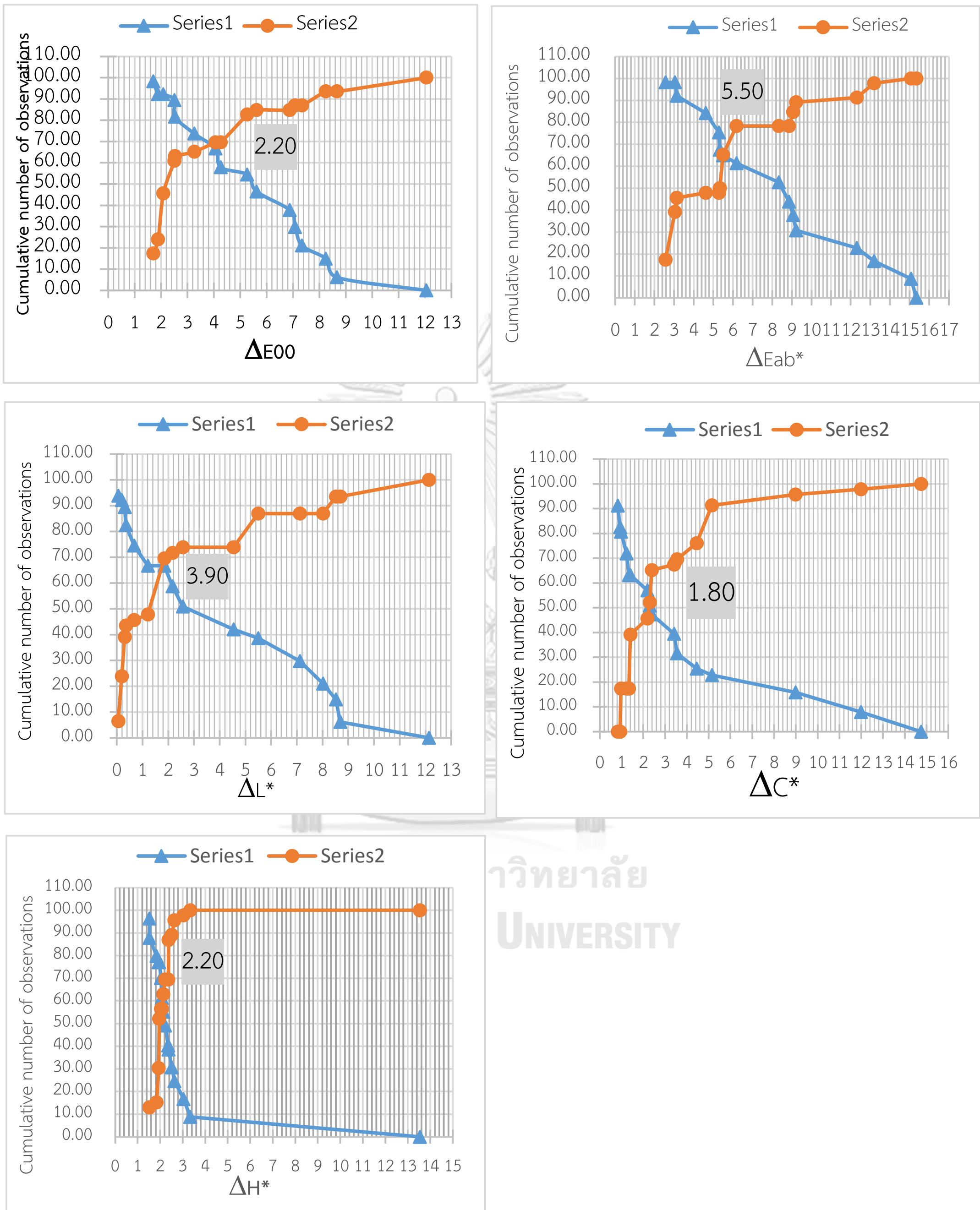


Figure 5.16 the relation of cumulative number of observations and total color difference ΔE_{00}, ΔEab^* and ΔL^*, ΔC^* and ΔH^* of “Hong Din”.

Table 5.28 Tolerance of ΔE_{00}, ΔEab^*, ΔL^*, ΔC^* and ΔH^* done by Thai artists under daylight 6500K, 45/0.

Color name	ΔE_{00}	ΔEab^*	ΔL^*	ΔC^*	ΔH^*
Dang Sen	4.70	6.0	3.90	1.80	1.4
Hong Din	2.20	5.5	3.90	1.80	2.2
Din Lueang	3.60	7.3	1.90	5.00	2.25
Nam-tan	4.00	6.2	3.50	4.60	0.64
It	5.40	7.6	4.20	3.80	2.9
Lueang Rong	3.00	7.0	2.40	5.10	2.35
Lueam Lueang	5.10	9.4	5.10	4.40	-
Khiao Karn Tong	4.00	5.6	3.70	2.30	
Khiao Luk Samo	5.00	7.0	4.50	1.90	1.1
Khiao Bai Kae	4.60	5.0	2.10	1.90	-
Nam Lai	2.80	4.6	3.50	2.50	0.8
Khiao Khram	3.50	5.3	3.10	2.50	1.2
Khiao Khap	5.60	6.8	5.10	2.40	4.0
Khap	3.00	1.57	2.40	2.80	-
Khrom Tha	3.70	4.5	2.45	1.85	1.1
Mo Mek	3.50	4.9	1.40	2.20	1.0
Dok Tabaek	4.80	8.4	4.20	5.40	1.45
Luk Wa	3.20	5.0	2.00	3.10	0.7
Dok Maiyarap	4.00	6,.4	2.20	3.60	3.5
Banyen	3.70	6.0	2.80	2.20	-

CHAPTER 6

Results and Discussion – Multi-Spectrum Imaging

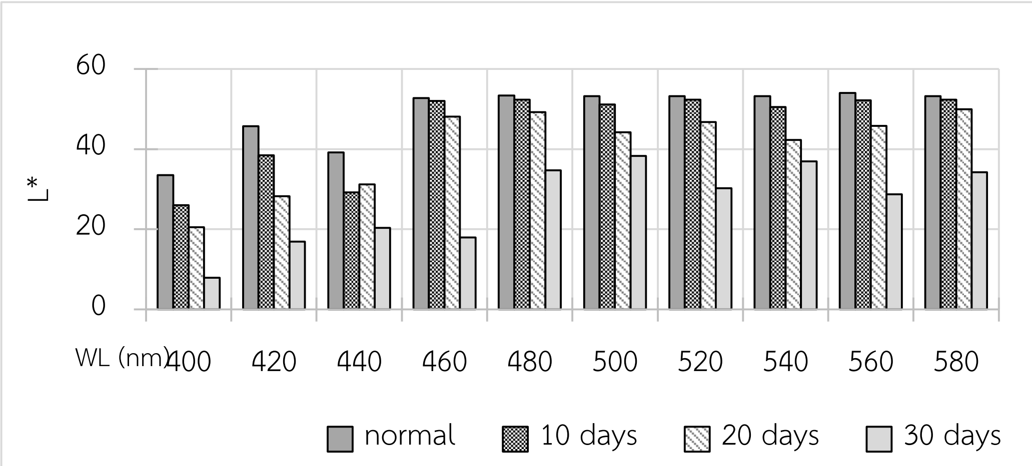
This part of the research presented the application of MSI system for examination of the primaries and traditional Thai style color of acrylic paint, pastel, and primers that were affected by humidity, heat, and light. Multi-spectrum images of the samples on substrates and simulated aging at different conditions were taken in the range of wavelength 400-700 nm. Then the MSI images were transferred to quantitative CIE L*, a* and b* values by the TCA system. We firstly discussed the documentation of acrylic paint, pastel and primers that were affected by moisture and heat. Then results of the same samples influenced by UV radiation at different conditions were presented.

6.1 Influence of humidity and heat

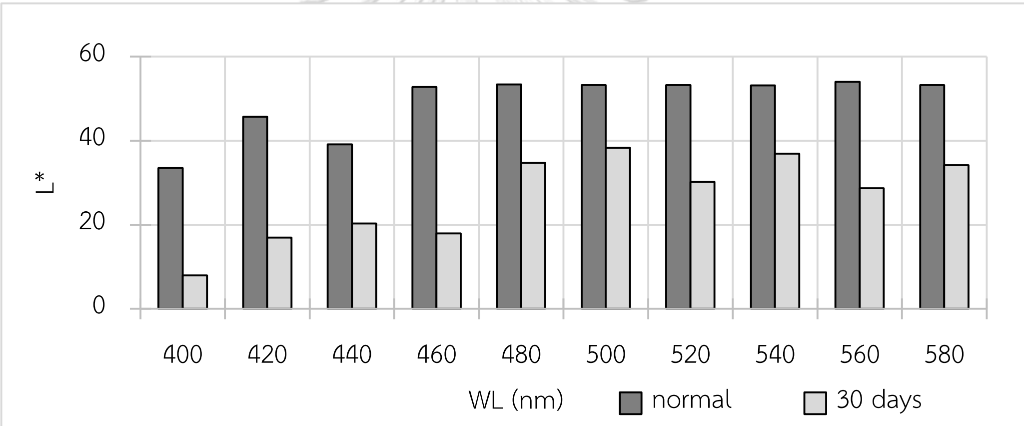
The following samples including 1) four primary colors: Colanyl Green GG 131-TH (Phthalocyanine Green, PG7), Colanyl Pink E (Quinacridone PR122), Hostaperm Red D3G 70 (Pyrrole Red, PR 254) and Hostoperm Violet RLS-EF (Dioxazine purple, PV23); 2) two traditional Thai style colors: “Dang Sen” and “Khiao Khram” and 3) three primers: novel primer NTA-Ag, novel primer NA-Ag and traditional primer that were applied on canvas and were under simulated aging at 50° C, 60% RH, for 40 days, were taken multi-spectrum images in the wavelength range 400-700 nm, with 20 nm intervals giving total of 16 bandwidths.

Colanyl Green GG 131-TH (Phthalocynanine green)

We simulated the condition mentioned above for Colanyl green for a total 30 days. It clearly showed CIE L* values difference when it was affected by humidity and heat at different time interval through the range of 400-580 nm.



(a)



(b)

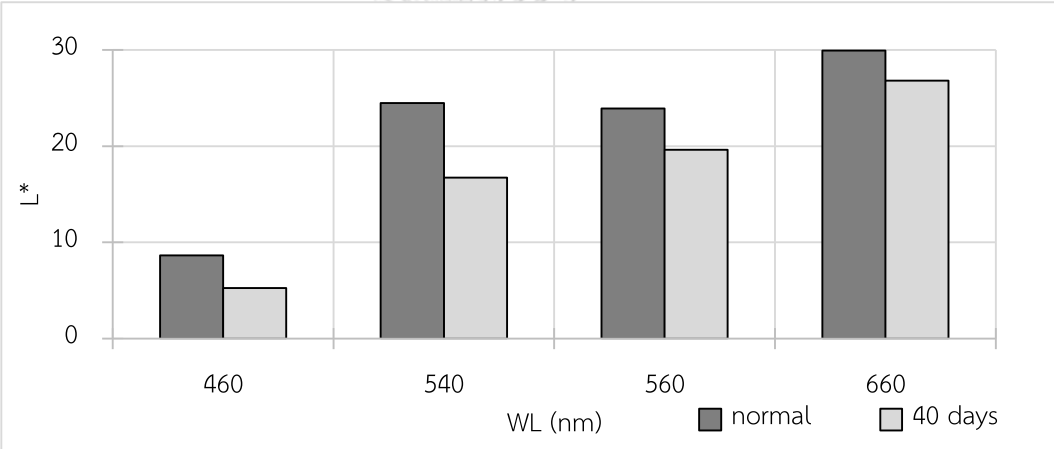
Figure 6.1 CIE L* of Colanyl Green at different aging conditions, (a) results of normal, 10, 20 and 30 days, and (b) comparison of normal condition and 30 days aging.

It can be seen in Figure 6.1 (a) that this color showed decreasing of CIE L* data relatively with the increasing of the aging time. We also illustrated in Figure 6.1 (b) comparing between the normal condition sample and the 30 days aged sample, this is to clearly present the CIE L*value when the sample was affected by humidity and heat for long time.

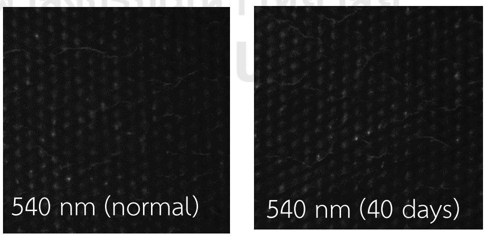
For other samples, only 2 aging conditions: normal and 40 days were presented. We selected only the distinguished wavelength that the CIE L* differences were more than 3.

Colanyl Pink E (Quinacridone PR122)

The acrylic paint primary color made of Colanyl Pink E showed decreasing of the CIE L* value after it was simulated aging for 40 days. The changing was clearly expressed at the wavelength 460, 540, 560 and 660 nm. We also showed the MSI images at 540 nm since it presented the biggest difference at this wavelength.



(a)

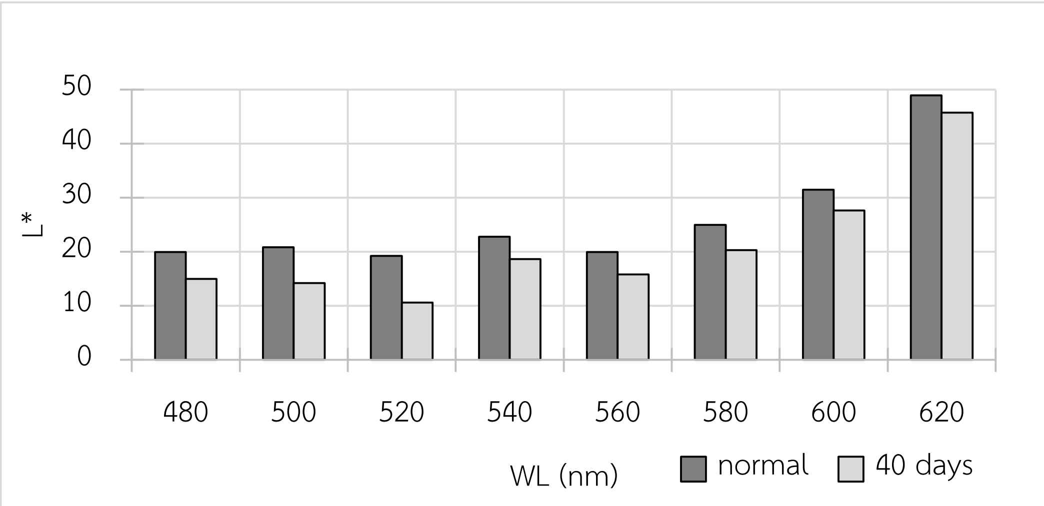


(b)

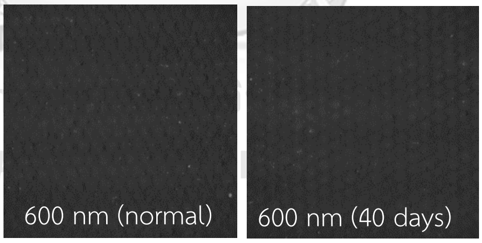
Figure 6.2 (a) CIE L* values of Pink E: normal condition and after simulated aging at 50^{o} C and 60% RH, for 40 days. (b) MSI images at 540 nm.

Hostaperm Red D3G 70 (Pyrrole Red PR254)

As shown in Figure 6.3, Hostaperm Red D3G 70 clearly presented the CIE L* difference at the wavelength range 480 to 620 nm. After aging for 40 days at 50° C / 60% RH, the CIE L* of this color was decreased. MSI image at 600 nm were shown in Figure 6.3 (b).



(a)

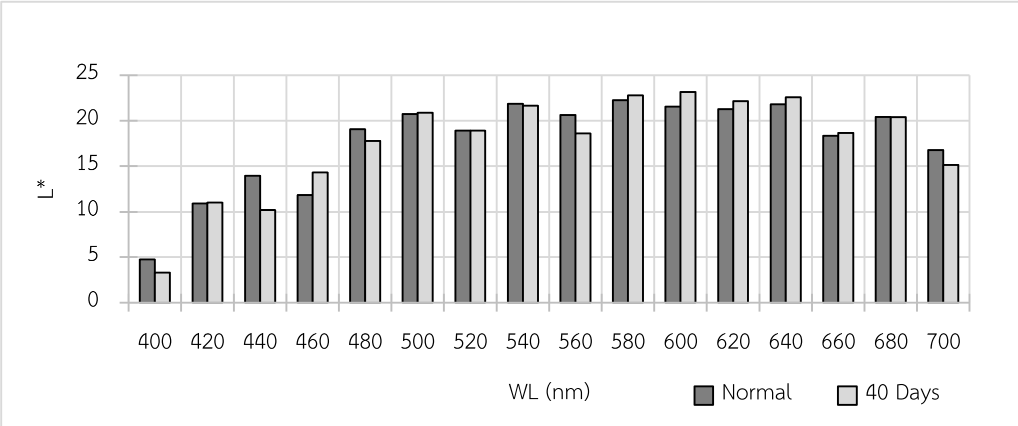


(b)

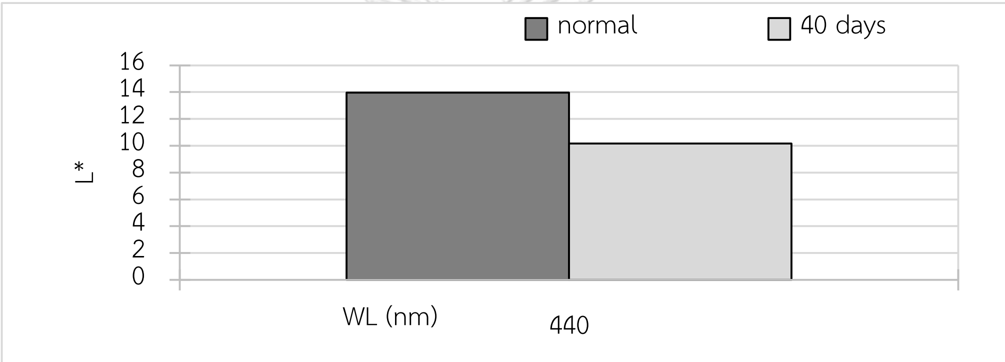
Figure 6.3 (a) CIE L* values of Red D3G: normal condition and after simulated aging at 50° C and 60% RH, for 40 days. (b) MSI images at 600 nm.

Violet RLS-EF (Dioxazine purple)

CIE L* values of violet slightly decreased when it was aged for 40 days. Figure 6.4 (a) showed the data from 400 to 700 nm but the clear difference was expressed at 440 nm (Figure 6.4 (b)).



(a)

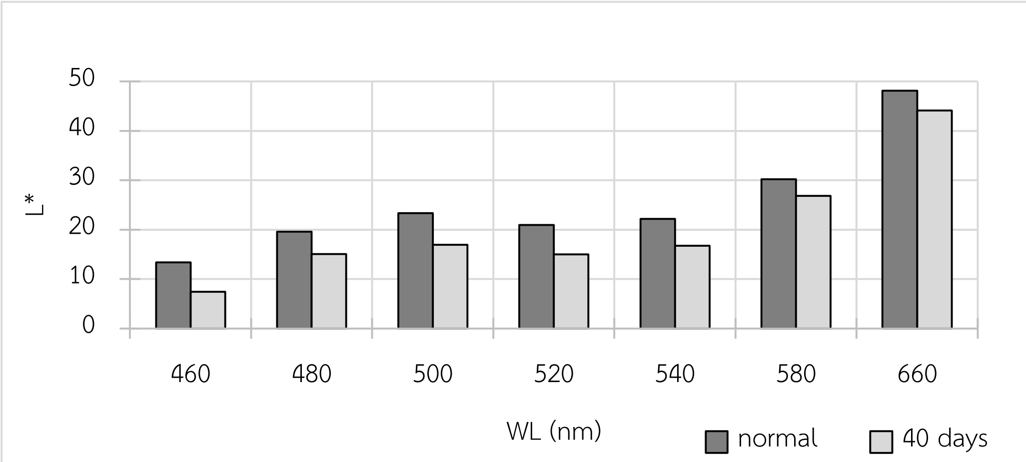


(b)

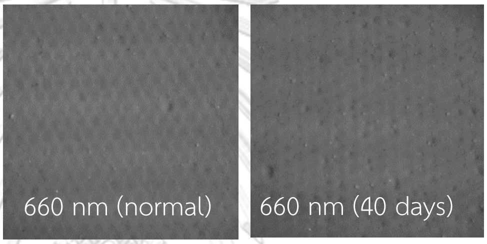
Figure 6.4 CIE L* values of violet: normal condition and after simulated aging at 50° C and 60% RH, for 40 days from 400-700 nm (a) and at 440 nm (b).

Dang Sen

As shown in Figure 6.5, “Dang Sen” showed clear difference of CIE L* values at the range of 460-580 and 660 nm. The same as results of other colors mentioned previously that the longer aging time, the lower CIE L* value.



(a)

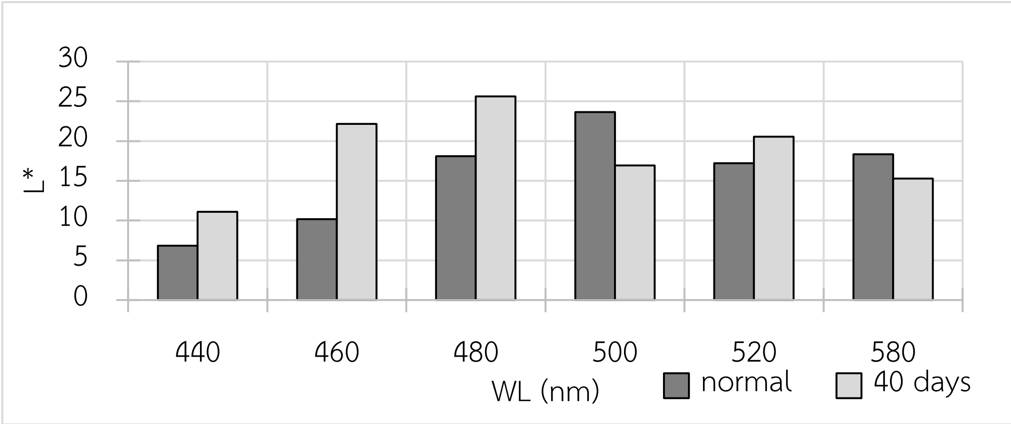


(b)

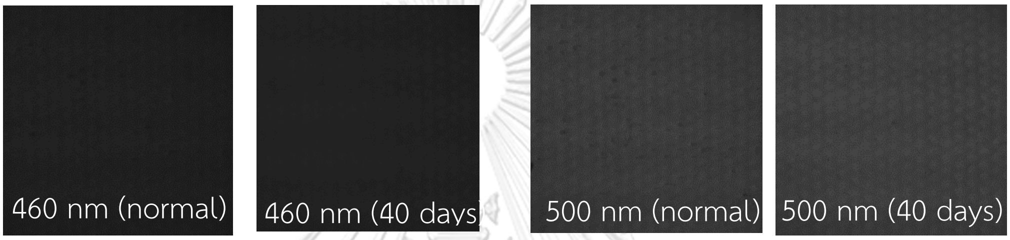
Figure 6.5 (a) CIE L* values of Dang Sen; normal condition and after simulated aging at 50° C / 60% RH, for 40 days. (b) MSI images at 660 nm.

Khiao Khram

We presented in Figure 6.6 data of "Khiao Khram". The clear differences of CIE L* were explicit at the wavelength 440-520 nm and 580 nm. "Khiao Khram" appeared oppositely from other colors mentioned previously. Although the CIE L* decreased at the 500 nm and 580 nm but it showed increasing at other wavelengths when it was aged for 40 days. MSI images of this color at 460 nm and 500 nm were shown in Figure 6.6 (b) and (c) respectively.



(a)

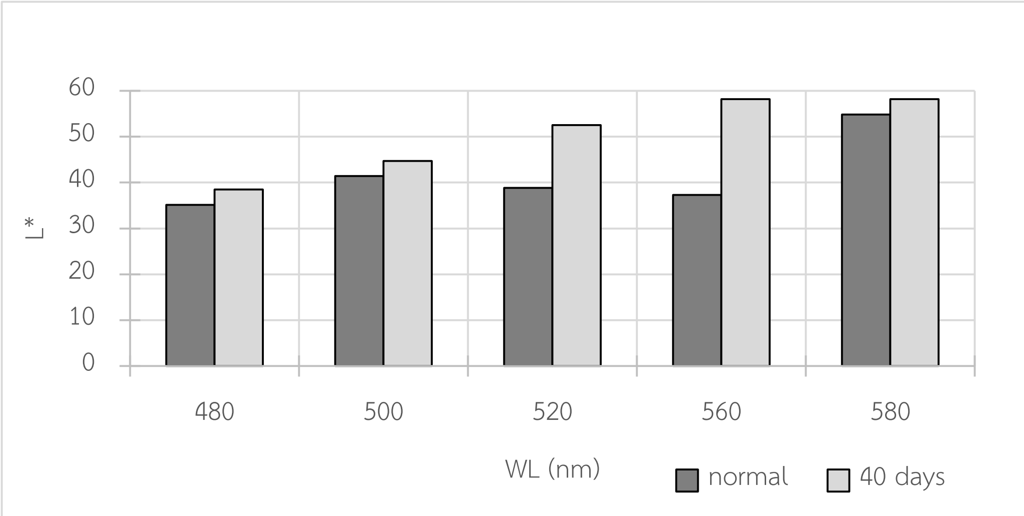


(b) (c)

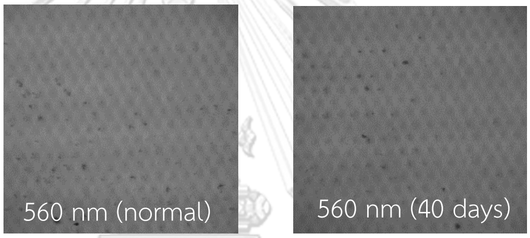
Figure 6.6 (a) CIE L* values of “Khiao Khram”; normal condition and after simulated aging at 50° C / 60% RH, for 40 days, (b) MSI images at 460 nm , and (c) MSI images at 500 nm.

Novel primer NTA-Ag

As shown in Figure 6.7, novel primer, NTA-Ag clearly expressed difference of CIE L* values at the range of 480-580 nm. After it was aged for 40 days, the L* data increased at the wavelength mentioned above.



(a)

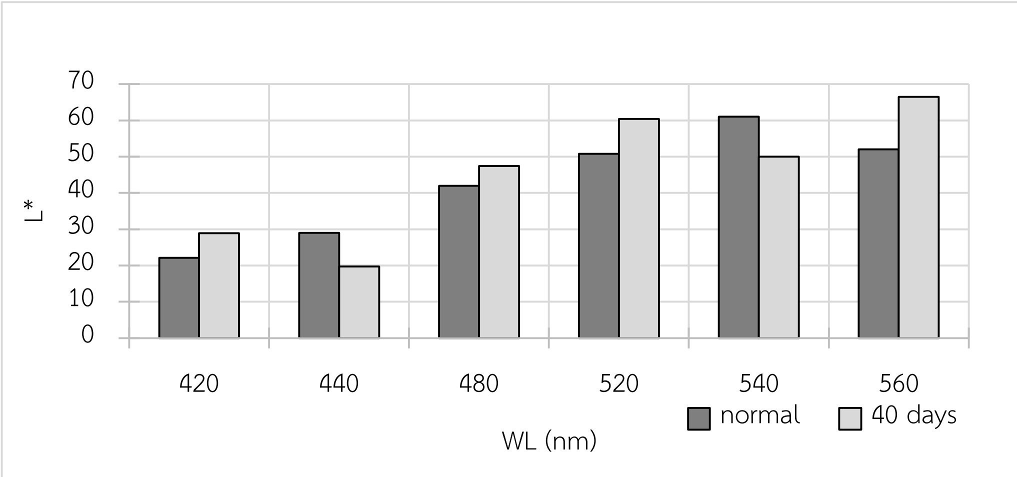


(b)

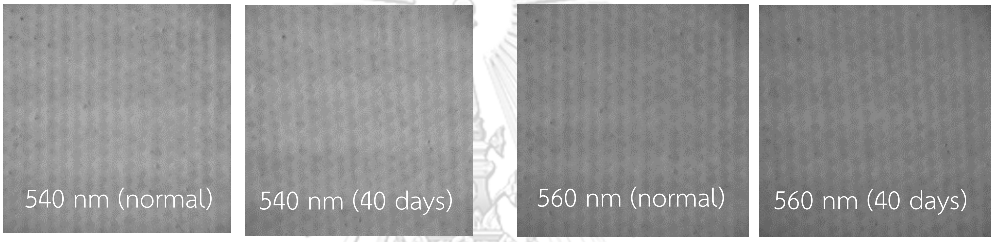
Figure 6.7, (a) CIE L* values of novel primer NTA-Ag; normal condition and after simulated aging at 50° C / 60% RH, for 40 days, (b) MSI images at 560 nm.

Novel Primer NA-Ag

This primer presented L* difference obviously at the wavelength 420, 480, 520, 560 nm. The CIE L* expressed increasing when the samples were aged as mentioned condition but not at 440 nm and 540 nm, as presented in Figure 6.8.



(a)

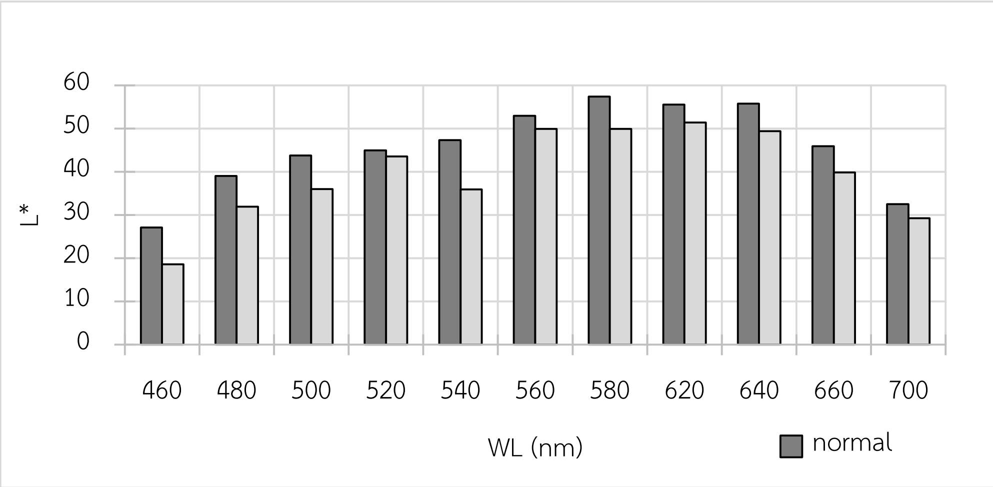


(b) (c)

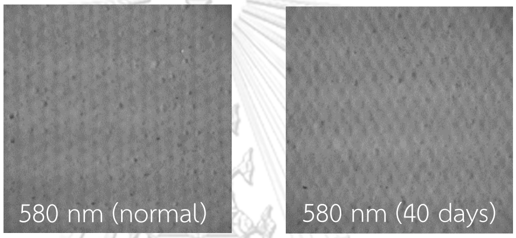
Figure 6.8, CIE L* values of novel primer NA-Ag; normal condition and after simulated aging at 50° C / 60% RH, for 40 days, (b) MSI images at 540 nm, and (c) MSI images at 560 nm.

Traditional primer

Figure 6.10 showed results of traditional primer. L* difference between normal sample and the one simulated aging for 40 days clearly shown almost through 460 to 700 nm. The CIE L* showed decreasing through the wavelength range mentioned. We also presented here in the Figure 6.10 (b) the MSI of this primer at 540 nm.



(a)



(b)

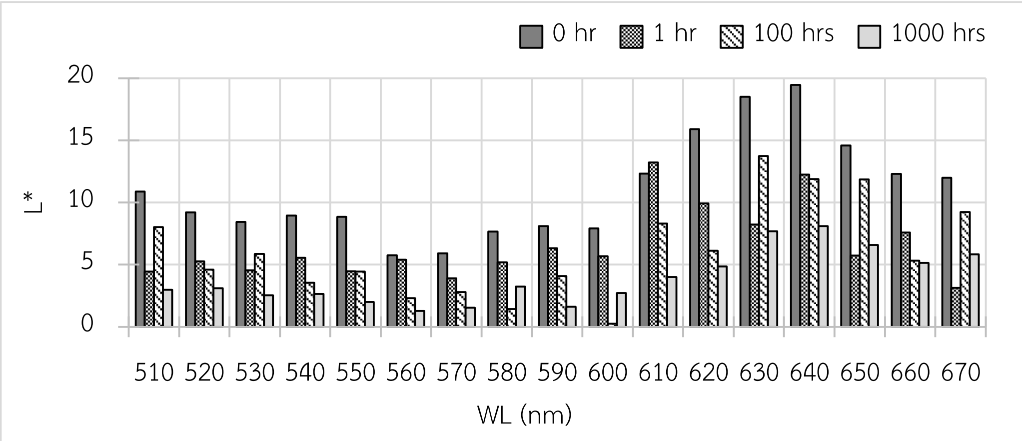
Figure 6.9, CIE L* values of traditional primer; normal condition and after stimulated aging at 50° C / 60% RH, for 40 days, (b) MSI images at 580 nm.

6.2 Influence of ultraviolet radiation

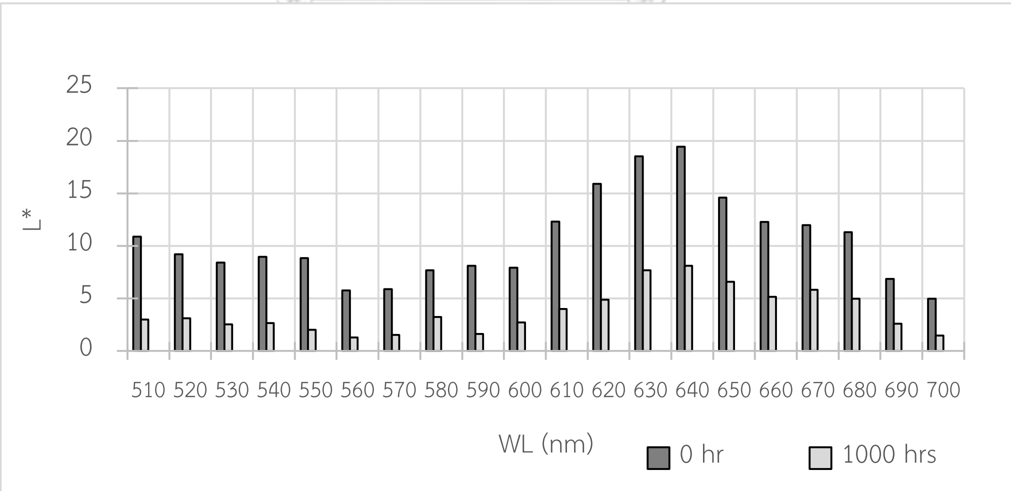
The same types of samples mentioned in previous were used. These samples were exposed inside the Q-Sun Xenon Test Chamber Xe-1 with Xenon Arc Lamp. Test conditions were 0.80 W/m^2 in the visible range at 420 nm. The average temperature was 50 °C for the total of time 1000 hours. Then multi-spectrum images were taken at the wavelength range 400-700 nm, 10 nm bandwidth.

Colanyl Green GG 131-TH (Phthalocyanine Green)

As shown in Figure 6.7 (a), CIE L* data of the sample aging at 0, 1, 10, 100 and 1000 hours clearly expressed at wavelength range 510 to 670 nm. The samples before aging showed higher CIE L* values. After UV radiation exposed was done for 1 hour, the CIE L* decreased. It can be seen that at 520, 540, 550, 560, 570, 590, 620, 640 and 660 nm, the CIE L* decreased relatively with increasing of aging time. But at the wavelength 510, 530, 630, 650, 670 nm, the CIE L* data of samples aging for 100 hours were higher than 1 hour aging samples. Figure 6.10 (b) presented comparison between the sample at normal condition (0 hour) and 1000 hours simulated aging. It clearly revealed that the CIE L* values of Colanyl Green decreased after it was exposed by UV radiation for 1000 hours.



(a)

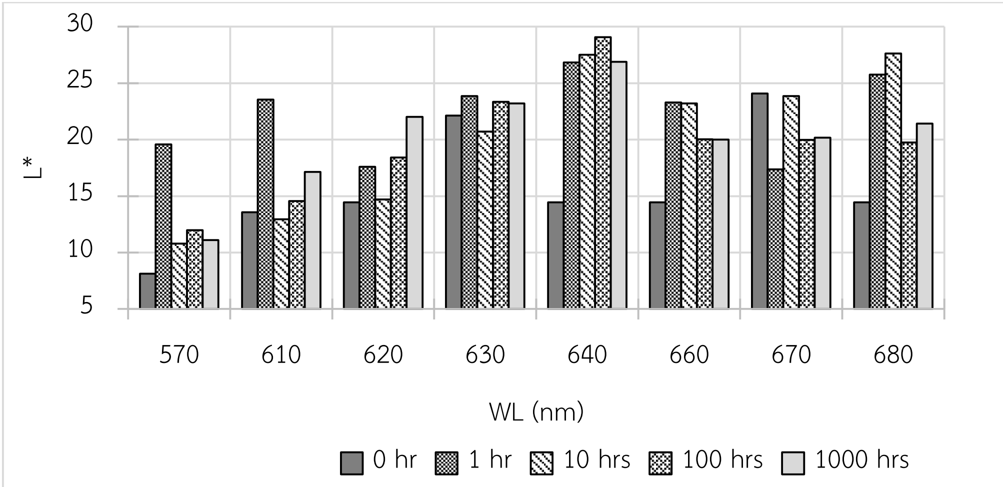


(b)

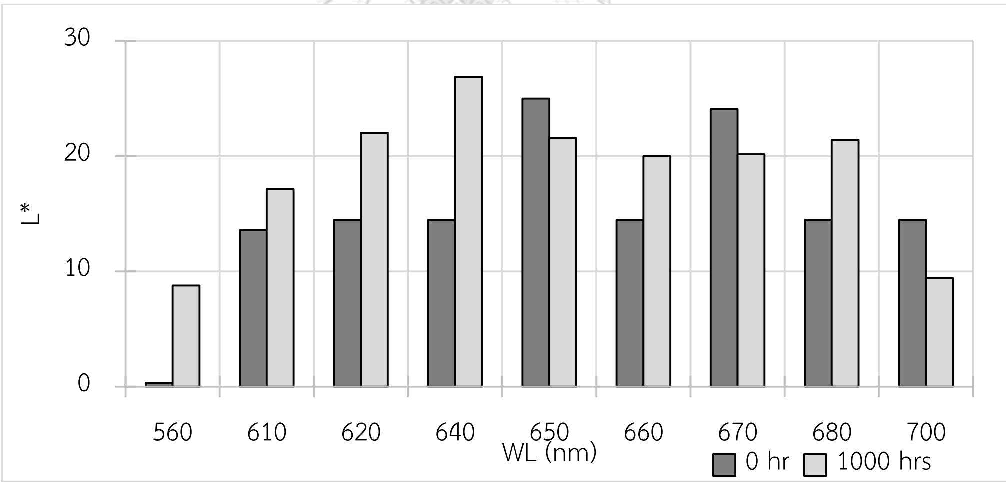
Figure 6.10 CIE L* values of Colanyl Green: (a) aging at different time interval and (b) compared between at normal condition (0 hour) and 1000 hours simulated aging.

Colanyl Pink E (Quinacridone PR122)

As shown in Figure 6.8, L* difference of Colanyl Pink E clearly expressed at the wavelength range 560 – 680 nm.



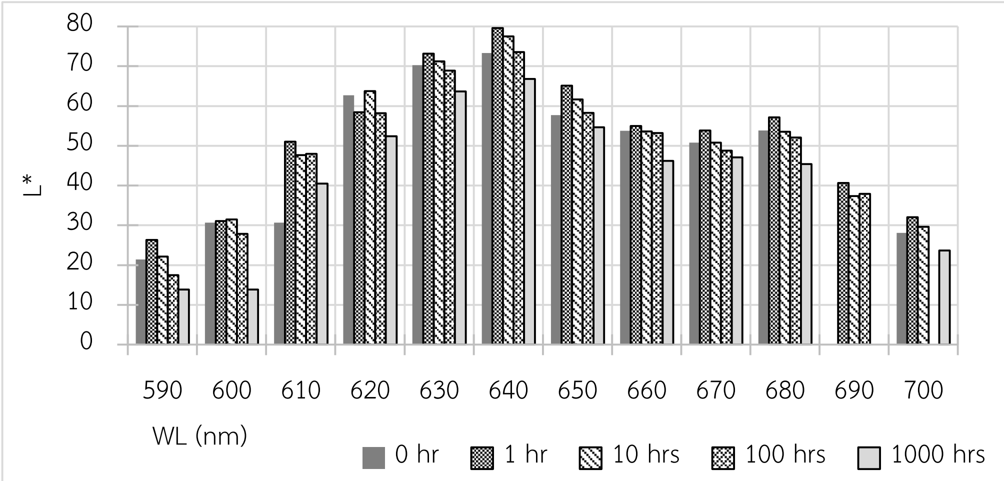
(a)



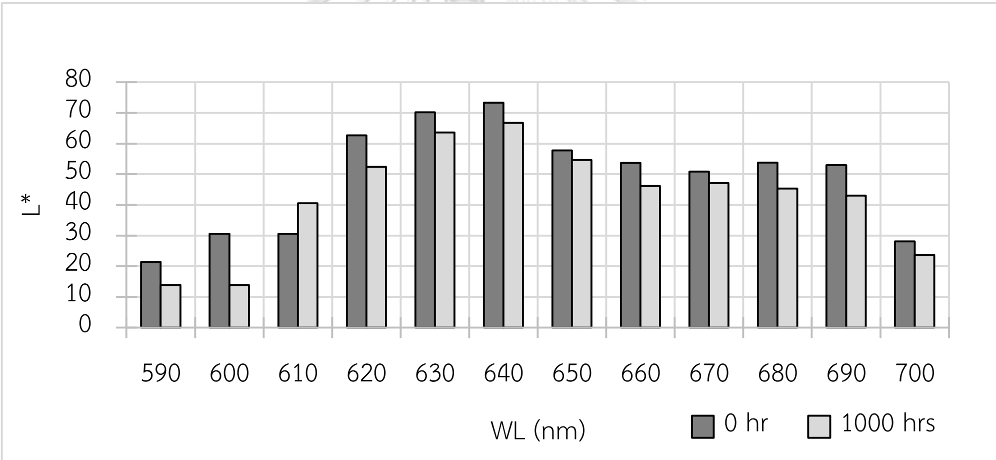
(b)

Figure 6.11 CIE L* values of Colanyl Pink E: (a) aging at different time interval and (b) compared between at normal condition (0 hour) and 1000 hours simulated aging.

Red D3G70



(a)



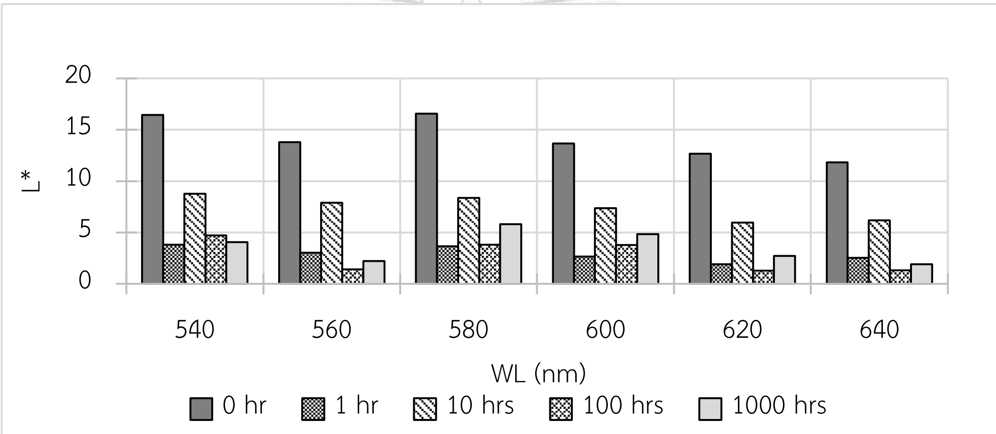
(b)

Figure 6.12 CIE L* values of Red D3G70: (a) aging at different time interval and (b) compared between at normal condition (0 hour) and 1000 hours simulated aging.

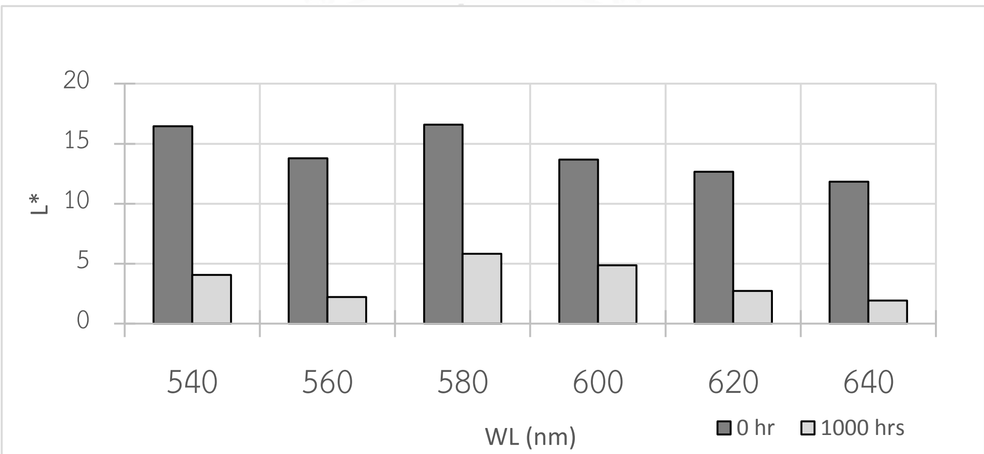
As shown in Figure 6.12, Red D3G 70 presented an increasing of L* value when it was exposed for 1 hour. After the exposure time was continually increased, the L* decreased. We presented in the figure 6.9 (b) comparison of normal sample and simulated aging sample at 1000 hours.

Violet RLS-EF (Dioxazine purple)

Figure 6.10 (a) presented CIE L* different at different time intervals and Figure 6.10 (b) showed particularly at 0 hour and 1000 hours simulated aging. The CIE L* showed clearly decreasing at 540-640 nm.



(a)

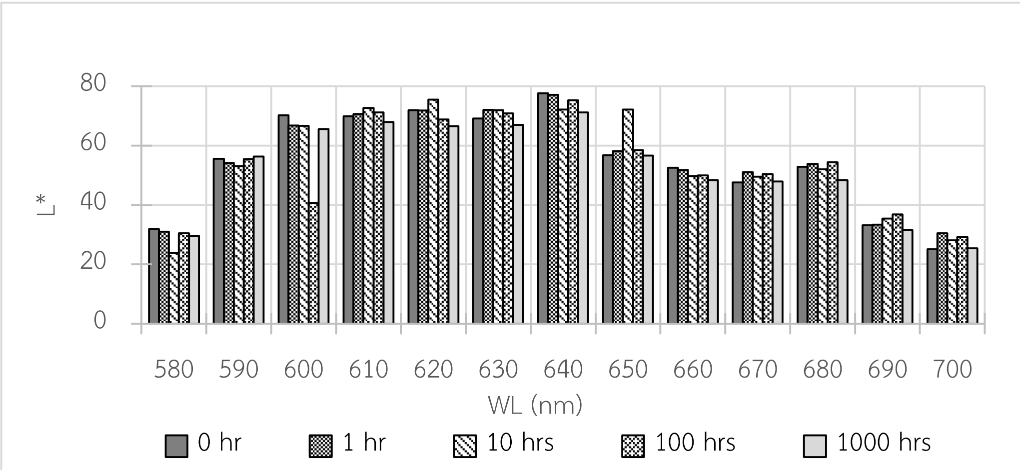


(b)

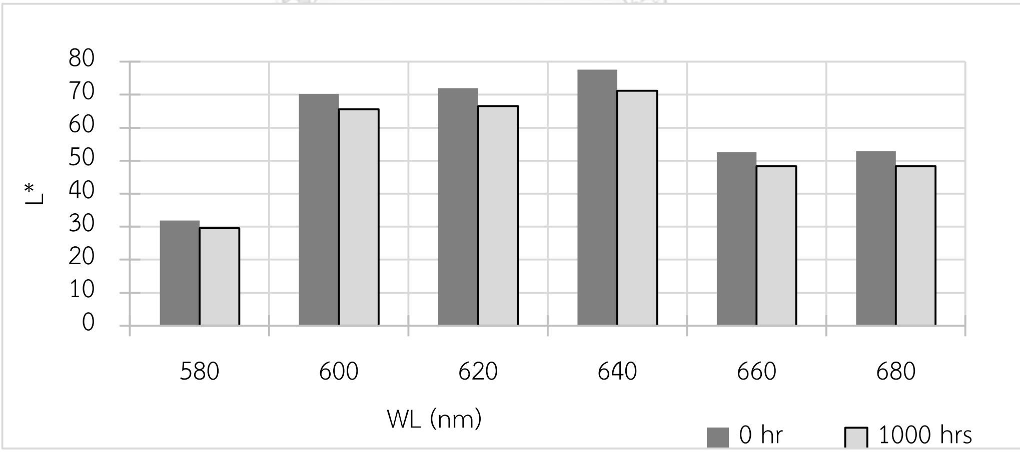
Figure 6.13 CIE L* values of Violet: (a) aging at different time interval and (b) compared between at normal condition (0 hour) and 1000 hours simulated aging.

Dang Sen

As shown in Figure 6.14, it seems that the L* data of “Dang Sen” increased when the exposed time increased from 1 hour to 10 hours then after that it showed decreasing, through the wavelength 580 to 700 nm. We compared the L* of normal condition and the one exposed 1000 hours in Figure 6.14 (b), the result obviously expressed differences at 580, 600, 620, 6060 and 680 nm that increasing of UV radiation aging time, the CIE L* of Dang Sen decreased.



(a)

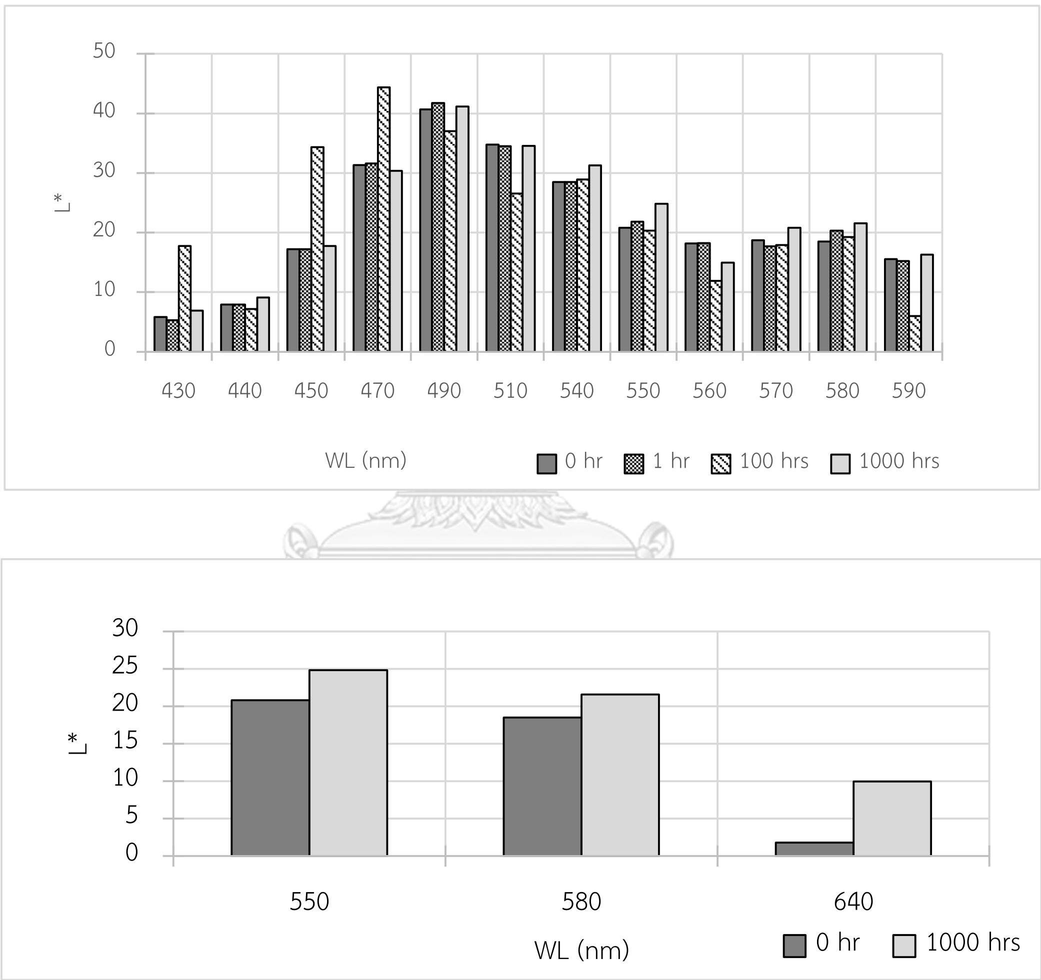


(b)

Figure 6.14 CIE L* values of Dang Sen: (a) aging at different time interval and (b) compared between at normal condition (0 hour) and 1000 hours simulated aging.

Khiao Khram

Figure 6.15 showed results of Khiao Khram. CIE L* values of “Khiao Khram” did not show any obvious differences through 450 to 590 nm for all conditions. Comparing between normal samples and 1000 hours samples found the clear difference at the wavelength of 550, 580 and 640 nm. The results presented decreasing of L* when the exposed time was 1000 hours.

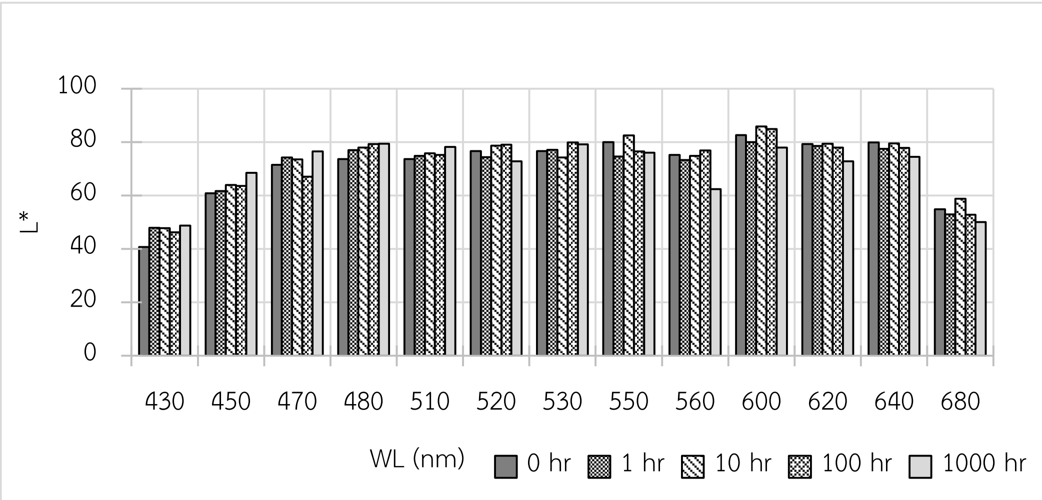


(b)

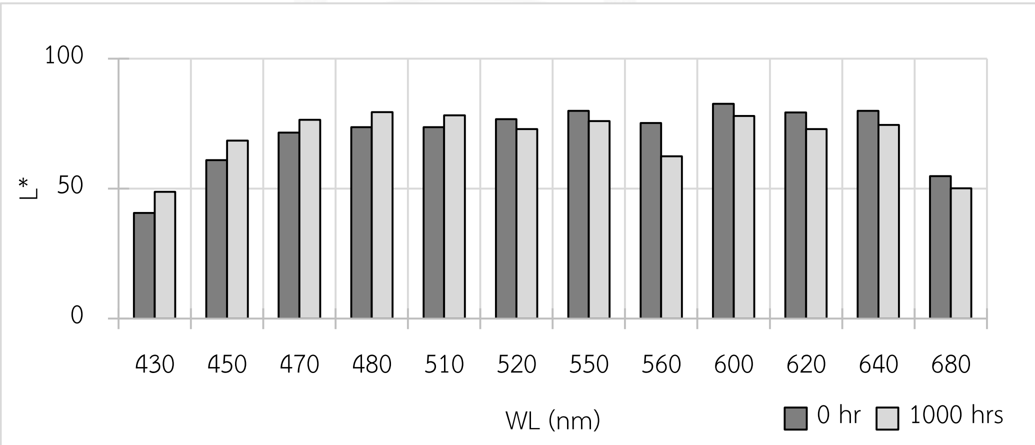
Figure 6.15 CIE L* values of Khiao Khram: (a) aging at different time interval and (b) compared between at normal condition (0 hour) and 1000 hours simulated aging.

Novel primer NTA-Ag

As shown in Figure 6.16, it seems the L* data increased after the sample was exposed for 1 hour but between 1 to 100 hours it showed inconsistency. However, comparing between normal condition and the one that was exposed 1000 hours, the L* of samples with 1000 hours at the wavelength range 430 to 510 nm increased but it deceased at the wavelength range 520 to 680 nm.



(a)

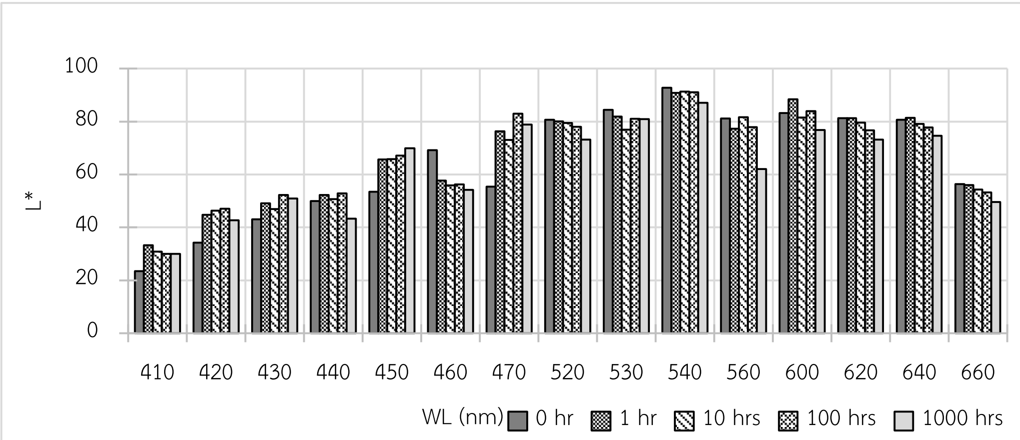


(b)

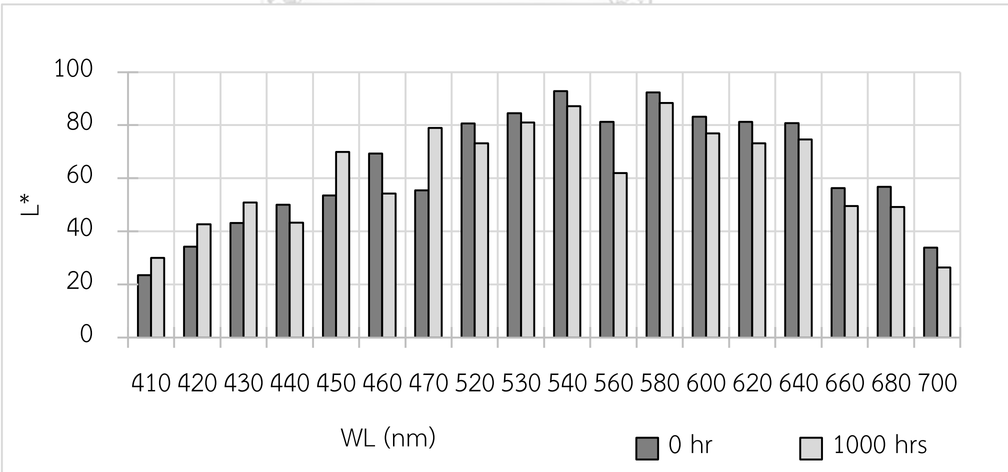
Figure 6.16 CIE L* values of traditional primer: (a) aging at different time interval and (b) compared between at normal condition (0 hour) and 1000 hours simulated aging.

Novel primer NA-Ag

As shown in Figure 6.17, NA-Ag showed the same trend as NTA-Ag that the L* data increased when the exposure time increased for a period of 1 to 100 hours but later that the increasing stopped. However, comparing between normal and 1000 hours aging time, the L* data increased, at the wavelength range 410 to 470 nm but decreased at 440, 460 nm and at the wavelength range 520 to 660 nm.



(a)

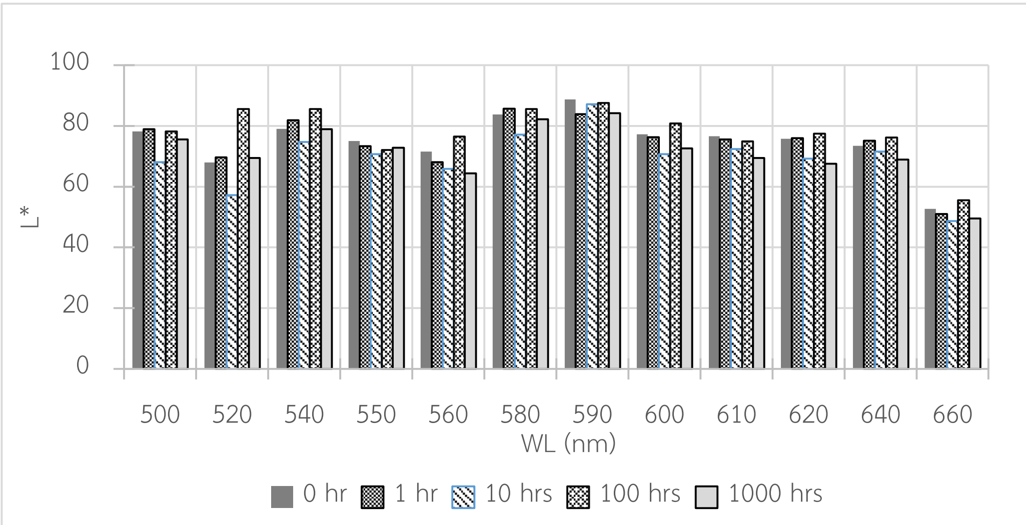


(b)

Figure 6.17 CIE L* values of novel primer-NTA-Ag: (a) aging at different time interval and (b) compared between at normal condition (0 hour) and 1000 hours simulated aging.

Traditional primer

Figure 6.18 presented results of traditional primer. It can be seen that L* values of traditional primer did not show any linear increasing or decreasing when it was exposed by UV light less than 100 hours. We then compared the L* data of the normal sample and the ones aging for 1000 hours. The difference expressed clearly at 550, 560, 590, 600, 620, 640, 660 and 700 nm that the L* of traditional primer decreased when it was exposed for 1000 hours.



(a)

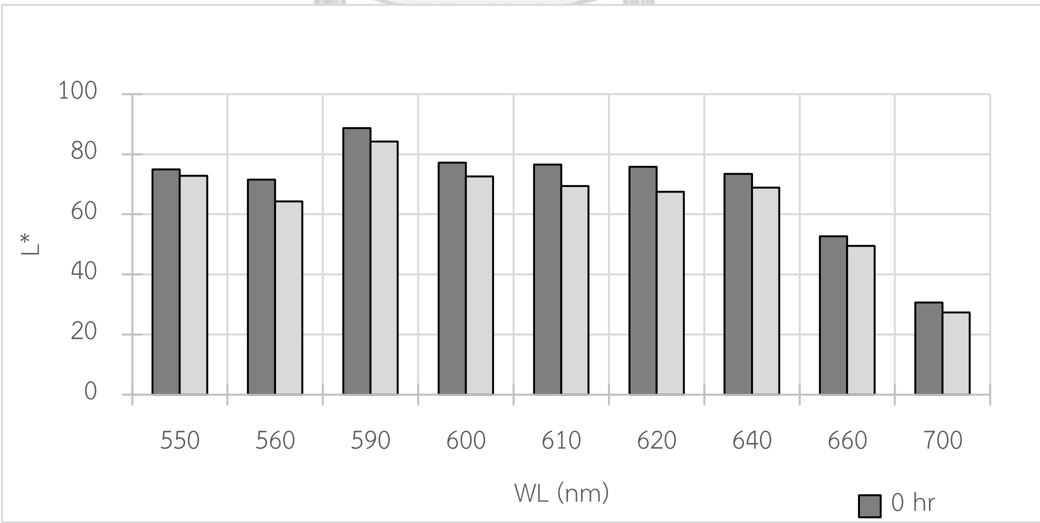


Figure 6.18 CIE L* values of novel primer-NA-Ag: (a) aging at different time interval and (b) compared between at normal condition (0 hour) and 1000 hours simulated aging.

We particularly compared color difference (ΔEab*) of three types of primer that were influenced by light, humidity and heat.

Figure 6.19 showed color difference of these primers; traditional one, NTA-Ag and NA-Ag after they were conditioned in the humidity chamber for 40 days. The results expressed clearly at the range of 440 to 660 nm. At 480, 660 nm, ΔEab* of traditional primer > NA-Ag > NTA-Ag. At 460, 500, 580, 620 and 640 nm, ΔEab* of traditional primer > NTA-Ag > NA-Ag. At 520 nm, the ΔEab* appeared differently as NTA-Ag showed highest ΔEab* at 13.72.

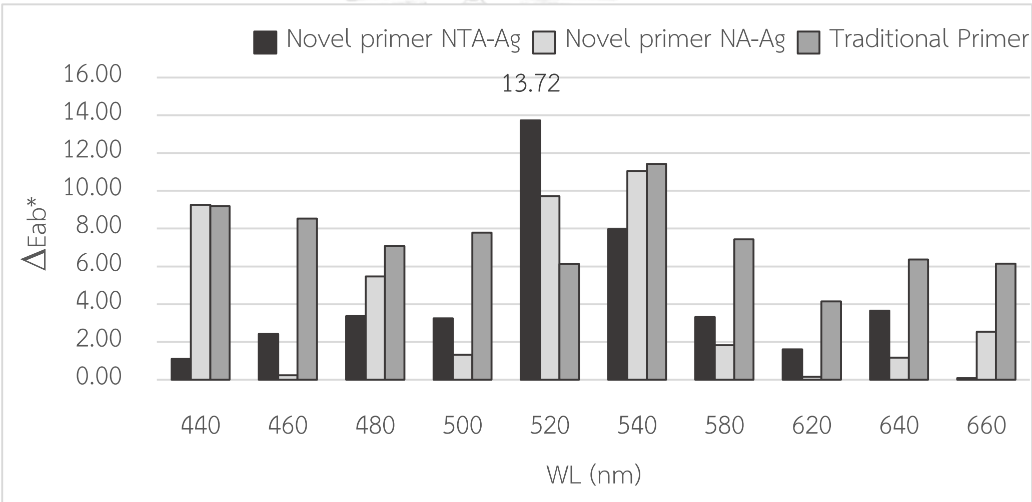


Figure 6.19 color difference (ΔEab*) of primers that were influenced by UV radiation for 40 days.

Figure 6.20 showed color difference of primers that were exposed by UV radiation for 1000 hours. The results expressed clearly at the range of 410 to 700 nm. At 410 and 690 nm, ΔEab* of traditional appeared very high. At 410 nm, ΔEab* of traditional primer was 29.73, while it was 6.13 for novel primer NTA-Ag and 1.54 for NA-Ag. At 690 nm, ΔEab* were 33.93, 1.54 and 2.94 for traditional primer, novel primer NTA-Ag, and NA-Ag respectively.

Considering of all wavelength range, ΔEab* of novel primer NTA-Ag after it was exposed by light, was not big difference, while the novel primer-NA-Ag and traditional primer appeared high ΔEab* at some particular wavelength.

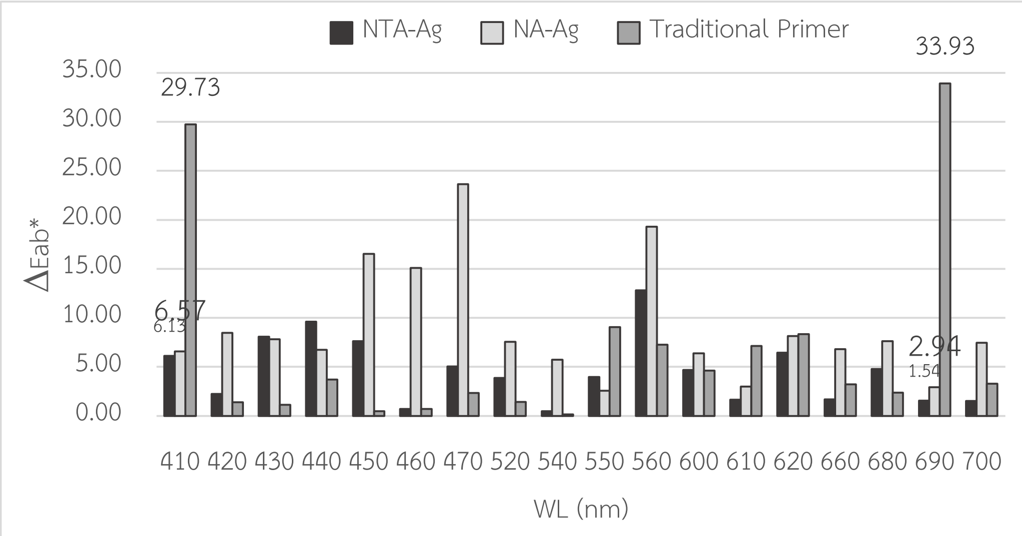


Figure 6.20 color difference (ΔEab*) of primers that were influenced by UV radiation for 1000 hours.

CHAPTER 7
Conclusion

In this research, we focused three major areas: primers' formulations and its antibacterial property, traditional Thai style color acrylic paint and pastel formulations, and multi-spectrum characterization of the primers, acrylic paints and pastels that were affected by light, heat and humidity.

Primers' formulations

It is important to find out that Thai traditional primer with AgNPs does not improve the antibacterial property tested against *Bacillus subtilis, B. cereus*, *B. mycoides,* and *Leclercia adecarboxylata* which were taken from the Thai mural painting surface. However, the amount and concentration of AgNPs used in this study was constant and may be insufficient. The further study of the effect of concentration and amount of AgNPs in the primer on inhibition of these 4 species should be carried out. The novel primers containing both TiO_2 and Al_2SiO_5 as pigments improved the antibacterial property tested against 4 species of bacteria mentioned above and adding AgNPs increased the inhibition effect. However, using this primer may be appropriate when painting layer is not applied because TiO_2 could discolor the paint. The primer that contained only Al_2SiO_5 as pigment could inhibit of *L. adecarboxylata.* Adding AgNPs to it could help in inhibiting one more strain of *B. mycoides*. Therefore, this primer could be a better choice to replace the traditional primer. Moreover, results of scrub resistance revealed that the novel primers showed dramatically high resistance to scrub compared with the Thai traditional primer which was easily damaged. Washability results of the novel primers also showed washable property without any damages on its surface, while the traditional primer film was erode and damaged by water easily. With regards to artists' satisfaction in using these novel primers, the results of brush testing performed by 5 Thai artists working at Ten Division of the Traditional Thai Crafts, The Fine Art Department, Ministry of Culture clearly showed the high percentage of satisfaction.

Pastel formulations

Formulations of traditional Thai style color pastel were well achieved. Twelve primary colors made of a mixture of organic, inorganic pigments, $CaCO_3$ and gum tragacanth. These primary colors were used to make paints calibration and the database of spectrum reflectance and the K/S over various concentrations. This database was used to generate the formulations of traditional Thai style colors pastels that correspond to colors named in the Thai color dictionary. To obtain color values accurately, we considered a good color matching if the maximum predicted ΔE_{00} was 1. Results showed that 99 colors out of 147 colors were formulated with predicted ΔE_{00} of no more than 1. Twenty-five colors were formulated but with predicted ΔE_{00} were between 1 and 2. Formulations of 14 colors were predicted with predicted ΔE_{00} between 2 to 3. Seven colors were considered as unmatchable because theΔE_{00} were higher than 3, while 2 colors were not able to formulate. Suggestion for further study or for industrial purpose should consider to add more primary colors. We formulated and made 40 colors of pastel samples with ΔE_{00} less than 3. Brush testing of these colors were performed by 5 Thai artists working at the Fine Art Department. The results presented that artists well satisfied overall of these pastels. A suggestion that may need to consider for further formulation is the hiding power. Artists mentioned that our pastel samples were proper for watery style or tinting area painting, while a more opacity is required for solid area. In addition, the color tolerance under 6500K, 45/0 by ten artists who expertise in Thai colors showed that, for 20 selected Thai colors covered 10 color categories, artists determined to accept ΔE_{00} color tolerance up to 5.6. This results related and supported the criteria of ΔE_{00} that we used in making the pastel samples.

Acrylic paints formulations

Formulation of the traditional Thai style color acrylic paints were achieved with suggestions. We formulated eleven primary colors by mixing of organic, inorganic pigments, styrene/acrylic as binder and aluminium silicate as filler. These primary colors were used to make paints calibration and database of spectrum reflectance and

K/S. The database was used to generate the formulations of traditional Thai style colors acrylic paints that correspond to colors named in the Thai color dictionary. We formulated only 100 colors out of 147 colors. The results showed that 33 out of 100 colors were well matched having predicted ΔE_{00} of less than 1, while 14 colors were able to match but the predicted ΔE_{00} were in between 1- 2. 19 colors were not good matched as the predicted ΔE_{00} were in between 2-3. Thirty-four colors would be considered as unmatchable since the predictive ΔE_{00} >3. Suggestion was to add red, green and blue shades to the primaries. Artists overall satisfied on Thai style color acrylic paints but strong recommendation was given for the tinting strength of the colors as it was particularly not satisfied. Suggestion was pigment volume concentration should be carried out to improve for further study.

Multi-spectrum imaging of simulated aging primary, traditional Thai style colors and primers

1) Four primary colors: Colanyl Green GG 131-TH (Phthalocyanine Green, PG7), Colanyl Pink E (Quinacridone PR122), Hostaperm Red D3G 70 (Pyrrole Red, PR 254) and Hostoperm Violet RLS-EF (Dioxazine purple, PV23); 2) two traditional Thai style colors: “Dang Sen” and “Khiao Khram” and 3) three primers: novel primer NTA-Ag, novel primer NA-Ag and traditional primer, were simulated under different conditions of humidity, heat and UV radiation. Multi-spectrum images of these samples were evaluated and distinguished wavelengths were used to study the changing of paints and primer affected by conditions mentioned above. Results presented that L* of all of colors were affected as decreasing when the aging time by humidity and heat increased, while the “Khiao Khram” and three types of primer showed increasing of L* data. Influencings of UV radiation on these paints and primers sample were summarized that UV radiation effected L* of paints and primers at different distinguished wavelength.

Analytical chemistry methods to evaluate the structural change of paints and primers would be recommended for further study, it might help to reach the understanding the causes of changing.

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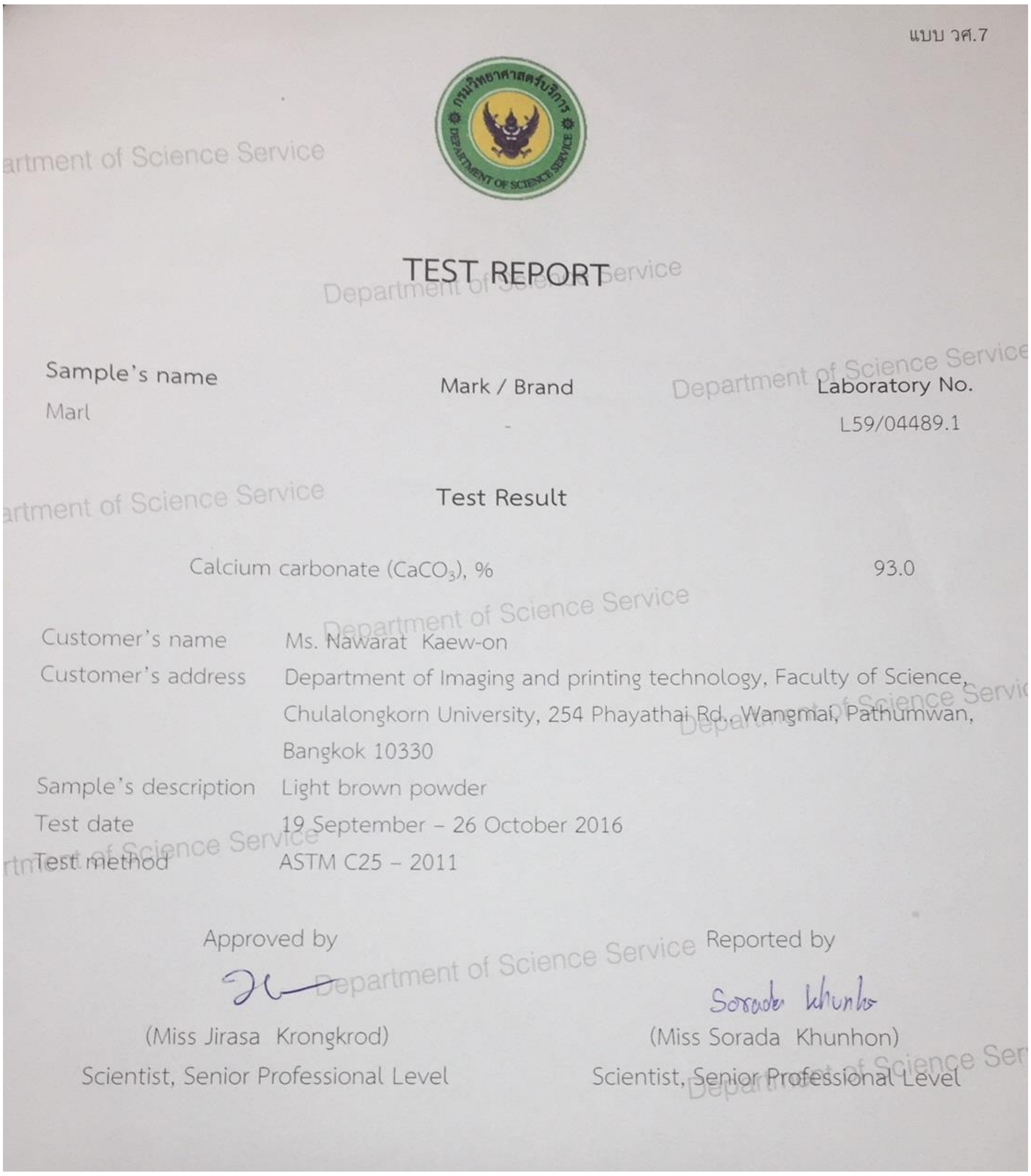
APPENDIX

APPENDIX A



แบบ วศ.7

TEST REPORT

Sample's name	Mark / Brand	Laboratory No.
Marl	-	L59/04489.1

Test Result

Calcium carbonate ($CaCO_3$), %	93.0

Customer's name: Ms. Nawarat Kaew-on

Customer's address: Department of Imaging and printing technology, Faculty of Science, Chulalongkorn University, 254 Phayathai Rd., Wangmai, Pathumwan, Bangkok 10330

Sample's description: Light brown powder

Test date: 19 September – 26 October 2016

Test method: ASTM C25 – 2011

Approved by

(Miss Jirasa Krongkrod)

Scientist, Senior Professional Level

Reported by

(Miss Sorada Khunhon)

Scientist, Senior Professional Level

Figure A1 Tested report of the white clay.

Figure A2

<u>B14 = *Bacillus Subtilis* (identify = 100%)</u>

GATGTTAGCGGCGGACGGGTGAGTAACACGTGGGTAACCTGCCTGTAAGA
CTGGGATAACTCCGGGAAACCGGGGCTAATACCGGATGGTTGTTTGAACC
GCATGGTTCAAACATAAAAGGTGGCTTCGGCTACCACTTACAGATGGACCC
GCGGCGCATTAGCTAGTTGGTGAGGTAATGGCTCACCAAGGCAACGATGC
GTAGCCGACCTGAGAGGGTGATCGGCCACACTGGGACTGAGACACGGCC
CAGACTCCTACGGGAGGCAGCAGTAGGGAATCTTCCGCAATGGACGAAAG
TCTGACGGAGCAACGCCGCGTGAGTGATGAAGGTTTTCGGATCGTAAAGCT
CTGTTGTTAGGGAAGAACAAGTACCGTTCGAATAGGGCGGTACCTTGACGG
TACCTAACCAGAAAGCCACGGCTAACTACGTGCCAGCAGCCGCGGTAATA
CGTAGGTGGCAAGCGTTGTCCGGAATTATTGGGCGTAAAGGGCTCGCAGG
CGGTTTCTTAAGTCTGATGTGAAAGCCCCCGGCTCAACCGGGGAGGGTCAT
TGGAAACTGGGGAACTTGAGTGCAGAAGAGGAGAGTGGAATTCCACGTGT
AGCGGTGAAATGCGTAGAGATGTGGAGGAACACCAGTGGCGAAGGCGAC
TCTCTGGTCTGTAACTGACGCTGAGGAGCGAAAGCGTGGGGAGCGAACAG
GATTAGATACCCTGGTAGTCCACGCCGTAAACGATGAGTGCTAAGTGTTAG
GGGGTTTCC

<u>C1 = *Bacillus cereus* (identify = 100%)</u>

ATGAAGTTAGCGGCGGACGGGTGAGTAACACGTGGGTAACCTGCCCATAA
GACTGGGATAACTCCGGGAAACCGGGGCTAATACCGGATAACATTTTGAAC
CGCATGGTTCGAAATTGAAAGGCGGCTTCGGCTGTCACTTATGGATGGACC
CGCGTCGCATTAGCTAGTTGGTGAGGTAACGGCTCACCAAGGCAACGATG
CGTAGCCGACCTGAGAGGGTGATCGGCCACACTGGGACTGAGACACGGC
CCAGACTCCTACGGGAGGCAGCAGTAGGGAATCTTCCGCAATGGACGAAA
GTCTGACGGAGCAACGCCGCGTGAGTGATGAAGGCTTTCGGGTCGTAAAA
CTCTGTTGTTAGGGAAGAACAAGTGCTAGTTGAATAAGCTGGCACCTTGAC
GGTACCTAACCAGAAAGCCACGGCTAACTACGTGCCAGCAGCCGCGGTAA
TACGTAGGTGGCAAGCGTTATCCGGAATTATTGGGCGTAAAGCGCGCGCA
GGTGGTTTCTTAAGTCTGATGTGAAAGCCCACGGCTCAACCGTGGAGGGTC

ATTGGAAACTGGGAGACTTGAGTGCAGAAGAGGAAAGTGGAATTCCATGTG
TAGCGGTGAAATGCGTAGAGATATGGAGGAACACCAGTGGCGAAGGCGAC
TTTCTGGTCTGTAACTGACACTGAGGCGCGAAAGCGTGGGGAGCAAACAG
GATTAG

C3 = *Bacillus subtilis* (identify = 100%)

GATGTTAGCGGCGGACGGGTGAGTAACACGTGGGTAACCTGCCTGTAAGA
CTGGGATAACTCCGGGAAACCGGGGCTAATACCGGATGGTTGTTTGAACC
GCATGGTTCAAACATAAAAGGTGGCTTCGGCTACCACTTACAGATGGACCC
GCGGCGCATTAGCTAGTTGGTGAGGTAACGGCTCACCAAGGCAACGATGC
GTAGCCGACCTGAGAGGGTGATCGGCCACACTGGGACTGAGACACGGCC
CAGACTCCTACGGGAGGCAGCAGTAGGGAATCTTCCGCAATGGACGAAAG
TCTGACGGAGCAACGCCGCGTGAGTGATGAAGGTTTTCGGATCGTAAAGCT
CTGTTGTTAGGGAAGAACAAGTACCGTTCGAATAGGGCGGTACCTTGACGG
TACCTAACCAGAAAGCCACGGCTAACTACGTGCCAGCAGCCGCGGTAATA
CGTAGGTGGCAAGCGTTGTCCGGAATTATTGGGCGTAAAGGGCTCGCAGG
CGGTTTCTTAAGTCTGATGTGAAAGCCCCCGGCTCAACCGGGGAGGGTCAT
TGGAAACTGGGGAACTTGAGTGCAGAAGAGGAGAGTGGAATTCCACGTGT
AGCGGTGAAATGCGTAGAGATGTGGAGGAACACCAGTGGCGAAGGCGAC
TCTCTGGTCTGTAACTGACGCTGAGGAGCGAAAGCGTGGGGAGCGAACAG
GATTA

D3 = *Bacillus mycoides* (identify = 99%)

GTCGAGCGAACTGATTAAGAGCTTGCTCTTATGAAGTTAGCGGCGGACGGG
TGAGTAACACGTGGGTAACCTGCCCATAAGACTGGGATAACTCCGGGAAA
CCGGGGCTAATACCGGATAATATTTTGCGCCTCATGGCGCGAAATTGAAAG
GCGGCTTCGGCTGTCACTTATGGATGGACCCGCGTCGCATTAGCTAGTTGG
TGAGGTAACGGCTCACCAAGGCGACGATGCGTAGCCGACCTGAGAGGGT
GATCGGCCACACTGGGACTGAGACACGGCCCAGACTCCTACGGGAGGCA
GCAGTAGGGAATCTTCCGCAATGGACGAAAGTCTGACGGAGCAACGCCGC
GTGAGTGATGAAGGCTTTCGGGTCGTAAAACTCTGTTGTTAGGGAAGAACA
AGTGTGAGTTGAATAAGCTCACGCCTTGACGGTACCTAACCAGAAAGCCAC

GGCTAACTACGTGCCAGCAGCCGCGGTAATACGTAGGTGGCAAGCGTTAT
CCGGAATTATTGGGCGTAAAGCGCGCAGGTGGTTTCTTAAGTCTGATGT
GAAAGCCCACGGCTCAACCGTGGAGGGTCATTGGAAACTGGGAGACTTGA
GTGCAGAAGAGGAAAGTGGAATTCCATGTGTAGCGGTGAAATGCGTAGAG
ATATGGAGGAACACCAGTGGCGAAGGCGACTTTCTGGTCTGTAACTGACAC
TGAGGCGCGAAAGCGTGGGGAGCAAACAGGATTAGATACCCTGGTAGTCC
ACGCCGTAAACGATGAGTGCTAAGTGTTAGAGGGTTTCCGCCCTTTAGTGC
TGAAGTTAACGCATTAAGCACTCCGCCTGGGGAGTACGGCCGCAAGGCTG
AACTCAAAGGAATTGACGGGGGCCCGCACAAGCGGTGGAGCATGTGGTTT
AATTCGAAGCAACGCGAAGAACCTTACCAGTCTTGACATCCTCTGACACCC
TAGAGATAGGGCTTCCCCTTCGGGCAGAGTGACAGTGGTGCATGGTTGTC
GTCAGCT

IM5 = *Leclercia adecarboxylata* (identify = 99%)

CGGGTGACGAGTGGCGGACGGGTGAGTAATGTCTGGGAAACTGCCTGATG
GAGGGGGATAACTACTGGAAACGGTAGCTAATACCGCATAACGTCGCAAG
ACCAAAGAGGGGGACCTTCGGGCCTCTTGCCATCGGATGTGCCCAGATGG
GATTAGCTAGTAGGTGGGGTAATGGCTCACCTAGGCGACGATCCCTAGCTG
GTCTGAGAGGATGACCAGCCACACTGGAACTGAGACACGGTCCAGACTCC
TACGGGAGGCAGCAGTGGGGAATATTGCACAATGGGCGCAAGCCTGATGC
AGCCATGCCGCGTGTATGAAGAAGGCCTTCGGGTTGTAAAGTACTTTCAGC
GAGGAGGAAGGCATTGTGGTTAATAACCTCAGTGATTGACGTTACTCGCAG
AAGAAGCACCGGCTAACTCCGTGCCAGCAGCCGCGGTAATACGGAGGGT
GCAAGCGTTAATCGGAATTACTGGGCGTAAAGCGCACGCAGGCGGTCTGT
TAAGTCAGATGTGAAATCCCCGGGCTCAACCTGGGAACTGCATTTGAAACT
GGCAGGCTTGAGTCTTGTAGAGGGGGGTAGAATTCCAGGTGTAGCGGTGA
AATGCGTAGAGATCTGGAGGAATACCGGTGGCGAAGGCGGCCCCCTGGA
CA

Table A1 Specification and certificate of analysis of the TiO_2

Grade:	R902
Manufacturer:	Dupont
Lot number	-

Property	Specification		
	Min	Max	Analysis
TiO_2	94		94
RES	4.0		9.6
pH	7.3	8.5	8.1
Gloss	60.0		67.8
L	99.2		99.8
CBU	10.0	14.0	12.1
OA	13.0	20.0	14.6
FINENESS	7.0		7.2
NDPT	4.0		6.6
SCATS		15.0	7.6
A	-0.90	-0.30	-0.53
B	1.60	2.80	2.16

Table A2 Specification of $CaCO_3$

Grade:	Calcium Carbonate 01 (Undercoating)
Manufacturer:	-
Lot number:	-

Property	Unit	
Specific Surface Area	cm2/g	18,000±1000
Average particle size	Micron 1/1,000 mm.	4.5
Residue on 325 mesh	%	3
Particle size distribution	1	25
(Diameter : micron)	2	36
	3	43
Percent finer than by weight	4	47
	5	51
True specific gravity	Ton/m3	2.7
Bulk density, Tapped	g/cc	1.15
Whiteness		95
Moisture	%	0.1 Max
pH		9±0.5
Ignition Loss	%	43.3
SiO_2	%	0.2 Max
Fe	%	0.02 Max
$CaCO_3$	%	98 Min
Oil absorption Value	C.C./100 g.	17

Table A3 Specification of ceramic microsphere

Product:	Ceramic Microsphere
Grade:	W410
Manufacturer:	3M
Lot number:	-

Property	
True Denty	2.4g/cc (20.0 lbs/gal)
Bulk Density	1.5 g/cc (12.6 lbs/gal)
Particle Size (micron)	Median: 4 Top: 24
Whiteness ("L" Value)[ASTM D2244]	95+ (Hunter L,a,b scale)
Crush Strength	>4,200 kg/cm2(>60,000 psi)
pH [ASTN E70]	9.0-12.0
Hardness [Mohs Scale]	7
Softening Point	1,020oC (1,870oF)
Refractive Index [Becke Line]	1.53
Dielectric Constant	3.19
UV Light Transmission	UV Transparent to 250 nm
Thermal Conductivity	2.3 W/mK

Figure A3

แบบสอบถามความพึงพอใจของศิลปินต่อการทดลองใช้สารรองพื้นแบบโบราณ

ชื่อศิลปิน ____ วันที่________________

กรุณาแสดงความคิดเห็นต่อลักษณะคุณสมบัติของสารรองพื้นโดยให้คะแนนตามเกณฑ์ด้านล่าง

7 = พอใจมากที่สุด (the most satisfied) 6 = พอใจมาก (very satisfied)

5 = พอใจ (satisfied) 4 = เฉยๆ (neither satisfied nor dissatisfied)

3 = ไม่พอใจ (the most satisfied) 2 = ไม่พอใจมาก (somewhat dissatisfied) 1 = ไม่พอใจมากที่สุด (the most dissatisfied)

	Score / คะแนน						
	7	6	5	4	3	2	1
A. satisfaction on viscosity ความพึงพอใจต่อความหนืด							
B. satisfaction on primers' fineness. ความพึงพอใจต่อความละเอียดของเนื้อสาร							
C. satisfaction on applying (flow or leveling) it on the substrate with painting brush? ความพึงพอใจต่อความยากง่าย ความสะดวกในการระบายลงบนพื้นผิว							
D. satisfaction on primer drying. ความพึงพอใจต่อการแห้งตัว							
E. satisfaction on color of primer after coating and drying. ความพึงพอใจต่อการแห้งตัวของสารรองพื้น							
F. satisfaction on hiding power. ความพึงพอใจต่อการกลบปิดพื้นผิว							
G. effect of primer on paints absorbance, paint drying. ความพึงพอใจต่อผลของสารรองพื้นที่มีต่อลักษณะของสีที่ระบายลงไป เช่นการดูดซึมสี การแห้งตัวของสี							
H. effect of primer on paints appearance after the paints dry completely. ความพึงพอใจของผลของสารรองพื้นที่มีต่อลักษณะของสีภายหลังจากที่สีนั้นแห้งตัวแล้ว							
I. Overall satisfaction. ความพึงพอใจโดยรวม							

Figure A4

แบบสอบถามความพึงพอใจของศิลปินต่อการทดลองใช้สารรองพื้นแบบใหม่

พื้นผิว____________________________ สูตรสารรองพื้น __________________

ชื่อศิลปิน ____ วันที่_______________________

กรุณาแสดงความคิดเห็นต่อลักษณะคุณสมบัติของสารรองพื้นโดยให้คะแนนตามเกณฑ์ด้านล่าง

7 = พอใจมากที่สุด (the most satisfied) 6 = พอใจมาก (very satisfied) 5 = พอใจ (satisfied) 4 = เฉยๆ (neither satisfied nor dissatisfied)

3 = ไม่พอใจ (the most satisfied) 2 = ไม่พอใจมาก (somewhat dissatisfied) 1 = ไม่พอใจมากที่สุด (the most dissatisfied)

	Score / คะแนน						
	7	6	5	4	3	2	1
satisfaction on viscosity ความพึงพอใจต่อความหนืด							
satisfaction on primers' fineness. ความพึงพอใจต่อความละเอียดของเนื้อสาร							
satisfaction on primers' wet color. ความพึงพอใจต่อสีของสารรองพื้นตอนเปียก							
satisfaction on primers' odour. ความพึงพอใจต่อกลิ่น							
A. satisfaction on applying (flow or leveling) it on the substrate with painting brush? ความพึงพอใจต่อความยากง่าย ความสะดวกในการระบายลงบนพื้นผิว							
B. satisfaction on primer drying. ความพึงพอใจต่อการแห้งตัว							
C. satisfaction on color of primer after coating and drying. ความพึงพอใจต่อการแห้งตัวของสารรองพื้น							
D. satisfaction on hiding power. ความพึงพอใจต่อการกลบปิดพื้นผิว							
E. effect of primer on paints absorbance, paint drying. ความพึงพอใจต่อผลของสารรองพื้นที่มีต่อลักษณะของสีที่ระบายลงไป เช่นการดูดซึมสี การแห้งตัวของสี							
F. effect of primer on paints appearance after the paints dry completely. ความพึงพอใจของผลของสารรองพื้นที่มีต่อลักษณะของสีภายหลังจากที่สีนั้นแห้งตัวแล้ว							
G. Overall satisfaction. ความพึงพอใจโดยรวม							

Figure A5

แบบสอบถามความพึงพอใจของศิลปินต่อการทดลองใช้สีอะคริลิก

ชื่อศิลปิน

_______________________________________ วันที่_______________________

กรุณาแสดงความคิดเห็นต่อลักษณะคุณสมบัติของสารรองพื้นโดยให้คะแนนตามเกณฑ์ด้านล่าง

7 = พอใจมากที่สุด (the most satisfied) 6 = พอใจมาก (very satisfied) 5 = พอใจ (satisfied) 4 = เฉยๆ (neither satisfied nor dissatisfied)

3 = ไม่พอใจ (the most satisfied) 2 = ไม่พอใจมาก (somewhat dissatisfied) 1 = ไม่พอใจมากที่สุด (the most dissatisfied)

	Score / คะแนน						
	7	6	5	4	3	2	1
A. ความพึงพอใจต่อความหนืด (satisfaction on viscosity)							
B. ความพึงพอใจต่อกลิ่น (satisfaction on odour)							
C. ความพึงพอใจต่อความละเอียดของเนื้อสี (satisfaction on fineness)							
E. ความพึงพอใจต่อความเข้มข้นของสารสี (satisfaction on tinting strength of color)							
F. ความพึงพอใจต่อการแห้งตัว (satisfaction on drying)							
G. ความพึงพอใจต่อความสามารถในการกลบผิว (satisfaction on hiding power)							
H. ความพึงพอใจต่อความถูกต้องของสีตามคำเรียกสีไทย (satisfaction on matching of the samples' colors with Thai color name)							
I. ความพึงพอใจโดยรวม (satisfaction on overall satisfaction)							

Figure A6

แบบสอบถามความพึงพอใจของศิลปินต่อการทดลองใช้พาสเทล

ชื่อศิลปิน

_______________________________________ วันที่___________________________

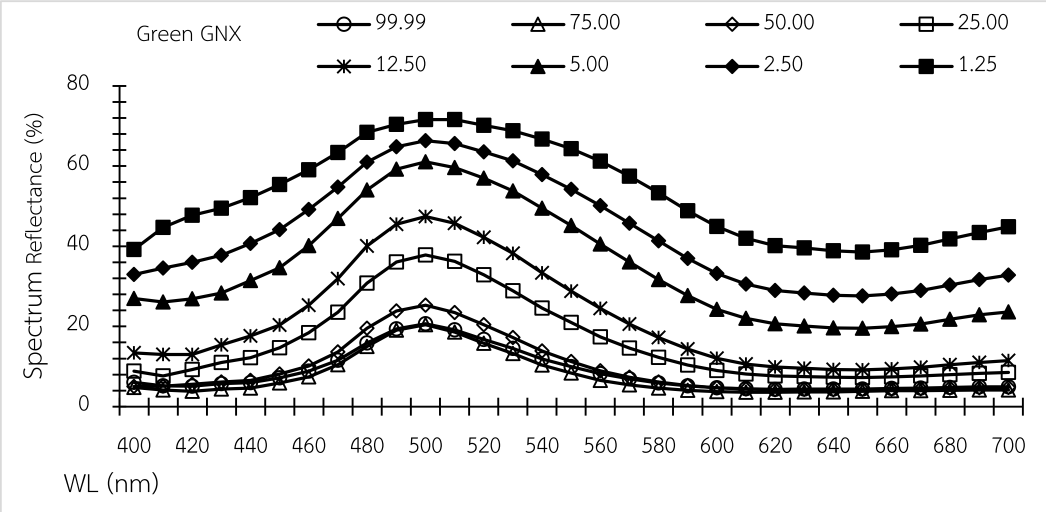
กรุณาแสดงความคิดเห็นต่อลักษณะคุณสมบัติของสารรองพื้นโดยให้คะแนนตามเกณฑ์ด้านล่าง

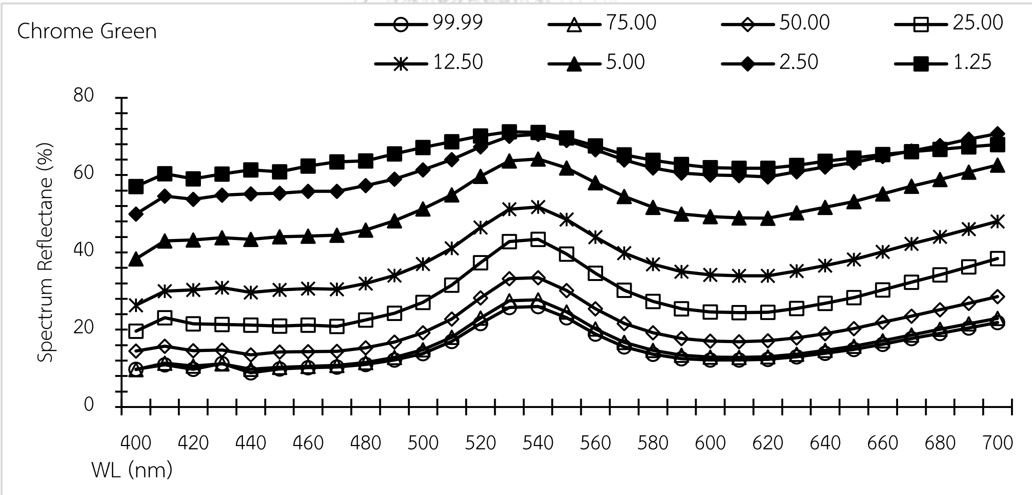
7 = พอใจมากที่สุด (the most satisfied) 6 = พอใจมาก (very satisfied) 5 = พอใจ (satisfied) 4 = เฉยๆ (neither satisfied nor dissatisfied)

3 = ไม่พอใจ (the most satisfied) 2 = ไม่พอใจมาก (somewhat dissatisfied) 1 = ไม่พอใจมากที่สุด (the most dissatisfied)

	Score / คะแนน						
	7	6	5	4	3	2	1
A. ความพึงพอใจต่อความเข้มของเนื้อสี (Tinting strength of color)							
B. ความพึงพอใจต่อความละเอียดของเนื้อสี (Fineness of powder)							
C.ความพึงพอใจต่อการกลบพื้นผิว Hiding power for solid painting							
D. ความพึงพอใจต่อความถูกต้องสอดคล้องกับคำเรียกสีไทย (Color matching with Thai color name)							
E. ความพึงพอใจโดยรวม (Overall satisfaction)							

APPENDIX B





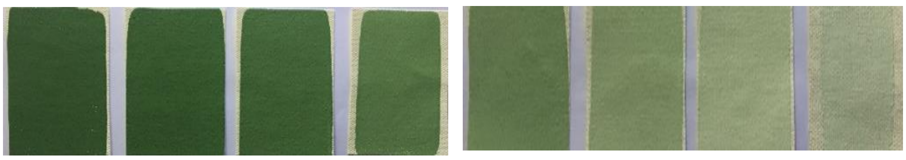
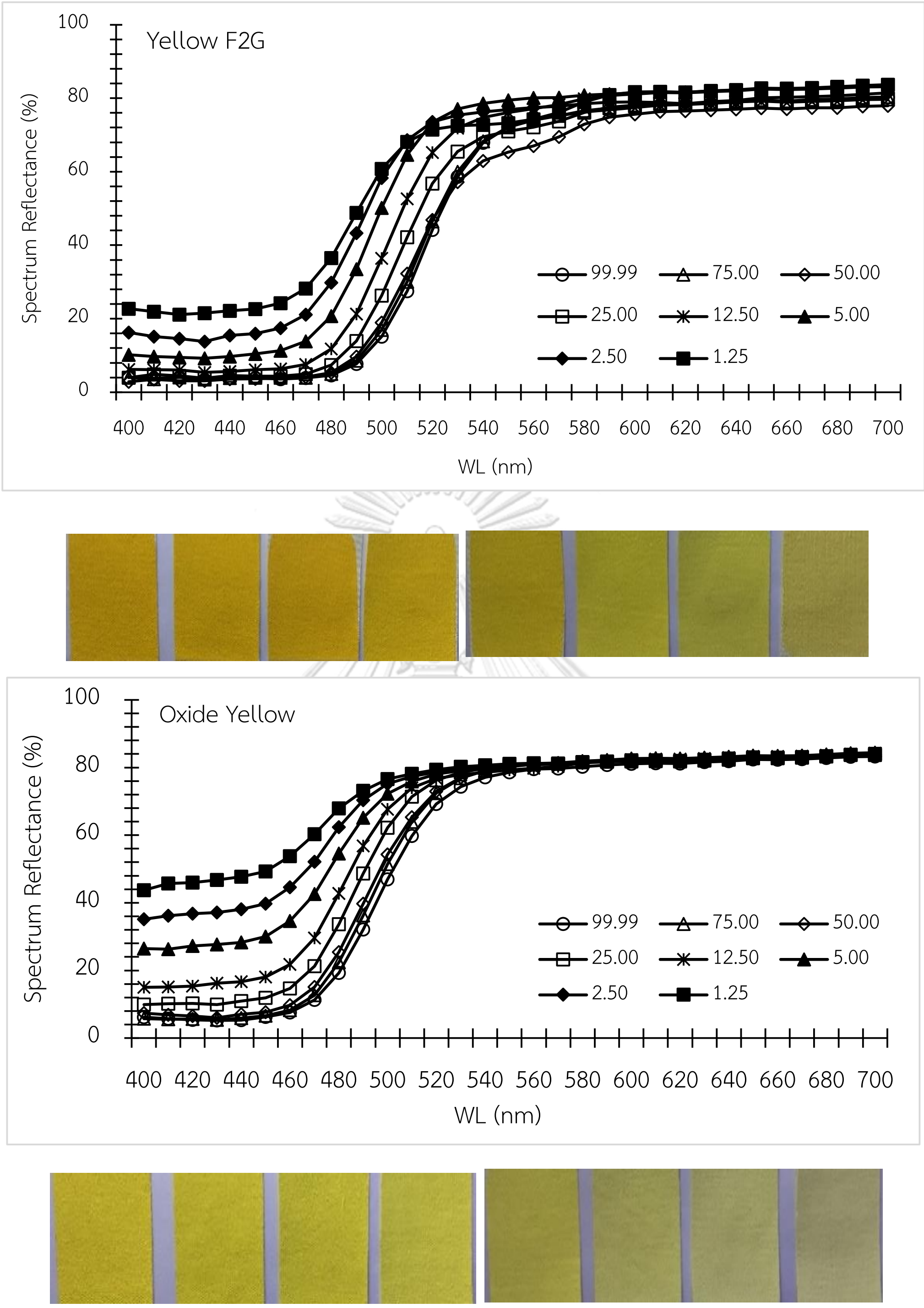


Figure B1 Spectrum reflectance (%) and calibrated color swatches at different concentrations of Green GNX (top) and Chrome Green (bottom**).** % concentration from left to right; 99.99, 75, 50, and 25, 12.50, 5.00, 2.50, and 1.25, respectively Measurement performed in five places with X-Rite SP62, illuminant /observers: D65/2, SPEX.



FigureB2 Spectrum reflectance (%) and calibrated color swatches at different concentrations of Yellow F2G (top) and Oxide Yellow (bottom). % concentration from left to right; 99.99, 75, 50, and 25, 12.50, 5.00, 2.50, and 1.25, respectively Measurement performed in five places with X-Rite SP62, illuminant /observers: D65/2, SPEX.

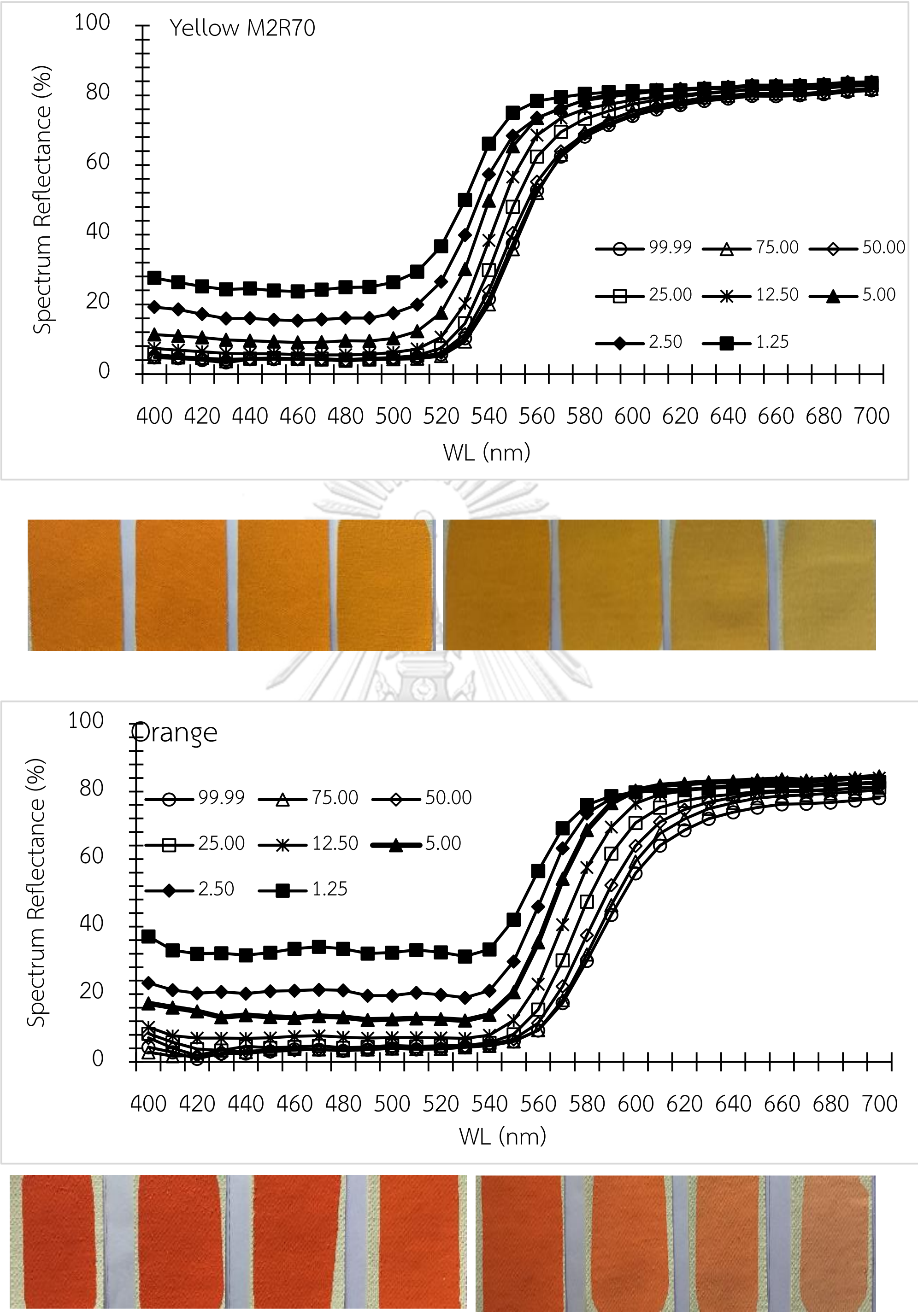


Figure B3 Spectrum reflectance (%) and calibrated color swatches at different concentrations of Yellow M2R70 (top) and Orange GR (bottom). % concentration from left to right; 99.99, 75, 50, and 25, 12.50, 5.00, 2.50, and 1.25, respectively Measurement performed in five places with X-Rite SP62, illuminant /observers: D65/2, SPEX.

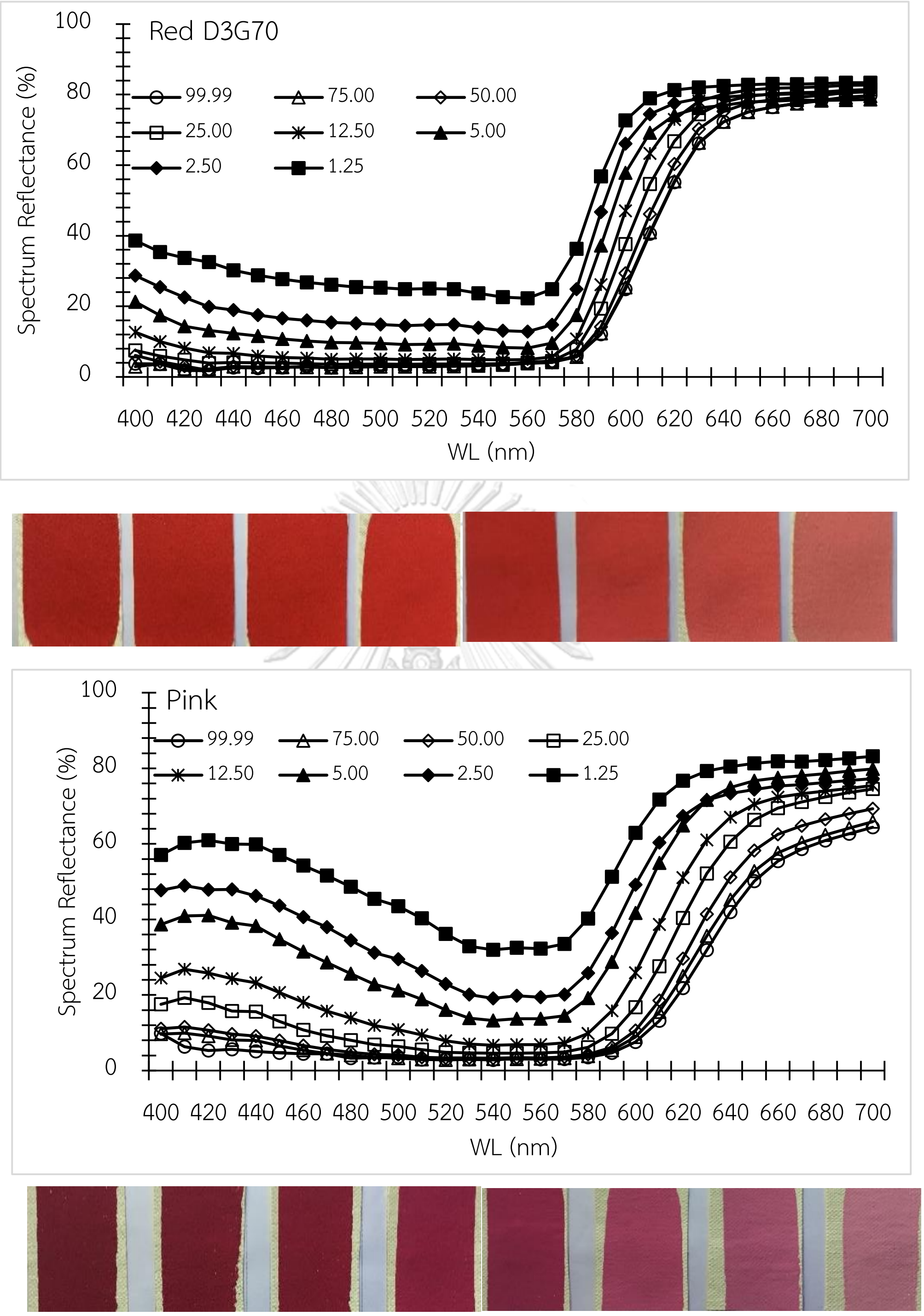


Figure B4 Spectrum reflectance (%) and calibrated color swatches at different concentrations of Red D3G70 (top) and Pink (bottom). % concentration from left to right; 99.99, 75, 50, and 25, 12.50, 5.00, 2.50, and 1.25, respectively Measurement performed in five places with X-Rite SP62, illuminant /observers: D65/2, SPEX.

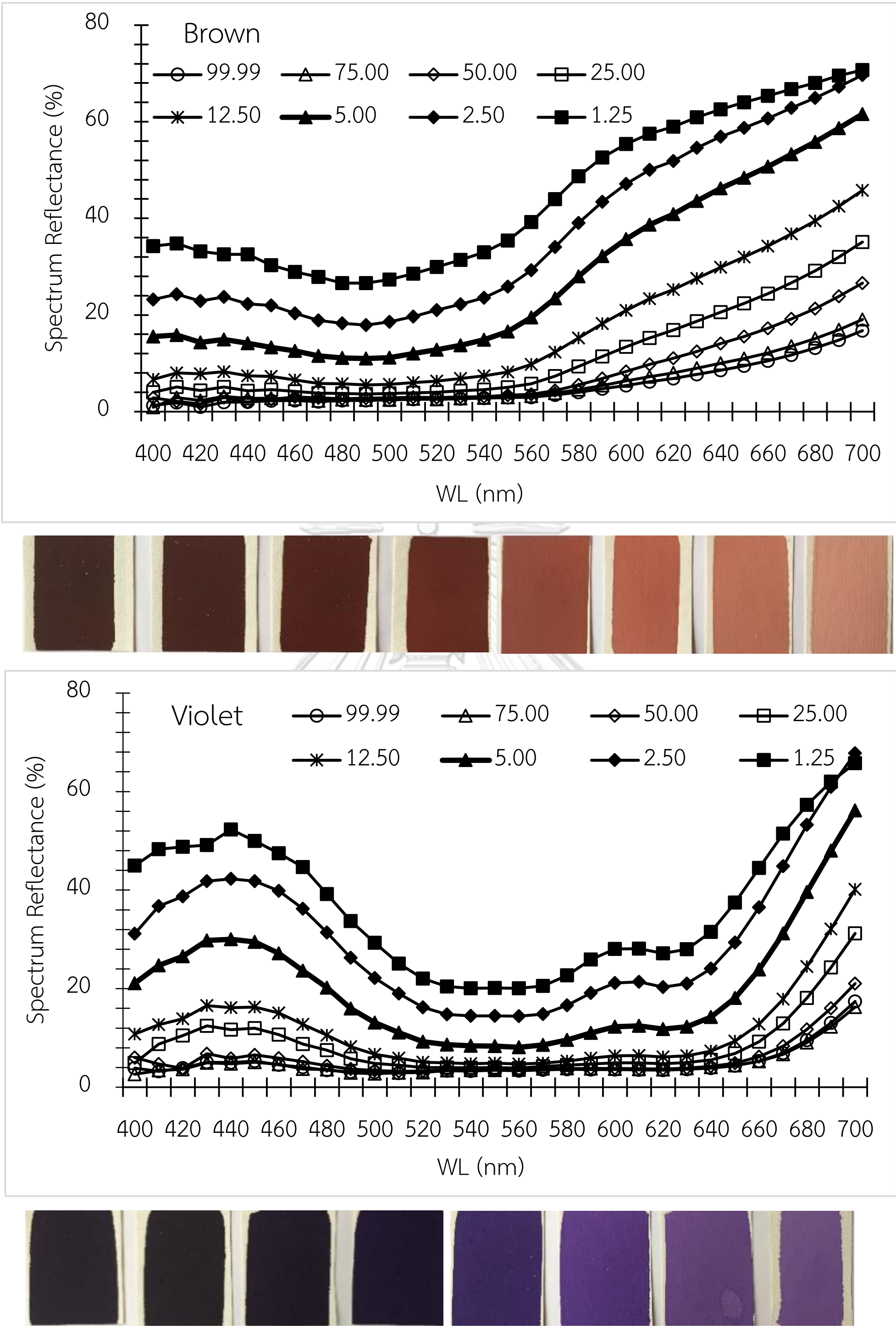


Figure B5 Spectrum reflectance (%) and calibrated color swatches at different concentrations of Brown (top) and Violet (bottom). % concentration from left to right; 99.99, 75, 50, and 25, 12.50, 5.00, 2.50, and 1.25, respectively Measurement performed in five places with X-Rite SP62, illuminant /observers: D65/2, SPEX.

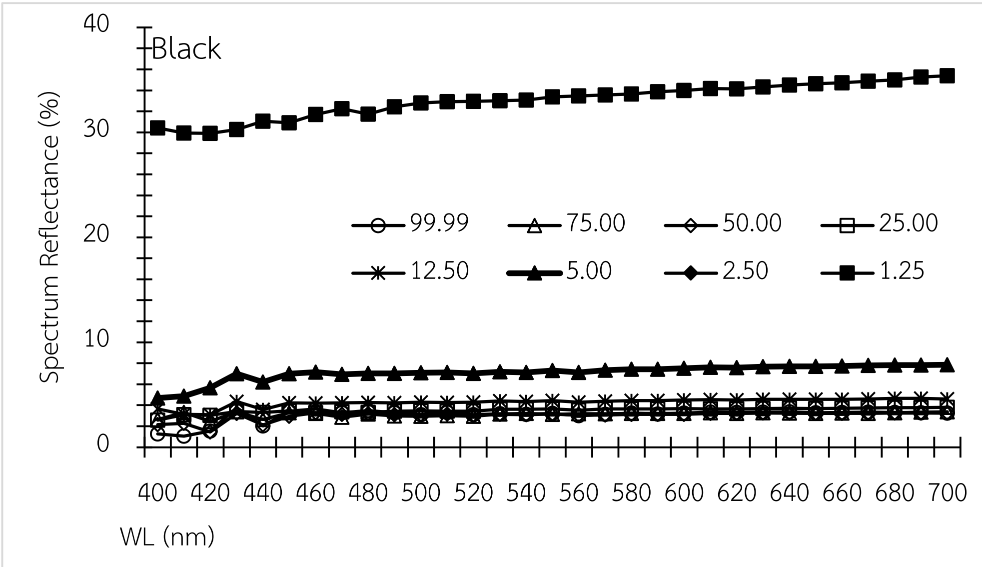


Figure B6 Spectrum reflectance (%) and calibrated color swatches at different concentrations of Black. % concentration from left to right; 99.99, 75, 50, and 25, 12.50, 5.00, 2.50, and 1.25, respectively Measurement performed in five places with X-Rite SP62, illuminant /observers: D65/2, SPEX.

Table B1 Spectrum reflectance of pastel primary color “Blue BX” at different concentration (%)

WL	Concentration (%)							
(nm)	99.99	75.00	50.00	25.00	12.50	5.00	2.50	1.25
400	7.1850	9.5580	9.9560	12.6000	18.0040	30.9650	39.7090	45.1810
410	7.5630	8.9160	10.1020	14.2370	23.2730	34.9850	44.9720	53.5790
420	8.5630	9.0200	10.9550	16.6520	27.1100	38.3750	47.6610	58.9010
430	10.9680	11.6590	15.2120	20.3940	32.1360	43.8540	53.2240	62.8190
440	14.8480	15.3580	19.4900	26.4150	38.5680	50.7750	60.0550	67.1540
450	18.9920	19.1920	24.4860	31.8660	45.5500	57.0750	65.3380	71.0580
460	20.1120	20.4700	26.2050	33.9250	47.2540	58.7860	66.3620	70.9170
470	19.9580	20.5710	25.8280	33.6570	46.7690	58.8380	65.8930	70.2990
480	18.4080	18.8810	24.1810	31.7910	45.2690	57.6560	65.7800	70.8210
490	16.0600	17.0060	21.4020	28.6390	41.9570	54.8540	63.3250	69.1330
500	13.5960	14.8880	18.7590	25.1950	38.2050	51.6440	60.5570	67.4050
510	10.8070	12.2650	15.2400	20.6200	33.0790	46.2580	55.6280	64.3420
520	8.4670	10.1690	12.0140	16.3720	27.6270	40.3990	49.7500	59.3670
530	6.5900	8.3670	9.5530	12.7220	22.3560	34.1480	43.3050	53.8580
540	5.0470	6.7450	7.3840	9.5940	17.6910	27.9770	36.3980	47.5120
550	4.3440	5.9900	6.1840	7.7030	14.3880	23.2610	30.4150	41.2450
560	3.5780	4.9090	4.9910	6.0140	11.1780	18.5420	24.7980	35.1050
570	3.3720	4.5050	4.3690	5.0720	9.2970	15.3830	20.7370	30.5420
580	3.3110	4.3010	4.1350	4.6330	8.3460	13.6050	18.5490	27.9090
590	3.3260	4.2890	4.0570	4.5020	7.7890	12.7740	17.3410	26.2930
600	3.3760	4.2370	4.0090	4.3680	7.4920	12.1010	16.3910	25.1980
610	3.4420	4.2770	4.0360	4.2980	7.1680	11.5250	15.6220	24.2620
620	3.5370	4.3480	4.0480	4.2820	7.0300	11.3420	15.3110	23.8060
630	3.6060	4.3700	4.1000	4.3490	7.1250	11.4770	15.5350	24.2570
640	3.6590	4.4490	4.1500	4.4010	7.2660	11.7680	15.8690	24.6940
650	3.6900	4.5340	4.1860	4.5190	7.5260	12.3300	16.6470	25.7240
660	3.7110	4.5880	4.2680	4.6370	7.7920	12.8930	17.4590	26.7270
670	3.6650	4.5600	4.2330	4.6140	7.8770	13.0530	17.6090	27.0530
680	3.7230	4.6070	4.2890	4.6420	7.7830	12.9330	17.5030	26.7570
690	3.7250	4.5670	4.2690	4.6030	7.5690	12.5460	17.0630	26.2550
700	3.7570	4.5050	4.1520	4.5020	7.3290	11.9660	16.3360	25.5440

Table B2 Spectrum reflectance of pastel primary color “Green GNX” at different concentration (%)

WL	Concentration (%)							
(nm)	99.99	75.00	50.00	25.00	12.50	5.00	2.50	1.25
400	6.0480	4.7780	5.0380	8.8290	13.4260	26.9580	32.9860	39.2030
410	5.1480	4.1510	5.0720	7.6550	13.0140	26.1150	34.5470	44.7000
420	5.1160	3.7850	5.5910	9.2550	12.9740	26.8610	35.9990	47.7070
430	5.7670	4.4100	6.1650	11.0150	15.4120	28.3430	37.7490	49.4700
440	5.9420	4.6540	6.5750	12.1880	17.6140	31.4630	40.6710	52.1430
450	7.1920	5.9010	8.1220	14.6430	20.3580	34.6140	44.1350	55.4250
460	8.8560	7.4220	10.1220	18.3950	25.2700	40.1510	49.1470	59.0750
470	11.5800	10.4470	13.6760	23.5230	31.9270	46.9020	54.7820	63.3570
480	15.8750	15.0050	19.5130	30.8450	40.0890	54.0220	60.9870	68.3770
490	19.4020	19.1080	23.8780	36.0600	45.4570	59.2040	64.8200	70.4380
500	20.6660	20.4680	25.2890	37.8100	47.3820	61.0630	66.3500	71.5810
510	19.1460	18.5590	23.4360	36.2400	45.7450	59.6560	65.5810	71.5740
520	16.7230	15.8330	20.3940	32.8440	42.2410	57.0170	63.5530	70.1860
530	14.5050	13.2690	17.2620	28.9170	38.2460	53.7750	61.2880	68.7850
540	11.9140	10.4020	13.9020	24.5700	33.3700	49.5200	57.9060	66.7440
550	9.9730	8.3930	11.2340	21.0190	28.8480	45.1450	54.1910	64.3500
560	8.2060	6.5540	8.9380	17.4000	24.4670	40.5400	50.1120	61.1960
570	6.8980	5.3980	7.3200	14.6000	20.5900	36.0570	45.7480	57.4910
580	5.9240	4.5870	6.1290	12.3220	17.2070	31.7060	41.3390	53.3210
590	5.2010	4.0610	5.2300	10.3460	14.3740	27.7110	36.9930	48.8470
600	4.7070	3.7480	4.7010	8.9830	12.0770	24.2500	33.2020	44.9390
610	4.4500	3.5990	4.3780	8.1040	10.6470	21.9940	30.5460	41.9770
620	4.3360	3.5840	4.2400	7.6240	9.8770	20.6960	28.9750	40.1500
630	4.3730	3.6620	4.2890	7.4810	9.5880	20.0880	28.3520	39.5850
640	4.3520	3.6930	4.2500	7.3070	9.2880	19.6320	27.7690	38.8560
650	4.4010	3.8070	4.2790	7.2470	9.1680	19.5180	27.5790	38.5700
660	4.5350	3.9670	4.4080	7.3900	9.4170	19.9150	28.0650	39.1390
670	4.5950	3.9770	4.4600	7.6310	9.7830	20.5760	28.9330	40.2080
680	4.7810	4.1000	4.6210	7.9960	10.4420	21.7970	30.3500	41.8170
690	4.9050	4.1190	4.7270	8.3040	11.0420	22.8900	31.7110	43.4190
700	4.9410	4.1380	4.8160	8.5280	11.4920	23.5990	32.7840	44.8510

Table B3 Spectrum reflectance of pastel primary color “Chrome Green” at different concentration (%)

WL	Concentration (%)							
(nm)	99.99	75.00	50.00	25.00	12.50	5.00	2.50	1.25
400	9.7470	9.6430	14.4660	19.5900	26.3550	38.3110	49.9160	57.0780
410	10.9160	11.3380	15.7190	23.1340	30.0000	42.9670	54.6020	60.3960
420	9.8080	10.6000	14.5840	21.5580	30.3240	43.2370	53.7280	59.0700
430	11.2650	11.1900	14.7580	21.3890	30.9270	43.7900	54.8240	60.3200
440	8.8310	9.7890	13.4710	21.1650	29.6480	43.3910	55.1640	61.3990
450	9.8330	10.2340	14.2110	20.9690	30.2820	44.0260	55.3430	60.8280
460	10.1960	10.5300	14.3490	21.1940	30.6500	44.2240	55.8160	62.3960
470	10.3310	10.7750	14.3760	20.8990	30.5070	44.5070	55.8230	63.3990
480	10.9780	11.4710	15.3170	22.5360	31.9370	45.8340	57.3150	63.6860
490	12.1500	12.8570	16.8060	24.2900	34.0070	48.2120	58.9710	65.4960
500	13.7860	14.7920	19.2280	27.1120	37.0240	51.2280	61.3510	67.1210
510	16.9900	18.0330	22.7710	31.5270	41.0580	54.9270	64.0040	68.6120
520	21.5800	23.0380	28.2560	37.3600	46.4930	59.6800	67.3440	70.1460
530	25.7850	27.4680	33.2150	42.7940	51.1940	63.6990	70.0770	71.2280
540	26.0310	27.7480	33.4870	43.4050	51.7230	64.2030	70.5950	71.0190
550	23.0620	24.6160	30.1490	39.6050	48.5350	61.8860	68.9800	69.6460
560	18.8520	20.2360	25.4090	34.6010	43.9520	58.0680	66.5740	67.6000
570	15.5750	16.7470	21.5780	30.1930	39.8720	54.4700	63.9260	65.2560
580	13.6620	14.6240	19.2150	27.3000	36.9430	51.7020	61.8990	63.8460
590	12.5310	13.3900	17.7330	25.4400	34.9880	49.9400	60.5410	62.7600
600	12.1490	12.9130	17.0580	24.5650	34.1770	49.2510	60.0700	61.9810
610	12.1500	12.8400	16.9090	24.4130	33.9690	48.9230	59.8330	61.7810
620	12.3450	13.0150	17.1560	24.4980	33.9620	48.8830	59.5550	61.7890
630	13.0020	13.6920	17.9200	25.5380	35.1760	50.2410	60.8580	62.5650
640	13.9060	14.6330	18.9960	26.8430	36.5820	51.6840	62.0800	63.6140
650	14.8690	15.7280	20.2790	28.3500	38.1770	53.2050	63.2380	64.4490
660	16.2500	17.1560	21.9110	30.3200	40.1560	55.1680	64.8030	65.3330
670	17.7320	18.6460	23.5300	32.2990	42.2190	57.1230	66.2610	66.1260
680	19.0530	20.0810	25.1440	34.2260	44.0370	58.8790	67.6340	66.6470
690	20.4450	21.5250	26.8480	36.3020	46.0470	60.7940	69.3050	67.3090
700	21.9000	22.9150	28.5340	38.4060	48.0500	62.5940	70.7200	67.9200

Table B4 Spectrum reflectance of pastel primary color “Yellow F2G” at different concentration (%)

WL	Concentration (%)							
(nm)	99.99	75.00	50.00	25.00	12.50	5.00	2.50	1.25
400	4.1470	4.0110	2.8250	4.0100	6.1700	10.1800	16.2270	22.7270
410	3.8020	3.5340	3.5300	4.8430	6.1050	9.6840	15.1040	21.9190
420	4.0310	4.0450	3.1140	4.4820	6.0190	9.5080	14.5880	21.1270
430	3.3940	3.4840	3.1220	3.8040	5.3850	9.2650	13.7900	21.4880
440	3.9250	3.8630	3.6020	4.5610	5.6540	9.7140	15.4910	22.1250
450	3.9220	3.9690	3.6160	4.3370	6.1540	10.4080	15.9520	22.6450
460	3.5980	3.9430	3.8230	4.3820	6.3250	11.2850	17.4390	24.2190
470	3.8790	3.9810	4.1150	4.9500	7.5970	13.8810	21.0940	28.1970
480	4.6190	4.9960	5.3580	7.4210	11.7780	20.7440	29.8620	36.4930
490	7.6920	8.5880	9.7040	13.9790	21.2900	33.4660	43.3040	48.8270
500	15.1080	16.9830	18.9580	26.3510	36.4350	50.2090	58.2800	60.8160
510	27.5110	30.0610	32.3050	42.1840	52.6160	64.6370	68.6080	68.1470
520	44.1700	46.5050	46.8920	56.8150	65.2880	73.5000	73.5850	71.4940
530	58.6200	59.9460	57.1780	65.5070	71.8410	77.0350	75.3820	72.5460
540	67.8560	68.2980	62.9140	69.4790	74.7440	78.6070	76.2890	72.7690
550	72.1570	72.1500	65.3330	71.0310	76.1240	79.4280	76.8860	73.2050
560	74.2460	74.0060	66.9870	72.0840	77.1630	80.0650	77.4810	74.2850
570	75.2470	75.2200	69.5000	73.6920	78.2570	80.1440	77.7670	76.0990
580	76.2940	76.6020	72.9030	76.1270	79.8790	80.7830	78.4720	78.9510
590	76.8200	77.2720	74.8560	77.5610	80.7280	81.1640	78.8970	80.9110
600	77.4500	77.8240	75.6550	78.1380	81.1610	81.4510	78.9440	81.6510
610	78.1280	78.4600	76.3640	78.5680	81.5020	81.6820	78.7850	81.7690
620	78.2370	78.5070	76.4670	78.5240	81.4810	81.6110	78.5340	81.6180
630	78.6010	78.8290	76.7570	78.7560	81.7430	81.8920	79.0290	82.0310
640	78.9700	79.1890	77.0110	78.9410	82.0430	82.1660	79.3790	82.2160
650	79.3380	79.5190	77.2820	79.2410	82.4820	82.5940	80.1230	82.7020
660	79.0190	79.2200	77.0250	78.9010	82.3240	82.4260	80.2180	82.6780
670	79.4070	79.6260	77.3590	79.1400	82.4930	82.6060	80.3970	82.7710
680	79.6380	79.7930	77.4190	79.2770	82.7230	82.9000	80.6520	83.1030
690	80.0050	80.1540	77.7850	79.5940	83.0300	83.1430	81.0300	83.4840
700	80.2650	80.3680	77.9270	79.6850	83.1510	83.2520	81.4300	83.6960

Table B5 Spectrum reflectance of pastel primary color "Oxide Yellow" at different concentration (%)

WL	Concentration (%)							
(nm)	99.99	75.00	50.00	25.00	12.50	5.00	2.50	1.25
400	6.1450	5.7840	7.4100	9.9090	15.0020	26.4420	35.1700	43.7040
410	5.7490	5.5780	6.8330	10.1750	15.1330	26.2670	36.1760	45.7460
420	5.4350	5.6600	6.5090	10.2450	15.3900	27.2400	36.8230	45.9990
430	5.1810	5.4210	5.9620	9.9330	16.2560	27.7140	37.1370	46.7140
440	5.3110	5.9580	7.0740	10.9120	16.6670	28.3170	38.0660	47.6900
450	6.2630	6.5950	7.6620	11.9080	18.0460	29.9940	39.7490	49.2550
460	7.5720	8.2680	9.7590	14.6830	21.7830	34.6540	44.5650	53.7350
470	11.2670	12.6920	15.1440	21.2360	29.6250	42.5960	52.1430	60.2660
480	19.3100	22.3960	25.4060	33.6680	42.7820	54.5120	62.3510	67.9120
490	32.0790	36.2710	39.7370	48.6240	56.7880	65.0900	70.3000	73.1030
500	46.9280	51.4610	54.2580	62.2190	67.6720	72.2330	75.1810	76.5710
510	59.7390	63.8760	65.2950	71.3570	73.9800	75.9110	77.3450	78.1160
520	69.1660	72.3740	72.9350	76.2590	76.7610	78.0210	78.6980	79.3180
530	74.3360	76.8330	77.0190	78.5590	77.9120	79.1220	79.5140	80.1870
540	77.0820	79.1280	79.1190	79.7750	78.5450	79.8260	80.0750	80.6630
550	78.5860	80.3780	80.2600	80.5960	79.2450	80.4890	80.5370	81.0440
560	79.5220	81.1870	80.9710	81.0930	79.8190	80.8340	80.8710	81.2820
570	79.6920	81.3210	80.9890	81.0780	80.3210	81.0430	80.9860	81.1510
580	80.2160	81.8350	81.3330	81.4890	81.3130	81.8310	81.5700	81.5690
590	80.7020	82.1970	81.6690	81.7740	81.8410	82.0750	81.7790	81.6640
600	81.1090	82.6040	82.0170	82.1510	82.3290	82.4220	82.0230	81.7510
610	81.2920	82.7130	81.9610	82.1240	82.4510	82.6610	82.3020	81.8570
620	81.1950	82.6340	81.6910	81.9420	82.4350	82.5980	82.2670	81.7870
630	81.6070	82.9330	82.0830	82.3020	82.6540	82.8120	82.4670	82.0230
640	81.9020	83.2010	82.3590	82.6050	82.9140	83.0690	82.7070	82.2890
650	82.3710	83.5460	82.7330	82.9660	83.2560	83.4000	83.1010	82.7690
660	82.3060	83.4650	82.7050	82.9470	83.2220	83.3320	83.0580	82.7670
670	82.4440	83.5230	82.8060	83.0480	83.3330	83.4570	83.1820	82.9350
680	82.7820	83.8360	83.1580	83.3290	83.6150	83.6710	83.4390	83.2590
690	83.1820	84.2100	83.6010	83.7380	83.9870	84.0350	83.8230	83.6590
700	83.2860	84.3930	83.8470	84.0230	84.1790	84.1260	83.8690	83.7100

Table B6 Spectrum reflectance of pastel primary color “Yellow M2R” at different concentration (%)

WL	Concentration (%)							
(nm)	99.99	75.00	50.00	25.00	12.50	5.00	2.50	1.25
400	4.7600	4.7940	4.8090	5.6830	7.3510	11.3380	19.2460	27.5610
410	4.4430	4.7670	4.6270	4.9970	6.8320	10.8810	18.5160	26.3050
420	4.0060	4.6340	4.2440	4.5850	6.4030	10.4540	17.1420	25.1700
430	3.3290	3.6680	3.5660	4.2060	5.8940	9.7770	15.8760	24.3110
440	4.1950	4.4910	4.2050	4.3740	5.8290	9.5440	15.9510	24.5250
450	4.2090	4.5690	4.4680	4.5550	5.8120	9.3290	15.5510	23.9450
460	4.1910	4.3100	4.2580	4.3800	5.5600	9.0650	15.3070	23.7100
470	4.1600	4.1080	4.2020	4.4110	5.5210	9.1320	15.6670	24.2100
480	3.7780	3.8270	3.8750	4.1330	5.4740	9.5580	16.0510	24.8630
490	4.1590	4.1420	4.2030	4.4650	5.6720	9.4840	16.0870	24.9210
500	4.3530	4.2710	4.4300	4.7140	6.2040	10.2650	17.4410	26.3530
510	4.6180	4.4100	4.7840	5.3530	7.2220	12.2890	19.8670	29.3900
520	5.5980	5.1730	6.0730	7.4390	10.5730	17.6410	26.4670	36.6080
530	10.2070	9.3400	11.4140	14.5830	20.1940	30.1210	39.8140	49.9520
540	21.4660	19.9910	23.8670	29.7970	38.3160	49.7480	57.3130	66.0480
550	37.4010	35.7820	40.4210	48.0180	56.5020	65.3210	68.3620	75.0060
560	52.7040	51.9840	55.1940	62.3350	68.4990	73.4250	73.5480	78.3870
570	62.3450	62.9250	63.8870	69.4450	73.4270	76.4200	76.1610	79.4260
580	68.0930	69.3770	68.9170	73.2900	76.0760	78.5640	78.7900	80.3950
590	71.4510	72.8550	71.9100	75.5210	77.4170	79.5110	80.2450	80.8540
600	74.0250	75.3890	74.4790	77.3860	78.6210	80.3910	80.9920	81.2440
610	75.9320	77.1290	76.3850	78.7030	79.5110	81.1660	81.5600	81.4410
620	77.1600	78.1890	77.5950	79.5060	80.0160	81.5570	81.8030	81.4410
630	78.3980	79.3960	78.9020	80.4780	80.6850	82.0170	82.1730	81.8170
640	79.0360	79.9160	79.5680	81.0480	81.1540	82.3650	82.4570	82.0520
650	79.8040	80.5970	80.2960	81.6210	81.6530	82.7600	82.8940	82.4930
660	79.6990	80.4820	80.3440	81.6910	81.7010	82.7870	82.9240	82.4900
670	79.9250	80.4820	80.5120	81.7710	81.7550	82.9190	83.0130	82.6250
680	80.3400	80.8200	80.8900	82.1230	82.0770	83.1960	83.2860	82.8730
690	81.0000	81.4580	81.5090	82.6150	82.6190	83.5840	83.7420	83.3010
700	81.4010	81.8090	81.8870	82.8680	83.0600	83.7630	83.8910	83.5190

Table B7 Spectrum reflectance of pastel primary color "Orange" at different concentration (%)

WL	Concentration (%)							
(nm)	99.99	75.00	50.00	25.00	12.50	5.00	2.50	1.25
400	4.3200	2.8010	7.1190	8.3400	10.2920	17.2950	23.3240	37.1000
410	2.8150	1.6920	4.1000	5.8290	7.7020	16.0630	21.2360	32.9930
420	0.9300	1.8830	1.8700	3.7640	7.0210	14.9710	20.3140	31.9500
430	2.4820	3.4450	2.1600	3.3480	7.0260	13.2190	20.7490	32.1450
440	2.4950	2.9510	3.2620	4.6110	6.9570	13.7990	20.2150	31.5750
450	3.0930	3.7410	3.0350	4.1130	7.0890	13.2640	20.9320	32.3510
460	3.6800	3.8970	3.4310	4.3770	7.5120	13.0250	21.1040	33.4600
470	3.6570	3.6760	3.7970	4.7940	7.7020	13.5340	21.3270	34.0410
480	3.2840	3.4620	3.2410	4.1770	7.3090	13.1910	21.1980	33.4490
490	3.6120	3.6730	3.6740	4.4500	7.0280	12.4360	19.5730	32.0870
500	3.9510	4.0040	4.1330	4.8850	7.1840	12.6420	19.6050	32.3300
510	3.7400	3.8150	3.7810	4.5570	7.1980	12.8630	20.4750	33.0940
520	3.8160	3.8570	3.9920	4.7940	7.1090	12.6980	19.8480	32.3860
530	4.3420	4.2800	4.5310	4.8670	6.9290	12.2750	18.9890	31.1900
540	4.8080	4.7360	5.0880	5.6100	7.9300	13.9020	21.1020	33.2930
550	6.0470	6.0450	6.7180	8.1740	12.2220	20.6730	29.6770	42.0690
560	9.2800	9.3400	11.4980	15.5160	22.9750	35.3630	45.9230	56.4660
570	17.4180	18.2640	22.3990	30.0650	40.5770	54.1850	63.1740	69.1650
580	29.8830	31.8440	37.4800	47.4080	57.5300	68.5820	73.5290	76.0420
590	43.5220	46.3840	52.2880	61.6210	69.5120	76.5470	77.9680	78.6320
600	55.7540	59.2970	63.9180	70.7120	76.4480	80.3490	79.9810	79.8040
610	64.0310	67.6140	71.0180	75.2360	79.2200	81.7740	80.5910	80.1220
620	68.5490	71.8190	74.6310	77.2650	80.1370	82.3030	80.6890	80.3990
630	71.9190	74.9360	76.7940	78.4560	81.2640	82.7830	80.9810	80.8770
640	73.8790	76.6430	78.1970	79.2040	81.6880	83.0010	81.1610	81.4590
650	75.2800	78.0310	79.4200	80.0050	82.4890	83.3990	81.4540	82.0150
660	76.1770	78.6250	79.8410	80.2050	82.8620	83.6080	81.5250	82.2130
670	76.3740	78.9710	80.0330	80.3120	82.7430	83.3020	81.5350	81.9730
680	76.7010	79.4400	80.4390	80.6110	83.1290	83.6210	81.8390	82.1470
690	77.3300	79.9500	80.9420	80.9410	83.6470	83.9590	82.1220	82.3790
700	78.0130	80.4030	81.4300	81.1930	83.9740	84.4730	82.4540	82.8340

Table B8 Spectrum reflectance of pastel primary color “Red” at different concentration (%)

WL	Concentration (%)							
(nm)	99.99	75.00	50.00	25.00	12.50	5.00	2.50	1.25
400	3.6990	2.8570	6.0820	7.4960	12.6410	21.2440	28.6500	38.6420
410	3.6180	3.6350	4.3420	5.9350	10.0240	17.4270	25.3980	35.3470
420	1.8400	2.1900	3.0230	4.8090	8.1140	14.3630	22.5140	33.6820
430	1.6850	2.2120	1.8420	3.8630	6.8070	13.1860	19.8580	32.5150
440	2.6270	2.8750	2.9360	4.0640	6.6360	12.3180	18.8780	30.1880
450	2.5100	2.7860	2.5210	4.0020	5.9170	11.5400	17.5370	28.7790
460	2.6560	2.7310	2.6490	3.8960	5.4840	10.7720	16.5510	27.6880
470	2.9440	2.7240	2.9830	3.7510	5.3240	10.1360	15.9770	26.7690
480	2.6180	2.6420	2.5490	3.5550	4.9930	9.7680	15.4540	26.1070
490	2.8770	2.6900	2.8340	3.5850	5.0270	9.6100	15.1330	25.4360
500	3.1640	2.8610	3.1110	3.6420	5.0970	9.4500	14.8360	25.2890
510	3.0790	2.8860	2.9330	3.5950	4.8640	9.1580	14.4760	24.8290
520	3.2000	2.9220	3.1040	3.6140	5.0000	9.2590	14.7600	25.0140
530	3.1310	2.9630	3.0820	3.6330	5.0690	9.3680	14.8180	24.8760
540	3.2290	3.0990	3.1500	3.6370	4.8860	8.7800	13.9040	23.6720
550	3.6220	3.3770	3.4280	3.7300	4.7670	8.3210	13.0820	22.5850
560	4.1170	3.8160	3.7720	3.9880	4.8870	8.1520	12.8540	22.2190
570	4.4590	4.1440	4.0730	4.5080	5.6550	9.5500	14.7730	24.8750
580	5.8290	5.6660	6.0100	7.8290	10.6990	17.5270	24.8880	36.3070
590	12.1100	12.2940	14.1870	19.3190	26.1030	37.1640	46.7020	56.7980
600	24.8760	25.3690	29.3170	37.5830	47.0760	57.8620	66.0910	72.6560
610	40.5100	40.9510	46.1430	54.6320	63.3600	69.1850	74.4540	78.9580
620	55.1160	55.3800	60.3320	66.7700	72.9690	74.2010	77.5410	81.3070
630	66.2140	66.3300	70.2270	74.4160	78.1310	76.1850	78.8480	82.0370
640	72.2850	72.2990	75.2250	77.9060	80.0950	76.9700	79.2810	82.4520
650	75.1480	75.0320	77.5990	79.5550	81.3040	77.9640	79.8160	82.8190
660	76.4790	76.4970	78.5050	80.1740	81.7960	78.1530	80.0060	83.0230
670	77.4900	77.4640	79.2400	80.5030	81.9230	78.4760	80.2410	82.9920
680	78.3570	78.2540	79.7800	80.6950	82.1910	78.3450	80.4730	83.1220
690	79.2650	79.1230	80.5180	81.1900	82.6470	78.4880	80.9770	83.3940
700	79.7190	79.5750	80.8130	81.4370	82.6790	78.6160	81.0630	83.3690

Table B9 Spectrum reflectance of pastel primary color “Pink E” at different concentration (%)

WL	Concentration (%)							
(nm)	99.99	75.00	50.00	25.00	12.50	5.00	2.50	1.25
400	9.8230	9.6700	11.0510	17.5130	24.4940	38.7010	47.7460	57.0780
410	6.3370	9.9100	11.5140	19.2280	26.8440	40.9430	48.9530	60.2380
420	5.2860	9.1150	10.6300	17.9340	25.7700	41.1100	47.8720	60.9690
430	5.5740	8.0560	9.6710	15.7260	24.3330	39.1420	47.9630	59.9470
440	5.0900	7.9530	9.1100	15.5740	23.1900	38.2400	46.2650	59.8420
450	4.6620	6.5740	7.9270	12.9870	20.6520	34.7620	43.6640	57.1030
460	4.4560	5.4020	6.5870	10.7360	18.0420	31.5100	40.6260	54.2740
470	4.4230	4.5340	5.6300	9.1780	15.7570	28.6260	37.9440	51.5870
480	3.2770	4.0390	4.7940	8.0370	13.8420	25.6560	34.4170	48.6130
490	3.4100	3.4760	4.2560	6.8810	11.9490	22.8720	31.2080	45.4420
500	3.5970	3.2730	4.1550	6.4130	10.8440	21.1820	29.4510	43.4830
510	2.8770	2.9620	3.4980	5.4860	9.4110	18.8390	26.3690	40.3390
520	3.0390	2.7650	3.3390	4.8420	7.8820	16.0370	22.9160	36.1580
530	2.9560	2.9620	3.3670	4.7020	7.0250	13.8760	20.0970	32.8600
540	2.7880	3.0220	3.2710	4.5710	6.6610	13.2600	19.1000	31.9290
550	3.1490	3.0160	3.4200	4.5950	6.8580	13.7340	19.8070	32.5350
560	2.9210	3.1270	3.3290	4.6280	6.8400	13.6930	19.4120	32.2530
570	2.9960	3.2960	3.5710	4.9280	7.3000	14.4730	20.1320	33.4960
580	3.4940	3.8200	4.2410	6.1160	9.8040	19.1300	25.7600	40.2150
590	4.7000	5.3690	6.1240	9.6980	15.8210	28.7430	36.3970	51.3230
600	7.5220	8.9050	10.5660	16.7310	25.8870	41.7310	49.1770	62.9430
610	13.1330	15.4920	18.5600	27.5940	38.6940	54.9250	60.3090	71.7350
620	21.8380	25.0100	29.6400	40.3820	51.0700	64.8440	67.3670	76.7440
630	31.9040	35.6100	41.3620	52.1760	61.0450	71.6470	71.5470	79.3220
640	41.9430	45.2290	51.1160	60.5960	67.0850	74.9070	73.3360	80.4350
650	50.1570	52.8000	58.2310	66.3460	70.5150	76.7200	74.3990	81.3440
660	55.4510	57.5870	62.4900	69.4700	72.3510	77.5120	75.3420	81.8740
670	58.6570	60.3800	64.8170	71.1000	73.2640	78.0210	75.7420	81.7590
680	60.9130	62.3820	66.5400	72.4270	73.9500	78.6200	76.2610	82.1680
690	62.7110	64.2020	68.0020	73.5920	74.7060	79.2570	76.7880	82.6390
700	64.4350	65.8840	69.3050	74.5400	75.5050	79.8310	77.2630	83.2220

Table B10 Spectrum reflectance of pastel primary color “Brown” at different concentration (%)

WL	Concentration (%)							
(nm)	99.99	75.00	50.00	25.00	12.50	5.00	2.50	1.25
400	1.2550	0.8810	2.8300	4.0120	6.6600	15.5480	23.1810	34.2600
410	1.9050	2.9060	2.1410	5.0800	8.0170	15.8370	24.2870	34.7810
420	0.9660	2.2850	1.5830	4.3390	7.7990	14.3400	22.9030	33.1310
430	1.9650	3.1580	2.8980	5.1000	8.2730	14.9190	23.7360	32.5250
440	1.9900	2.7480	1.9260	4.3180	7.4240	14.1180	22.3080	32.5490
450	2.2440	2.7660	2.5660	4.5430	7.2920	13.3010	21.9810	30.2740
460	2.2820	2.5920	3.0190	4.2060	6.5260	12.5480	20.3120	28.9180
470	2.0740	2.2580	2.8420	3.8270	5.8040	11.5430	18.8840	27.8820
480	2.3110	2.4920	2.6880	3.7350	5.7360	11.0810	18.2870	26.6060
490	2.2780	2.4300	2.8040	3.6660	5.5400	10.9970	17.9350	26.5960
500	2.4450	2.4110	2.8340	3.7300	5.6460	11.1670	18.5560	27.3310
510	2.5200	2.6460	2.9450	3.9010	6.0110	12.0390	19.6830	28.5670
520	2.5230	2.5550	2.9350	3.9940	6.3120	12.8270	21.0190	29.9620
530	2.6940	2.7150	3.0120	4.2890	6.8530	13.7480	22.2470	31.3880
540	2.7810	2.8530	3.0660	4.5640	7.3870	14.8530	23.5480	32.9540
550	2.9070	2.9650	3.3680	5.0380	8.2150	16.5900	25.8460	35.4190
560	2.9960	3.2100	3.5930	5.7830	9.7510	19.4750	29.2970	39.2580
570	3.4520	3.8310	4.3870	7.3650	12.2930	23.4230	34.0740	43.9650
580	3.9880	4.5570	5.5410	9.3640	15.2510	27.9910	39.0330	48.7230
590	4.7220	5.4230	6.8840	11.4320	18.2000	32.1700	43.4130	52.6100
600	5.4250	6.3450	8.3320	13.4390	20.9590	35.7330	47.1370	55.3740
610	6.1900	7.2220	9.7670	15.2610	23.3760	38.6700	50.0260	57.5430
620	6.8520	8.0000	11.0510	16.8810	25.2520	40.8750	51.8830	58.9930
630	7.7050	9.0060	12.4720	18.7000	27.5960	43.6120	54.6130	60.9190
640	8.5710	9.9900	14.0580	20.5560	29.8860	46.2090	56.9220	62.5840
650	9.4550	10.9800	15.5440	22.4340	31.9940	48.3730	58.7020	63.9990
660	10.5150	12.1390	17.2660	24.4270	34.2620	50.7360	60.6760	65.3210
670	11.7460	13.5660	19.1700	26.6480	36.7770	53.2920	62.8450	66.7290
680	13.1740	15.1020	21.3360	29.1440	39.4700	55.8180	64.9200	68.0430
690	14.8070	16.9230	23.8720	31.9740	42.5140	58.6800	67.2550	69.5110
700	16.7530	19.0760	26.6200	35.1040	45.7880	61.5860	69.6440	70.7240

Table B11 Spectrum reflectance of pastel primary color “Violet” at different concentration (%)

WL	Concentration (%)							
(nm)	99.99	75.00	50.00	25.00	12.50	5.00	2.50	1.25
400	4.3200	2.8010	7.1190	8.3400	10.2920	17.2950	23.3240	37.1000
410	2.8150	1.6920	4.1000	5.8290	7.7020	16.0630	21.2360	32.9930
420	0.9300	1.8830	1.8700	3.7640	7.0210	14.9710	20.3140	31.9500
430	2.4820	3.4450	2.1600	3.3480	7.0260	13.2190	20.7490	32.1450
440	2.4950	2.9510	3.2620	4.6110	6.9570	13.7990	20.2150	31.5750
450	3.0930	3.7410	3.0350	4.1130	7.0890	13.2640	20.9320	32.3510
460	3.6800	3.8970	3.4310	4.3770	7.5120	13.0250	21.1040	33.4600
470	3.6570	3.6760	3.7970	4.7940	7.7020	13.5340	21.3270	34.0410
480	3.2840	3.4620	3.2410	4.1770	7.3090	13.1910	21.1980	33.4490
490	3.6120	3.6730	3.6740	4.4500	7.0280	12.4360	19.5730	32.0870
500	3.9510	4.0040	4.1330	4.8850	7.1840	12.6420	19.6050	32.3300
510	3.7400	3.8150	3.7810	4.5570	7.1980	12.8630	20.4750	33.0940
520	3.8160	3.8570	3.9920	4.7940	7.1090	12.6980	19.8480	32.3860
530	4.3420	4.2800	4.5310	4.8670	6.9290	12.2750	18.9890	31.1900
540	4.8080	4.7360	5.0880	5.6100	7.9300	13.9020	21.1020	33.2930
550	6.0470	6.0450	6.7180	8.1740	12.2220	20.6730	29.6770	42.0690
560	9.2800	9.3400	11.4980	15.5160	22.9750	35.3630	45.9230	56.4660
570	17.4180	18.2640	22.3990	30.0650	40.5770	54.1850	63.1740	69.1650
580	29.8830	31.8440	37.4800	47.4080	57.5300	68.5820	73.5290	76.0420
590	43.5220	46.3840	52.2880	61.6210	69.5120	76.5470	77.9680	78.6320
600	55.7540	59.2970	63.9180	70.7120	76.4480	80.3490	79.9810	79.8040
610	64.0310	67.6140	71.0180	75.2360	79.2200	81.7740	80.5910	80.1220
620	68.5490	71.8190	74.6310	77.2650	80.1370	82.3030	80.6890	80.3990
630	71.9190	74.9360	76.7940	78.4560	81.2640	82.7830	80.9810	80.8770
640	73.8790	76.6430	78.1970	79.2040	81.6880	83.0010	81.1610	81.4590
650	75.2800	78.0310	79.4200	80.0050	82.4890	83.3990	81.4540	82.0150
660	76.1770	78.6250	79.8410	80.2050	82.8620	83.6080	81.5250	82.2130
670	76.3740	78.9710	80.0330	80.3120	82.7430	83.3020	81.5350	81.9730
680	76.7010	79.4400	80.4390	80.6110	83.1290	83.6210	81.8390	82.1470
690	77.3300	79.9500	80.9420	80.9410	83.6470	83.9590	82.1220	82.3790
700	78.0130	80.4030	81.4300	81.1930	83.9740	84.4730	82.4540	82.8340

Table B12 Spectrum reflectance of pastel primary color “Black” at different concentration (%)

WL	Concentration (%)							
(nm)	99.99	75.00	50.00	25.00	12.50	5.00	2.50	1.25
400	1.2810	2.6350	2.1640	2.5680	3.6540	4.6930		30.4240
410	1.0420	3.3110	2.2680	3.0860	3.1340	4.8750		29.9180
420	1.5340	2.4530	1.4350	3.0310	3.1010	5.6610		29.9150
430	3.7760	3.3680	3.2170	3.4130	4.3560	6.9910		30.2530
440	2.0200	2.6500	2.1240	3.3210	3.5920	6.2140		31.0470
450	3.4320	3.2840	2.9410	3.4480	4.2320	7.0050		30.8920
460	3.6430	3.2080	3.2660	3.2890	4.2050	7.1600		31.7130
470	3.2650	2.8520	3.1250	3.3690	4.2220	6.9360		32.2550
480	3.4890	3.1470	3.1750	3.3180	4.2510	7.0440		31.7160
490	3.2710	2.9830	3.1100	3.4340	4.2240	7.0300		32.4320
500	3.1100	2.9510	3.1000	3.4660	4.2990	7.0830		32.8000
510	3.3100	3.0070	3.1430	3.4350	4.2590	7.1080		32.9190
520	3.0950	2.9430	3.0770	3.4220	4.2710	7.0420		32.9350
530	3.1730	3.1590	3.1320	3.6220	4.3950	7.1880		33.0050
540	3.1130	3.2080	3.1110	3.6050	4.3510	7.1340		33.0770
550	3.2240	3.1370	3.1530	3.6390	4.4450	7.3190		33.3760
560	3.0010	3.2010	3.0360	3.5330	4.2800	7.1120		33.4620
570	3.1300	3.1840	3.0770	3.6510	4.3850	7.3400		33.5680
580	3.2460	3.2100	3.1200	3.6570	4.4510	7.4300		33.6490
590	3.1680	3.2180	3.1250	3.6540	4.4300	7.4230		33.8750
600	3.2630	3.2260	3.1350	3.6700	4.4870	7.5300		33.9850
610	3.3550	3.2650	3.2290	3.6540	4.5310	7.6110		34.1550
620	3.3160	3.2200	3.2110	3.6510	4.5080	7.5880		34.1430
630	3.3520	3.2810	3.2390	3.6890	4.5650	7.6810		34.3310
640	3.3630	3.2570	3.2610	3.7060	4.5670	7.7000		34.5110
650	3.2930	3.2090	3.2210	3.6870	4.5580	7.6910		34.6420
660	3.3020	3.2350	3.2190	3.7130	4.5750	7.7300		34.7170
670	3.3380	3.2320	3.2550	3.7240	4.6050	7.8000		34.8630
680	3.3170	3.2730	3.2580	3.7580	4.6470	7.8210		34.9900
690	3.2860	3.3340	3.2460	3.7570	4.6400	7.8100		35.2650
700	3.2390	3.3570	3.2390	3.7990	4.6030	7.8500		35.4010

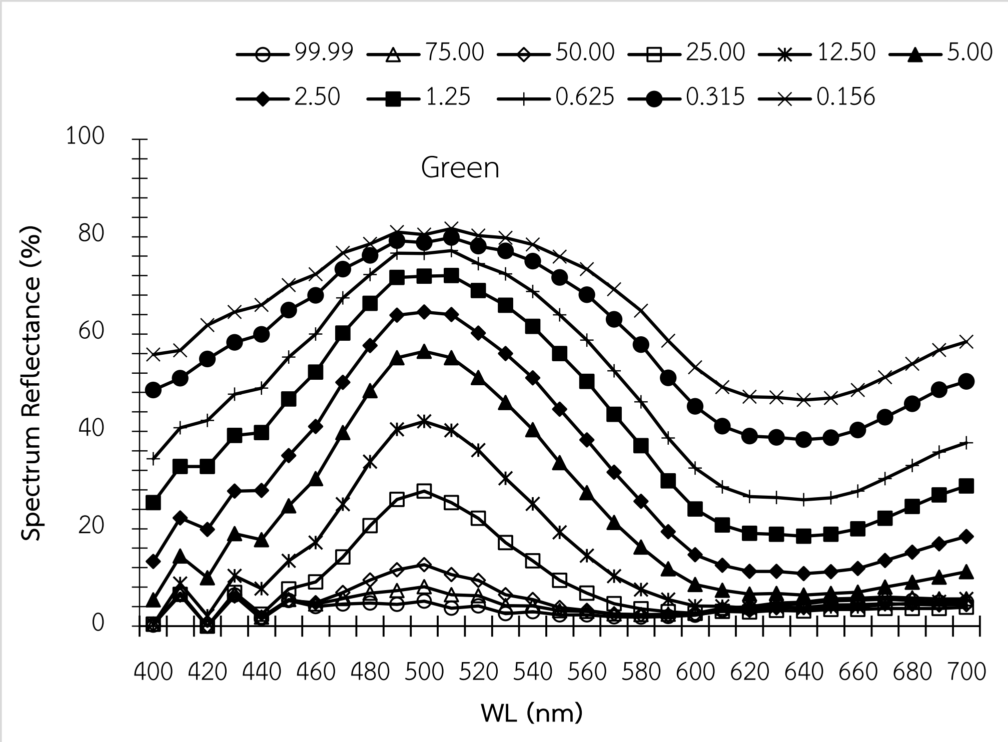


Figure B7 Spectrum reflectance (%) and calibrated color swatches of green at different concentrations. From left to right; 99.99, 75.00, 50.00, 25.00, 12.50 (top), 5.00, 2.50, 1.25, 0.635, 0.315, and 0.156 (bottom).

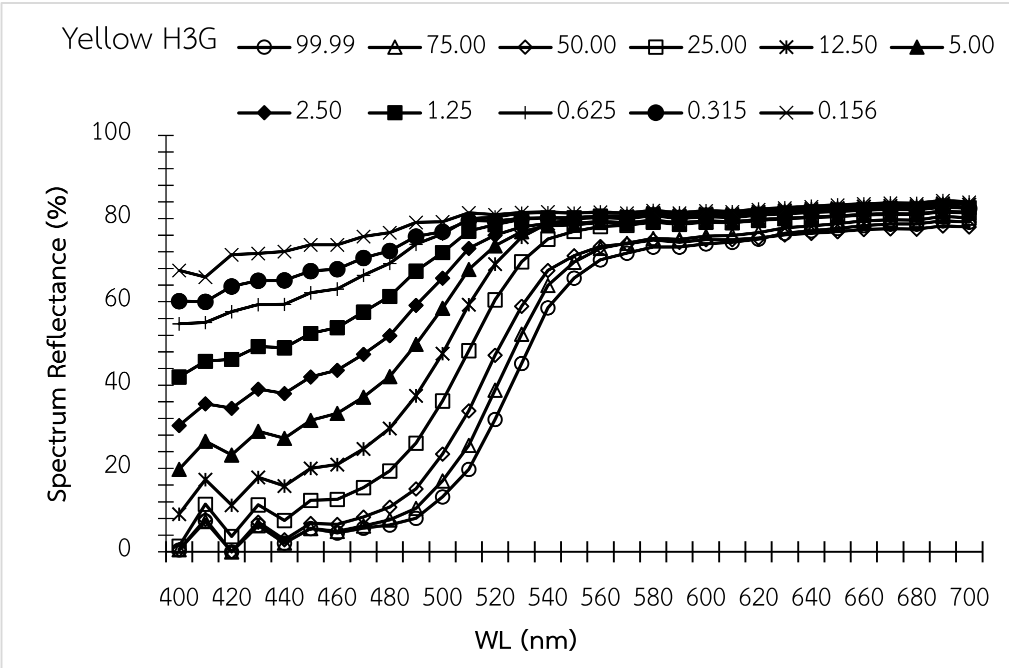


Figure B8 Spectrum reflectance (%) and calibrated color swatches of Yellow H3G at different concentrations. From left to right; 99.99, 75.00, 50.00, 25.00, 12.50 (top), 5.00, 2.50, 1.25, 0.635, 0.315, and 0.156 (bottom).

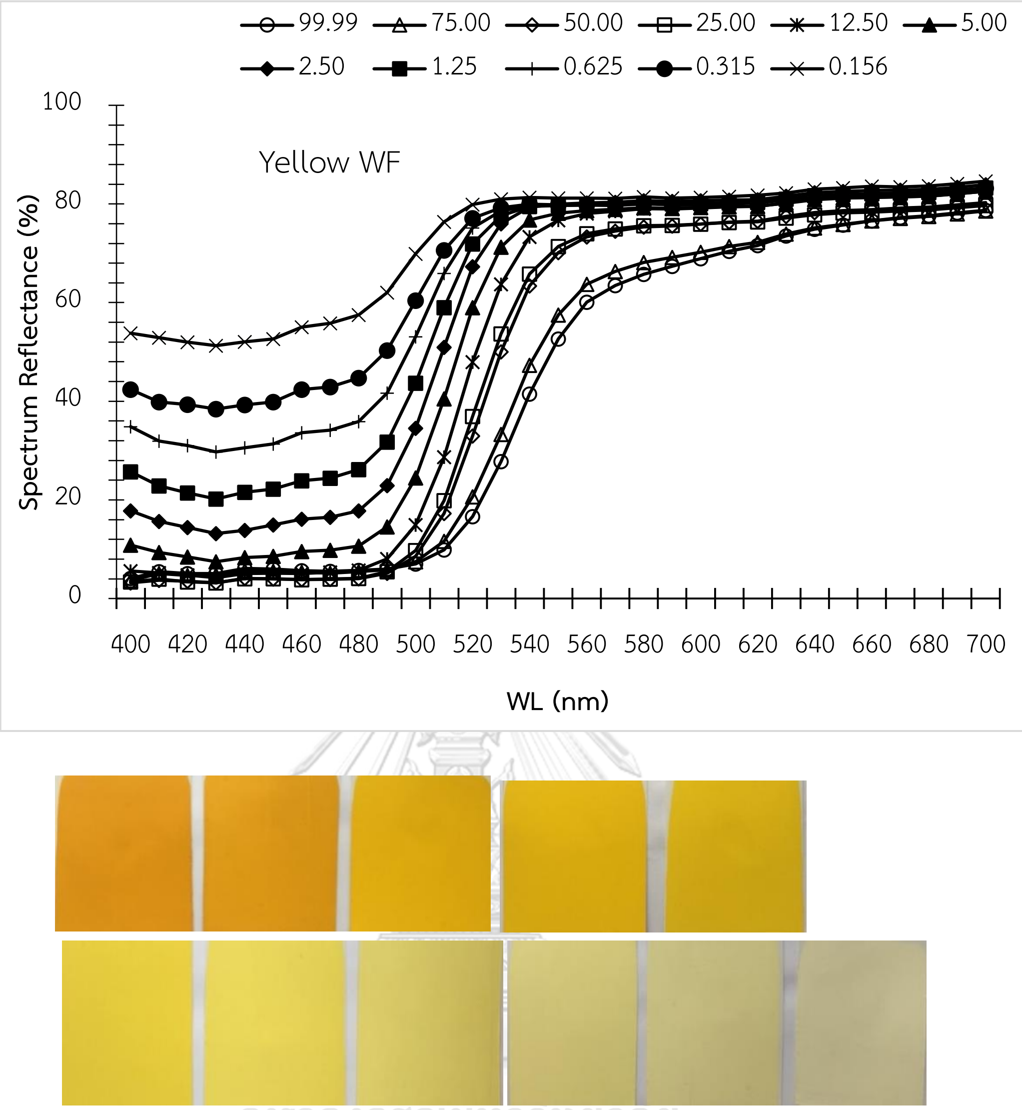


Figure B9 Spectrum reflectance (%) and calibrated color swatches of Yellow WF at different concentrations. From left to right; 99.99, 75.00, 50.00, 25.00, 12.50 (top), 5.00, 2.50, 1.25, 0.635, 0.315, and 0.156 (bottom).

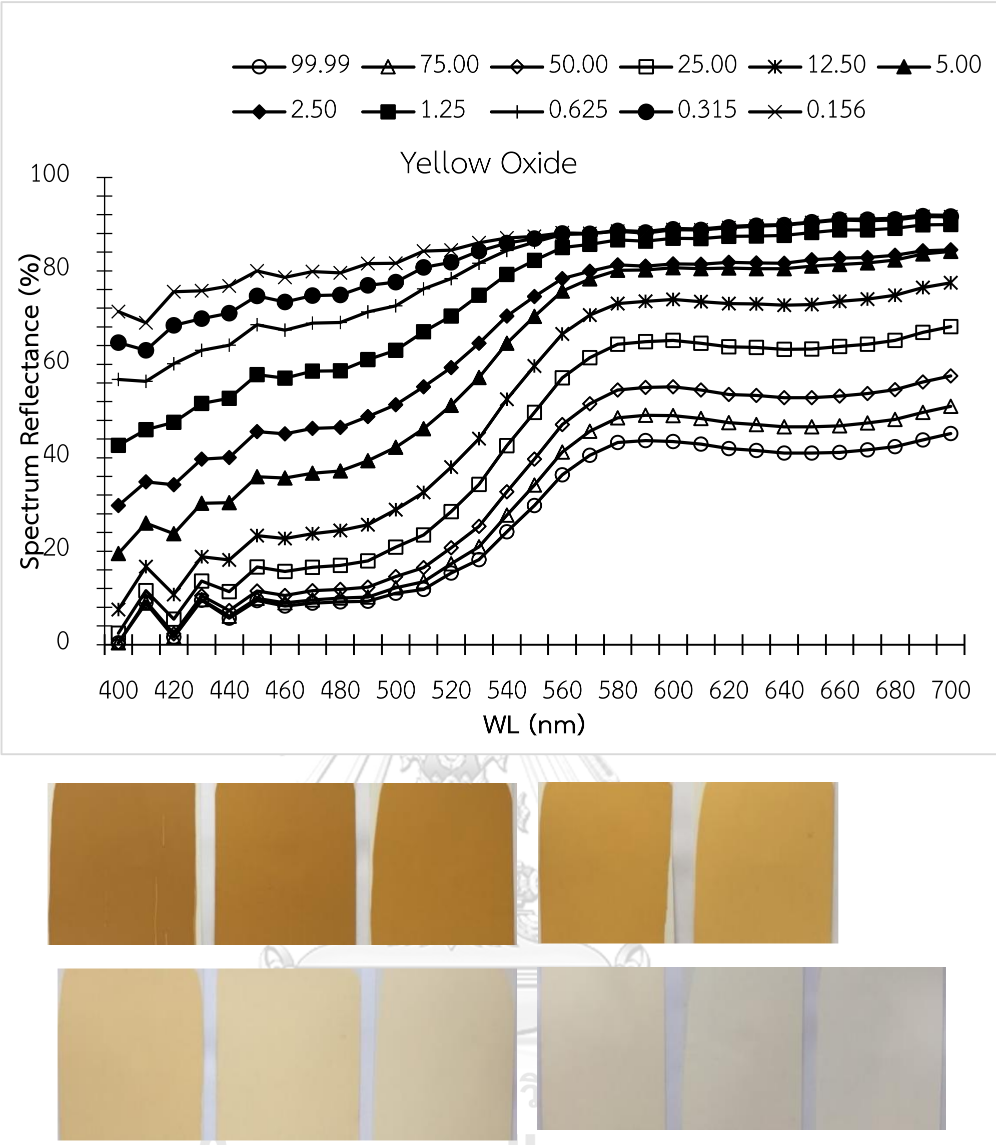
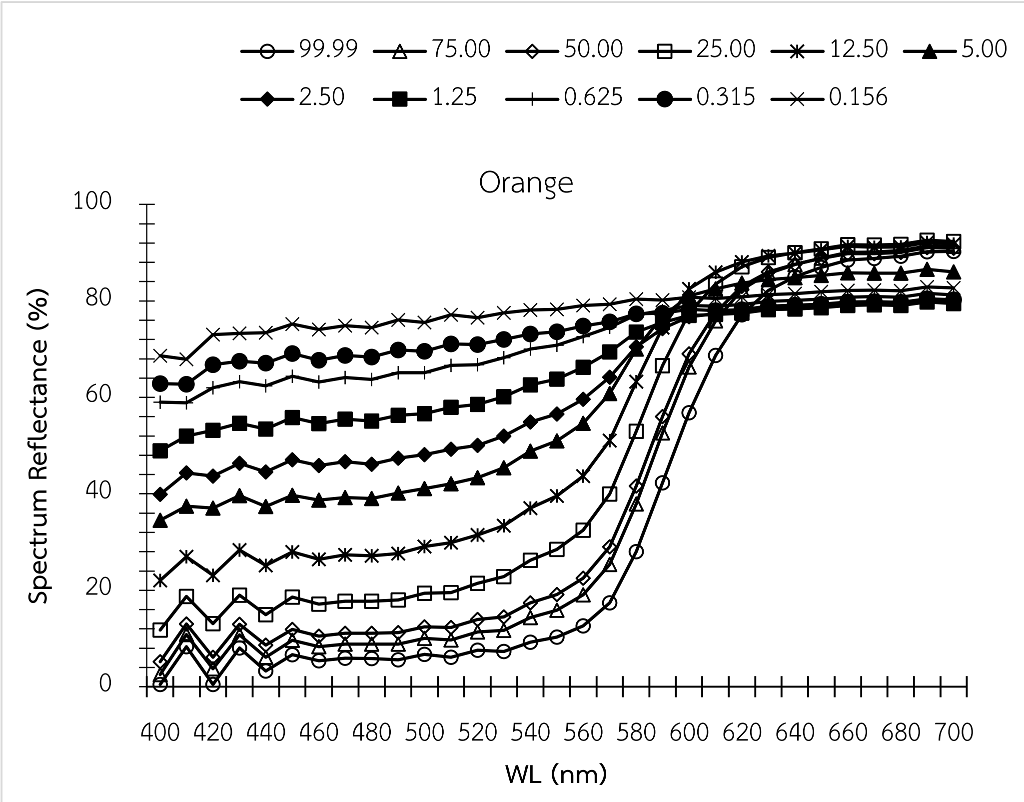


Figure B10 Spectrum reflectance (%) and calibrated color swatches of Yellow Oxide at different concentrations. From left to right; 99.99, 75.00, 50.00, 25.00, 12.50 (top), 5.00, 2.50, 1.25, 0.635, 0.315, and 0.156 (bottom).



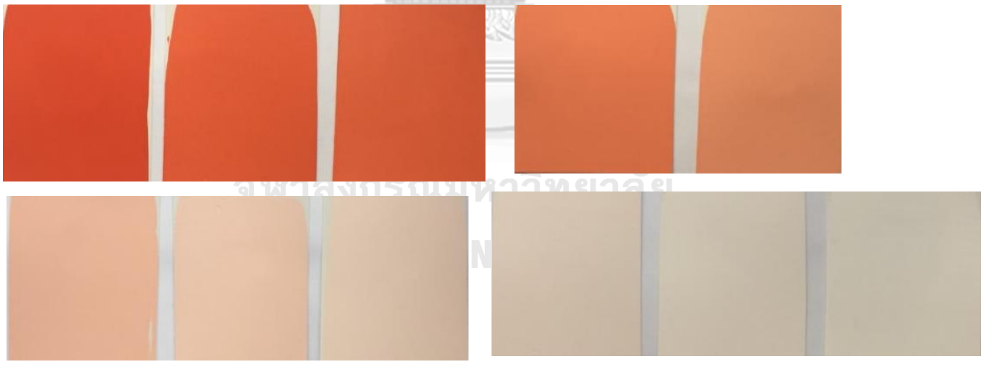


Figure B11 Spectrum reflectance (%) and calibrated color swatches of Orange at different concentrations. From left to right; 99.99, 75.00, 50.00, 25.00, 12.50 (top), 5.00, 2.50, 1.25, 0.635, 0.315, and 0.156 (bottom).

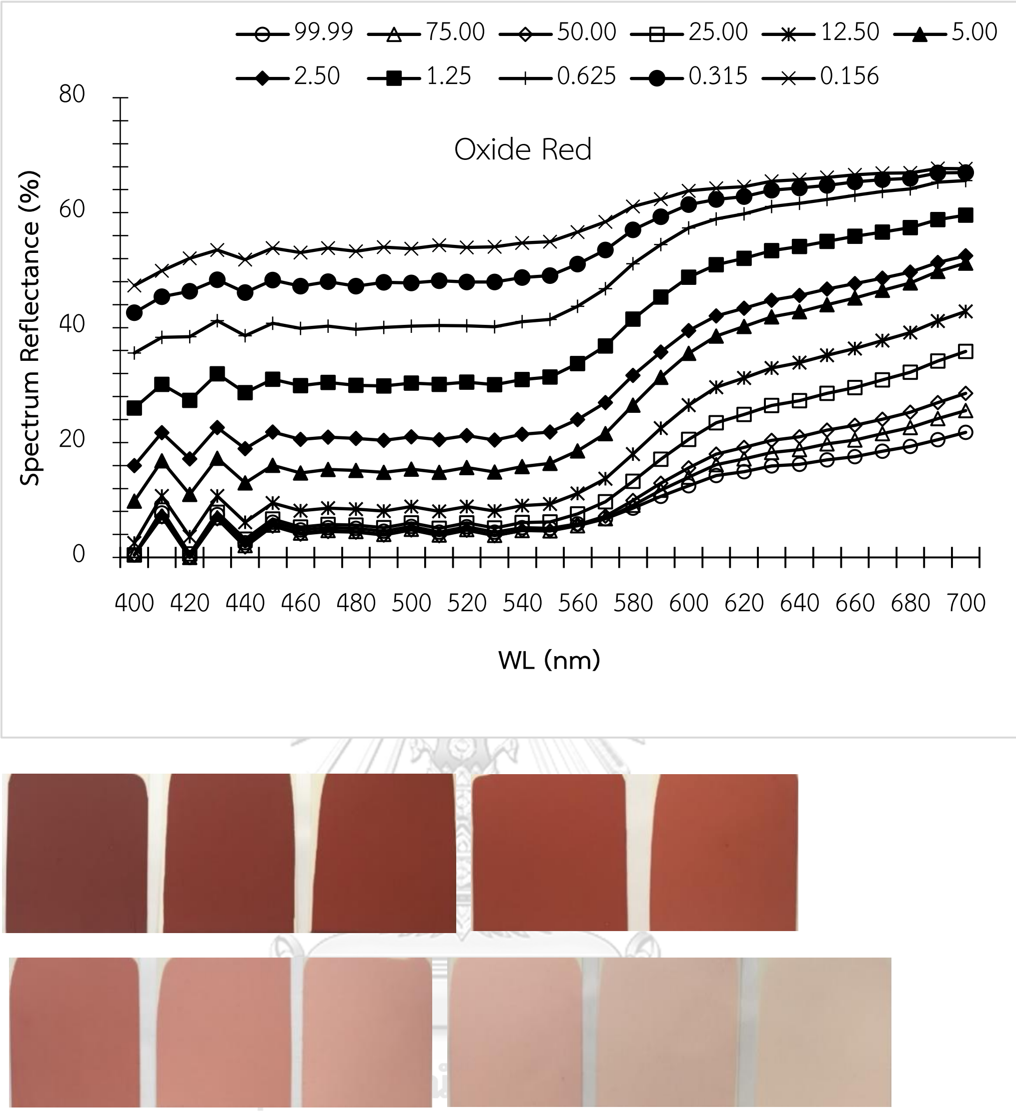


Figure B12 Spectrum reflectance (%) and calibrated color swatches of oxide red at different concentrations. From left to right; 99.99, 75.00, 50.00, 25.00, 12.50 (top), 5.00, 2.50, 1.25, 0.635, 0.315, and 0.156 (bottom).

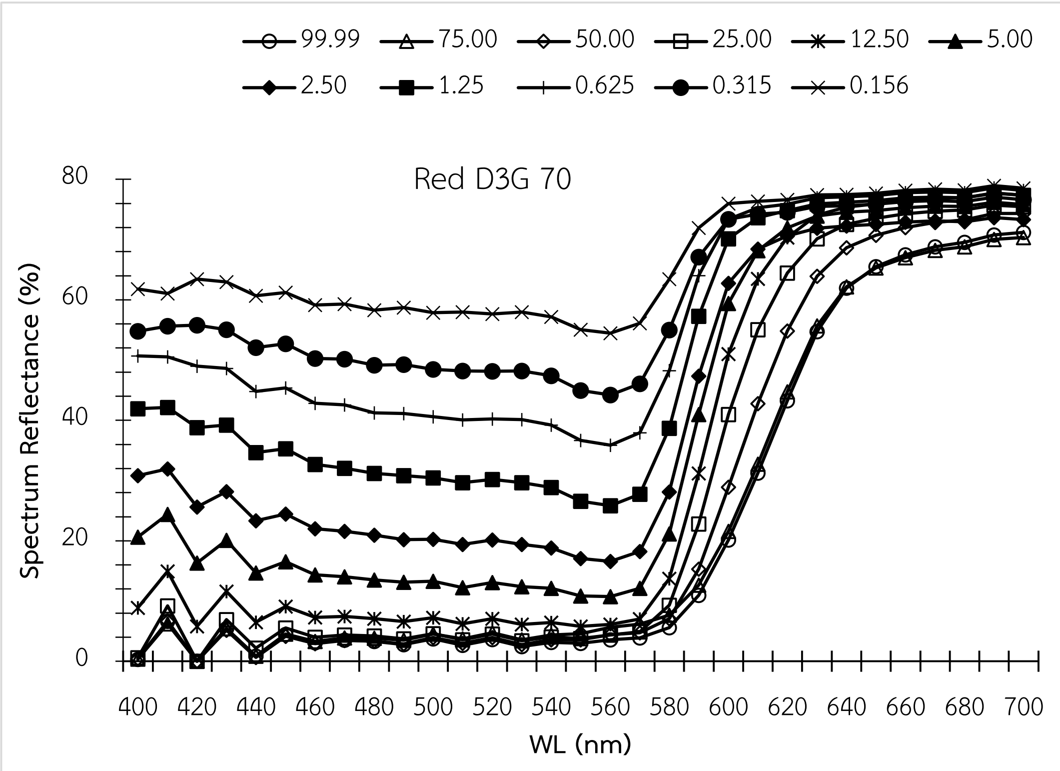


Figure B13 Spectrum reflectance (%) and calibrated color swatches of Red at different concentrations. From left to right; 99.99, 75.00, 50.00, 25.00, 12.50 (top), 5.00, 2.50, 1.25, 0.635, 0.315, and 0.156 (bottom).

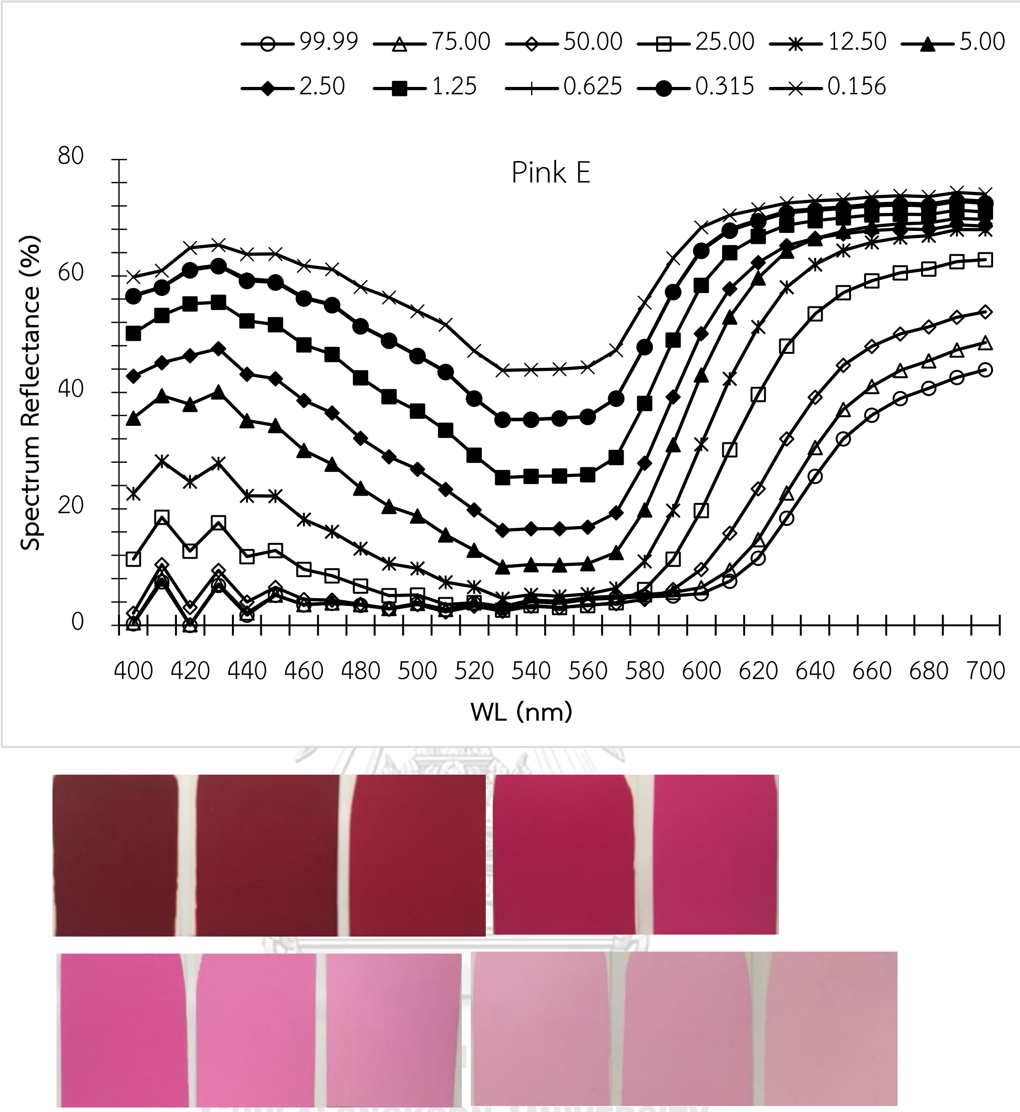


Figure B14 Spectrum reflectance (%) and calibrated color swatches of Pink E at different concentrations. From left to right; 99.99, 75.00, 50.00, 25.00, 12.50 (top), 5.00, 2.50, 1.25, 0.635, 0.315, and 0.156 (bottom).

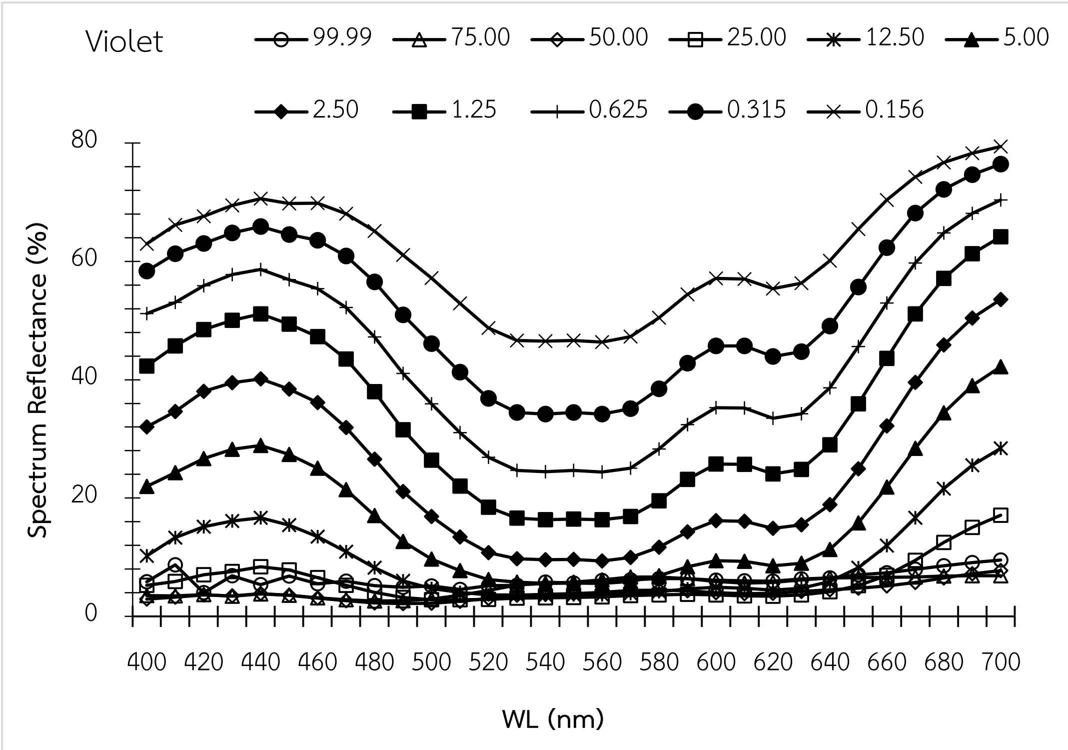


Figure B15 Spectrum reflectance (%) and calibrated color swatches of Violet at different concentrations. From left to right; 99.99, 75.00, 50.00, 25.00, 12.50 (top), 5.00, 2.50, 1.25, 0.635, 0.315, and 0.156 (bottom).

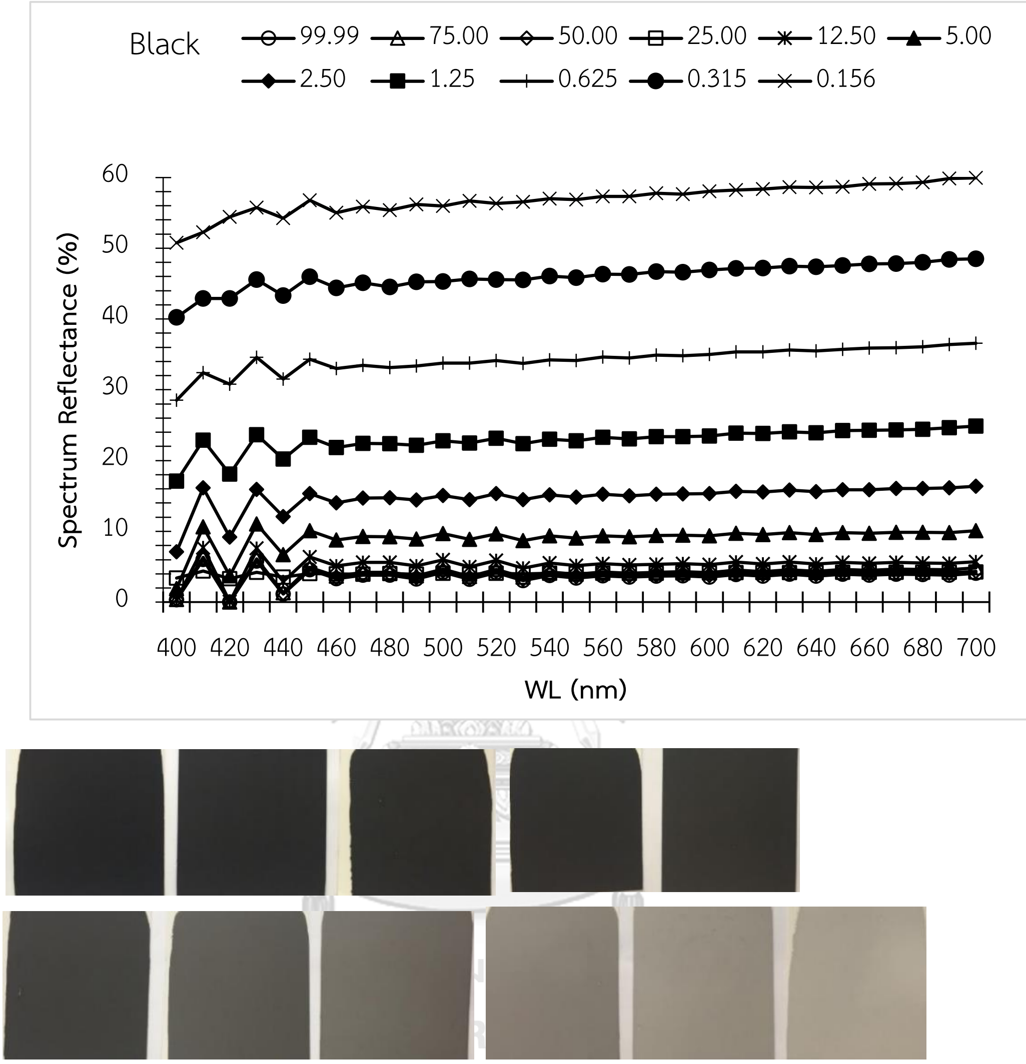


Figure B16 Spectrum reflectance (%) and calibrated color swatches of Black at different concentrations. From left to right; 99.99, 75.00, 50.00, 25.00, 12.50 (top), 5.00, 2.50, 1.25, 0.635, 0.315, and 0.156 (bottom).

Table B13 Spectrum reflectance of acrylic paint primary color "Blue" at different concentration (%)

WL	Concentration (%)										
(nm)	99.99	75.00	50.00	25.00	12.50	5.00	2.50	1.25	0.625	0.315	0.156
400	6.115	5.153	5.587	14.852	16.259	26.517	34.859	47.036	53.668	55.987	60.613
410	6.186	5.755	6.964	16.287	21.871	33.647	42.021	52.178	58.43	59.795	64.174
420	6.502	6.283	8.09	19.361	25.692	37.204	45.773	55.391	61.145	62.154	66.141
430	6.526	6.535	9.56	21.55	29.821	41.467	49.951	59.093	64.429	64.877	68.576
440	7.794	8.349	13.246	30.716	37.179	48.193	55.642	63.289	67.047	66.553	70.02
450	8.506	9.506	16.147	35.137	42.526	52.71	59.177	65.67	68.404	67.134	70.121
460	8.37	9.524	17.158	37.93	44.722	54.864	61.268	67.697	70.259	68.894	71.764
470	7.586	8.781	16.258	36.746	43.744	54.26	61.014	67.569	70.377	68.888	71.949
480	6.492	7.615	14.337	33.775	41.35	52.606	59.759	66.881	70.101	69.06	72.181
490	5.386	6.322	12.033	29.801	37.884	49.653	57.583	65.638	69.615	69.083	72.481
500	4.493	5.157	9.553	25.559	33.662	46.072	54.792	63.736	68.668	68.89	72.834
510	3.825	4.175	7.172	19.929	28.154	40.9	50.261	60.084	66.203	67.509	71.963
520	3.242	3.365	5.121	14.467	21.855	34.497	44.338	54.845	62.182	65.007	70.403
530	2.965	2.933	3.871	10.257	16.294	27.914	37.874	48.906	57.662	61.971	68.58
540	2.702	2.554	2.896	6.915	11.517	21.588	31.118	42.345	51.859	57.674	65.514
550	2.622	2.443	2.439	5.125	8.147	16.291	24.857	35.668	45.639	52.737	61.794
560	2.793	2.526	2.245	3.951	5.736	11.838	19.077	29.1	39.211	47.356	57.381
570	3.285	2.912	2.33	3.463	4.549	9.101	15.2	24.315	34.225	42.704	53.255
580	3.804	3.295	2.453	3.244	4.014	7.75	13.05	21.617	31.179	39.9	50.707
590	4.276	3.69	2.656	3.274	3.781	7.06	11.812	19.932	29.154	37.876	48.837
600	4.818	4.087	2.847	3.287	3.609	6.541	10.93	18.556	27.573	36.311	47.348
610	5.423	4.595	3.103	3.21	3.529	6.222	10.382	17.789	26.754	35.439	46.479
620	5.89	4.945	3.288	3.403	3.484	6.097	10.2	17.585	26.357	34.982	45.95
630	6.282	5.274	3.483	3.389	3.545	6.185	10.335	17.715	26.578	35.262	46.347
640	6.503	5.437	3.59	3.539	3.612	6.352	10.635	18.152	27.155	35.895	46.994
650	6.44	5.416	3.611	3.572	3.757	6.743	11.322	19.129	28.293	36.968	48.017
660	6.237	5.24	3.542	3.673	3.899	7.19	12.116	20.241	29.619	38.248	49.248
670	6.053	5.109	3.481	3.559	3.938	7.369	12.443	20.654	30.109	38.752	49.804
680	6.127	5.16	3.497	3.601	3.844	7.127	12.068	20.123	29.537	38.239	49.388
690	6.437	5.425	3.629	3.656	3.729	6.749	11.413	19.195	28.562	37.269	48.442
700	6.996	5.852	3.848	3.6	3.589	6.251	10.553	18.024	27.209	35.933	47.2

Table B14 Spectrum reflectance of acrylic paint primary color “Green” at different concentration (%)

WL	Concentration (%)										
(nm)	99.99	75.00	50.00	25.00	12.50	5.00	2.50	1.25	0.625	0.315	0.156
400	0.219	0.373	0.405	0.394	0.366	5.372	13.237	25.358	34.37	48.481	55.791
410	6.75	6.737	6.337	6.524	8.722	14.415	22.223	32.775	40.721	50.938	56.621
420	0	0	0	0	2.09	9.938	19.86	32.777	42.245	54.837	61.814
430	6.374	6.661	6.204	6.928	10.339	19.001	27.726	39.167	47.657	58.283	64.52
440	1.653	1.805	1.44	2.458	7.678	17.717	27.825	39.768	48.855	59.957	65.941
450	5.227	5.456	5.246	7.593	13.427	24.719	35.016	46.644	55.231	64.933	70.059
460	3.991	4.557	4.803	9.091	17.158	30.278	41.012	52.187	60.012	67.953	72.257
470	4.548	5.67	6.891	14.221	25.048	39.736	50.067	60.217	67.396	73.347	76.67
480	4.74	6.738	9.456	20.647	33.776	48.368	57.616	66.33	72.201	76.174	78.516
490	4.459	7.285	11.532	25.998	40.42	55.136	63.861	71.625	76.598	79.168	80.922
500	5.129	8.105	12.608	27.701	42.019	56.444	64.543	71.888	76.539	78.812	80.412
510	3.668	6.418	10.582	25.37	40.23	55.109	63.992	72.005	77.123	79.822	81.662
520	4.132	6.239	9.378	22.115	36.122	51.056	60.192	68.912	74.464	78.067	80.233
530	2.586	4.192	6.423	17.118	30.387	45.916	55.987	65.926	72.336	77.076	79.767
540	2.942	4.134	5.432	13.4	25.075	40.366	51.021	61.591	68.734	74.984	78.395
550	2.266	3.153	3.805	9.369	19.23	33.583	44.542	56.01	63.95	71.636	75.904
560	2.328	2.993	3.23	6.754	14.468	27.399	38.246	50.252	58.767	68.067	73.308
570	1.906	2.493	2.518	4.626	10.255	21.254	31.586	43.487	52.413	63.036	69.2
580	1.832	2.365	2.273	3.559	7.462	16.219	25.597	37.053	46.084	57.79	64.782
590	1.963	2.446	2.24	2.983	5.441	11.736	19.377	29.823	38.65	51.011	58.601
600	2.199	2.644	2.269	2.614	4.153	8.545	14.655	24.035	32.461	45.149	53.153
610	3.287	3.691	3.074	3.041	4.063	7.363	12.462	20.755	28.564	41.034	49.1
620	3.63	4.01	3.189	2.87	3.652	6.564	11.245	19.069	26.599	38.998	47.143
630	4.359	4.745	3.759	3.232	3.907	6.685	11.224	18.87	26.394	38.787	46.961
640	4.517	4.907	3.78	3.062	3.64	6.35	10.782	18.436	25.923	38.291	46.486
650	5.211	5.601	4.327	3.438	3.954	6.672	11.148	18.877	26.362	38.707	46.858
660	5.319	5.728	4.374	3.382	3.959	6.985	11.827	19.968	27.742	40.278	48.487
670	5.495	5.971	4.595	3.624	4.404	8.009	13.482	22.162	30.269	42.896	51.133
680	5.229	5.76	4.45	3.597	4.69	9.016	15.206	24.587	33.008	45.698	53.884
690	4.943	5.552	4.305	3.597	5.015	10.069	16.907	26.966	35.728	48.528	56.737
700	4.903	5.571	4.407	3.861	5.576	11.191	18.402	28.782	37.63	50.274	58.413

Table B15 Spectrum reflectance of acrylic paint primary color "Yellow H3G" at different concentration (%)

WL	Concentration (%)										
(nm)	99.99	75.00	50.00	25.00	12.50	5.00	2.50	1.25	0.625	0.315	0.156
400	0.481	0.498	0.507	1.361	9.065	19.838	30.323	41.985	54.772	60.213	67.594
410	7.427	7.271	7.826	11.441	17.336	26.528	35.534	45.766	55.028	60.059	65.979
420	0	0	0	3.649	11.225	23.264	34.446	46.252	57.639	63.693	71.342
430	6.325	6.292	7.131	11.305	17.902	28.956	39.05	49.27	59.328	65.135	71.653
440	2.029	2.106	2.935	7.511	15.781	27.23	38.008	48.981	59.435	65.19	72.054
450	5.607	5.632	6.839	12.32	20.037	31.52	41.979	52.436	62.193	67.41	73.668
460	4.517	4.909	6.588	12.615	20.972	33.231	43.602	53.794	63.103	67.905	73.732
470	5.661	6.244	8.384	15.386	24.69	37.139	47.416	57.557	66.388	70.587	75.734
480	6.467	7.667	10.735	19.406	29.663	42.034	51.932	61.35	69.218	72.239	76.587
490	8.067	10.453	15.099	26.119	37.477	49.844	59.222	67.377	73.89	75.726	79.111
500	13.216	17.065	23.498	36.248	47.598	58.497	65.729	71.826	76.291	76.821	79.247
510	19.813	25.548	33.883	48.26	59.377	67.753	72.836	76.995	79.955	79.531	81.35
520	31.781	38.879	47.231	60.526	69.07	73.471	75.982	78.556	80.409	79.42	80.911
530	45.182	52.247	58.935	69.607	75.567	76.887	78.037	79.837	81.304	80.072	81.474
540	58.547	63.981	67.54	75.064	78.858	78.312	78.829	80.26	81.44	80.18	81.603
550	65.726	69.552	71.074	76.93	79.835	78.492	78.872	80.214	81.318	79.991	81.278
560	70.08	72.883	73.306	78.098	80.594	79.114	79.322	80.607	81.649	80.26	81.526
570	71.745	74.067	73.961	78.413	80.628	78.873	79.028	80.293	81.315	79.983	81.271
580	73.194	75.216	74.871	79.179	81.36	79.521	79.595	80.912	81.961	80.657	81.932
590	73.178	75.014	74.328	78.623	80.74	78.867	79.01	80.31	81.35	79.993	81.305
600	73.954	75.774	74.905	79.121	81.242	79.295	79.48	80.833	81.902	80.473	81.821
610	74.323	75.959	74.917	78.995	81.074	79.094	79.216	80.551	81.674	80.252	81.602
620	75.107	76.648	75.298	79.56	81.641	79.691	79.784	81.109	82.276	80.818	82.154
630	76.455	77.743	76.111	80.011	82.009	79.982	80.106	81.413	82.574	81.131	82.533
640	77.07	78.271	76.497	80.326	82.306	80.26	80.374	81.721	82.961	81.454	82.868
650	77.607	78.768	76.88	80.587	82.567	80.464	80.628	82.036	83.3	81.679	83.216
660	78.332	79.437	77.387	81.008	82.942	80.815	80.937	82.243	83.558	81.989	83.505
670	78.706	79.687	77.509	81.218	83.088	81.013	81.102	82.443	83.747	82.192	83.666
680	78.66	79.649	77.436	81.097	82.995	80.966	81.089	82.407	83.688	82.076	83.538
690	79.487	80.534	78.271	81.854	83.705	81.634	81.775	83.064	84.367	82.79	84.295
700	79.174	80.192	78.009	81.444	83.347	81.269	81.314	82.625	84.002	82.451	83.943

Table B16 Spectrum reflectance of acrylic paint primary color “Yellow WF” at different concentration (%)

WL	Concentration (%)										
(nm)	99.99	75.00	50.00	25.00	12.50	5.00	2.50	1.25	0.625	0.315	0.156
400	4.13	3.663	3.197	3.412	5.62	10.853	17.796	25.721	34.838	42.357	53.776
410	5.463	5.099	3.734	3.948	5.241	9.389	15.639	22.844	31.95	39.861	52.891
420	5.056	4.684	3.5	3.413	4.734	8.485	14.442	21.403	31.033	39.352	52.018
430	5.101	4.727	3.169	3.185	4.229	7.477	13.161	20.221	29.735	38.421	51.241
440	6.139	5.659	4.094	4.045	5.07	8.325	13.833	21.565	30.584	39.286	52.062
450	5.992	5.535	4.007	4.013	5.137	8.567	14.918	22.231	31.339	39.848	52.66
460	5.684	5.362	3.874	3.866	5.058	9.551	16.099	23.891	33.652	42.41	55.039
470	5.538	5.17	3.924	3.966	5.366	9.793	16.49	24.405	34.149	42.931	55.813
480	5.728	5.445	4.055	4.12	5.749	10.633	17.823	26.14	35.91	44.718	57.499
490	6.002	5.855	5.131	5.488	8.08	14.581	22.935	31.777	41.687	50.28	62.051
500	7.033	7.481	8.571	9.744	14.932	24.487	34.539	43.662	53.071	60.423	69.925
510	9.851	11.637	17.247	19.891	28.715	40.475	50.929	58.999	65.906	70.61	76.412
520	16.619	20.676	32.997	36.922	47.94	58.985	67.266	71.876	75.162	77.074	79.912
530	27.811	33.312	50.009	53.682	63.753	71.284	76.011	77.605	78.579	79.255	80.961
540	41.496	47.307	63.407	65.778	73.312	76.8	79.333	79.465	79.63	79.933	81.339
550	52.657	57.485	70.173	71.396	76.7	78.151	79.931	79.677	79.66	79.821	81.188
560	60.08	63.709	73.36	73.984	78.043	78.658	80.213	79.85	79.739	79.854	81.157
570	63.441	66.295	74.518	74.926	78.55	78.898	80.327	79.861	79.716	79.842	81.119
580	65.766	68.126	75.311	75.634	79.03	79.233	80.663	80.141	79.986	80.114	81.417
590	67.335	69.149	75.554	75.678	78.987	79.105	80.533	79.996	79.817	79.849	81.185
600	68.891	70.228	75.932	75.917	79.187	79.28	80.687	80.079	79.845	79.923	81.311
610	70.413	71.389	76.346	76.239	79.426	79.436	80.808	80.197	80.035	80.125	81.495
620	71.548	72.207	76.496	76.409	79.528	79.489	80.886	80.32	80.235	80.356	81.749
630	73.495	73.936	77.503	77.15	80.163	80.181	81.579	80.989	80.784	80.83	82.209
640	74.885	75.162	78.265	77.837	80.857	80.917	82.3	81.718	81.515	81.575	82.971
650	75.763	75.857	78.621	78.173	81.172	81.222	82.573	81.961	81.74	81.831	83.254
660	76.592	76.562	78.877	78.345	81.343	81.298	82.763	82.099	81.925	82.018	83.593
670	77.214	77.098	79.175	78.588	81.42	81.428	82.779	82.2	81.988	81.983	83.433
680	77.644	77.469	79.347	78.769	81.594	81.571	82.957	82.366	82.196	82.22	83.674
690	78.204	78.006	79.835	79.221	82.046	82.069	83.378	82.784	82.607	82.69	84.131
700	78.73	78.555	80.267	79.695	82.585	82.539	83.888	83.287	83.132	83.186	84.632

Table B17 Spectrum reflectance of acrylic paint primary color “Yellow Oxide” at different concentration (%)

WL	Concentration (%)										
(nm)	99.99	75.00	50.00	25.00	12.50	5.00	2.50	1.25	0.625	0.315	0.156
400	0.416	0.403	0.389	2.411	7.483	19.478	29.764	42.637	56.776	64.651	71.268
410	9.046	8.901	9.3	11.523	16.671	25.978	34.83	46.022	56.316	62.966	68.861
420	1.628	1.606	2.328	5.429	10.701	23.725	34.229	47.582	60.08	68.311	75.519
430	9.478	9.609	10.477	13.633	18.782	30.267	39.677	51.611	63.002	69.795	75.739
440	5.692	6.094	7.288	11.332	18.133	30.391	40.024	52.728	64.072	70.902	76.739
450	9.424	9.92	11.457	16.589	23.317	35.953	45.559	57.8	68.471	74.594	79.989
460	8.292	8.933	10.537	15.675	22.69	35.623	45.09	56.998	67.296	73.318	78.575
470	8.861	9.563	11.562	16.549	23.742	36.659	46.239	58.519	68.804	74.7	79.862
480	9.156	9.959	11.807	16.974	24.396	37.136	46.472	58.597	68.966	74.81	79.586
490	9.264	10.209	12.309	17.933	25.676	39.351	48.823	60.986	71.227	76.917	81.557
500	11.022	12.163	14.541	20.857	28.901	42.197	51.321	62.973	72.481	77.545	81.583
510	11.844	13.433	16.489	23.499	32.542	46.171	55.151	66.957	76.147	80.713	84.211
520	15.287	17.296	20.751	28.461	37.96	51.176	59.283	70.332	78.308	81.828	84.421
530	18.206	20.958	25.3	34.271	44.114	57.163	64.481	74.786	81.637	84.196	86.027
540	24.177	27.703	32.733	42.573	52.517	64.509	70.315	79.235	84.33	85.954	87.01
550	29.775	34.169	39.723	49.722	59.598	70.262	74.465	82.217	86.128	86.863	87.334
560	36.332	41.189	47.087	57.084	66.486	75.623	78.302	84.943	87.762	87.969	88.128
570	40.533	45.665	51.556	61.419	70.488	78.285	79.896	85.623	87.912	87.906	87.952
580	43.267	48.558	54.463	64.251	72.996	80.084	81.267	86.607	88.675	88.537	88.46
590	43.642	49.046	55.04	64.82	73.463	80.145	81.01	86.328	88.392	88.187	88.071
600	43.483	48.989	55.178	65.125	73.899	80.662	81.471	86.929	89.046	88.842	88.791
610	42.922	48.408	54.471	64.48	73.375	80.423	81.395	86.858	88.945	88.75	88.732
620	41.924	47.475	53.522	63.765	73.009	80.612	81.809	87.384	89.508	89.309	89.226
630	41.532	47.115	53.336	63.575	72.899	80.447	81.654	87.463	89.732	89.605	89.534
640	41.019	46.606	52.859	63.183	72.613	80.46	81.63	87.541	89.888	89.796	89.742
650	41.028	46.597	52.878	63.272	72.774	80.976	82.337	88.22	90.455	90.375	90.297
660	41.164	46.82	53.217	63.813	73.444	81.316	82.697	88.726	91.063	90.922	90.883
670	41.667	47.411	53.766	64.285	73.936	81.702	82.852	88.74	91.034	90.902	90.753
680	42.382	48.196	54.577	65.121	74.763	82.266	83.308	89.05	91.239	90.989	90.83
690	43.797	49.709	56.185	66.805	76.404	83.578	84.261	89.842	91.946	91.691	91.587
700	45.153	51.018	57.502	68.037	77.458	84.15	84.499	89.887	91.919	91.604	91.513

Table B18 Spectrum reflectance of acrylic paint primary color “Orange” at different concentration (%)

WL	Concentration (%)										
(nm)	99.99	75.00	50.00	25.00	12.50	5.00	2.50	1.25	0.625	0.315	0.156
400	0.483	2.506	5.185	11.753	22.021	34.522	39.87	48.915	58.985	62.843	68.653
410	8.323	10.849	12.995	18.747	26.945	37.426	44.317	51.981	58.906	62.755	67.906
420	0.5	3.733	6.143	13.08	23.101	37.019	43.696	53.149	61.971	66.771	72.986
430	8.017	10.774	12.938	18.977	28.368	39.62	46.358	54.654	63.27	67.527	73.307
440	3.268	6.145	8.635	14.966	25.189	37.393	44.572	53.412	62.428	67.137	73.386
450	6.647	9.622	11.901	18.591	27.923	39.713	47.093	55.828	64.39	69.068	75.234
460	5.382	8.298	10.522	17.145	26.449	38.681	45.879	54.562	63.189	67.71	74.045
470	5.932	8.81	11.097	17.731	27.332	39.212	46.645	55.465	64.098	68.669	74.868
480	5.867	8.823	11.112	17.733	27.171	39.052	46.125	55.109	63.751	68.363	74.48
490	5.584	8.818	11.236	17.98	27.641	40.144	47.394	56.298	65.117	69.821	76.077
500	6.715	10.02	12.456	19.369	29.068	41.106	48.099	56.652	65.137	69.584	75.561
510	6.127	9.712	12.266	19.526	29.887	42.078	49.228	57.98	66.643	71.104	77.122
520	7.557	11.354	13.93	21.418	31.489	43.342	50.038	58.53	66.78	70.933	76.546
530	7.307	11.695	14.505	22.811	33.363	45.385	51.957	60.161	68.218	72.047	77.528
540	9.26	14.346	17.385	26.219	37.067	48.871	54.926	62.598	70.018	73.136	78.102
550	10.286	15.906	19.117	28.497	39.555	50.975	56.577	63.821	70.805	73.584	78.224
560	12.615	19.053	22.518	32.491	43.695	54.661	59.629	66.251	72.587	74.8	79.039
570	17.427	25.354	29.01	39.943	51.076	60.817	64.211	69.424	74.511	75.664	79.316
580	28.03	37.907	41.627	52.956	63.27	70.055	70.482	73.569	77.157	77.351	80.385
590	42.259	52.671	56.002	66.558	74.46	76.78	74.269	75.538	78.016	77.482	80.167
600	56.812	66.303	69.048	77.512	82.51	81.053	76.714	77.023	79.036	78.228	80.792
610	68.698	75.895	77.621	83.512	85.927	82.518	77.299	77.169	78.946	78.022	80.508
620	77.102	82.384	83.049	87.099	88.103	83.719	77.848	77.437	79.256	78.22	80.878
630	82.144	85.66	86.025	89.03	89.345	84.408	78.552	78.206	79.926	78.909	81.332
640	85.046	87.546	87.612	89.983	89.938	84.801	78.724	78.326	80.104	79.095	81.529
650	86.927	88.88	88.807	90.79	90.568	85.307	79.056	78.609	80.407	79.326	81.914
660	88.492	90.051	89.831	91.638	91.324	85.798	79.495	79.039	80.771	79.753	82.16
670	88.779	90.128	89.809	91.568	91.117	85.747	79.568	79.181	80.905	79.852	82.214
680	89.282	90.487	90.066	91.714	91.228	85.743	79.469	79.044	80.778	79.724	82.139
690	90.209	91.364	91.051	92.591	92.116	86.531	80.272	79.809	81.555	80.478	82.928
700	90.294	91.33	90.906	92.318	91.802	86.043	79.96	79.457	81.266	80.234	82.689

Table B19 Spectrum reflectance of acrylic paint primary color “Oxide Red” at different concentration (%)

WL (nm)	Concentration (%)										
	99.99	75.00	50.00	25.00	12.50	5.00	2.50	1.25	0.625	0.315	0.156
400	0.474	0.472	0.466	0.447	2.516	9.828	15.965	25.994	35.601	42.59	47.34
410	7.763	7.208	7.065	8.252	10.711	16.832	21.697	30.119	38.336	45.405	49.876
420	0.032	0	0	0.649	3.628	10.997	17.183	27.366	38.446	46.318	52.034
430	7.451	6.887	6.726	7.883	10.676	17.259	22.6	31.954	41.197	48.306	53.511
440	2.557	2.058	1.868	3.163	6.153	12.968	18.916	28.698	38.589	46.109	51.832
450	6.123	5.626	5.449	6.709	9.485	16.025	21.849	31.022	40.778	48.249	53.846
460	4.804	4.236	4.069	5.325	8.166	14.729	20.527	29.9	39.884	47.223	53.032
470	5.216	4.664	4.526	5.76	8.577	15.296	20.966	30.486	40.275	48.009	53.854
480	5.065	4.522	4.399	5.656	8.435	15.164	20.701	29.975	39.728	47.192	53.31
490	4.6	4.032	3.908	5.187	8.094	14.835	20.368	29.866	40.012	47.89	54.009
500	5.438	4.894	4.804	6.032	8.846	15.388	20.984	30.376	40.262	47.797	53.735
510	4.435	3.906	3.77	5.093	8.013	14.826	20.489	30.106	40.373	48.174	54.36
520	5.382	4.843	4.752	6.044	8.87	15.627	21.193	30.513	40.34	47.915	53.974
530	4.395	3.845	3.788	5.136	8.084	14.891	20.466	30.092	40.139	47.919	54.086
540	5.205	4.703	4.663	6.058	9.03	15.841	21.452	30.965	41.041	48.716	54.736
550	5.06	4.619	4.645	6.205	9.311	16.361	21.827	31.422	41.453	49.038	54.945
560	5.849	5.538	5.708	7.569	11.12	18.557	24.004	33.729	43.734	51.066	56.645
570	6.751	6.754	7.191	9.715	13.728	21.571	26.965	36.825	46.75	53.527	58.423
580	8.57	9.081	9.913	13.246	17.984	26.506	31.681	41.489	51.09	57.009	61.085
590	10.659	11.691	12.905	17.12	22.506	31.354	35.76	45.309	54.445	59.311	62.377
600	12.476	13.999	15.588	20.56	26.501	35.536	39.454	48.749	57.36	61.402	63.79
610	14.272	16.146	17.979	23.463	29.623	38.515	42.013	50.924	58.929	62.3	64.249
620	14.948	17.159	19.179	24.909	31.264	40.195	43.347	52.06	59.793	62.821	64.531
630	15.929	18.274	20.381	26.445	32.967	41.868	44.762	53.388	61.098	63.927	65.487
640	16.219	18.753	21.013	27.299	33.908	42.787	45.606	54.13	61.647	64.291	65.772
650	17.007	19.762	22.166	28.541	35.202	43.999	46.688	55.024	62.284	64.76	66.118
660	17.524	20.464	22.975	29.568	36.337	45.143	47.67	55.888	63.017	65.364	66.579
670	18.483	21.545	24.07	30.926	37.725	46.498	48.631	56.644	63.671	65.741	66.861
680	19.313	22.618	25.283	32.268	39.134	47.785	49.651	57.398	64.12	65.976	66.912
690	20.5	24.146	26.972	34.189	41.137	49.757	51.325	58.814	65.283	66.907	67.717
700	21.791	25.582	28.595	35.841	42.814	51.214	52.481	59.583	65.612	66.98	67.626

Table B20 Spectrum reflectance of acrylic paint primary color “Red” at different concentration (%)

WL	Concentration (%)										
(nm)	99.99	75.00	50.00	25.00	12.50	5.00	2.50	1.25	0.625	0.315	0.156
400	0.325	0.409	0.453	0.591	8.868	20.643	30.832	41.947	50.7	54.781	61.779
410	6.651	6.242	6.637	9.208	14.921	24.397	31.968	42.123	50.519	55.648	61.055
420	0	0	0	0.019	5.826	16.307	25.639	38.802	49.008	55.81	63.423
430	5.446	5.422	5.147	6.948	11.585	20.105	28.195	39.199	48.641	55.057	62.977
440	0.884	0.878	0.648	2.211	6.489	14.688	23.358	34.658	44.796	52.096	60.695
450	4.469	4.511	4.163	5.524	9.113	16.535	24.438	35.317	45.396	52.714	61.203
460	3.078	3.302	2.945	4.002	7.307	14.337	21.996	32.666	42.833	50.298	59.138
470	3.538	3.893	3.461	4.394	7.443	14.062	21.585	32.069	42.551	50.189	59.283
480	3.327	3.849	3.361	4.209	7.108	13.534	20.927	31.198	41.217	49.176	58.311
490	2.801	3.503	2.905	3.73	6.612	13.146	20.229	30.81	41.124	49.238	58.694
500	3.721	4.543	3.933	4.606	7.254	13.312	20.27	30.461	40.627	48.452	57.844
510	2.685	3.712	2.997	3.598	6.223	12.257	19.405	29.636	40.079	48.191	57.99
520	3.627	4.726	3.965	4.543	7.107	13.07	20.17	30.182	40.244	48.137	57.655
530	2.451	3.563	2.778	3.412	6.106	12.4	19.392	29.664	40.109	48.217	57.962
540	3.151	4.351	3.579	4.064	6.44	12.107	18.848	28.859	39.224	47.392	57.195
550	3.007	4.594	3.586	3.776	5.804	10.832	17.043	26.564	36.668	44.958	55.054
560	3.567	5.655	4.415	4.39	6.104	10.758	16.608	25.833	35.88	44.228	54.458
570	3.914	6.203	4.732	4.903	7.038	12.122	18.23	27.725	37.939	46.098	56.106
580	5.6	7.667	7.064	9.316	13.733	21.168	28.138	38.666	48.242	55.014	63.425
590	10.978	12.642	15.332	22.819	31.196	40.958	47.337	57.288	64.017	67.109	71.959
600	20.129	21.611	28.941	40.992	51.016	59.415	62.742	70.132	73.384	73.373	75.992
610	31.247	32.721	42.797	55.054	63.501	68.181	68.446	73.65	75.294	74.24	76.333
620	43.272	44.721	54.814	64.439	70.372	71.968	70.597	74.791	75.878	74.566	76.611
630	54.747	55.715	63.928	70.149	74.056	73.916	71.908	75.939	76.925	75.507	77.414
640	61.952	62.187	68.649	72.556	75.404	74.552	72.288	76.22	77.09	75.607	77.484
650	65.519	65.297	70.746	73.563	75.956	74.831	72.515	76.438	77.293	75.852	77.707
660	67.489	67.026	72.011	74.297	76.535	75.301	72.907	76.946	77.804	76.306	78.17
670	68.837	68.206	72.823	74.713	76.866	75.563	73.118	77.072	77.911	76.456	78.356
680	69.555	68.812	73.296	74.939	76.942	75.51	72.963	76.938	77.785	76.311	78.215
690	70.796	70.018	74.362	75.733	77.672	76.195	73.652	77.747	78.61	77.051	78.946
700	71.228	70.378	74.35	75.467	77.339	75.847	73.348	77.365	78.155	76.623	78.522

Table B21 Spectrum reflectance of acrylic paint primary color "Pink E" at different concentration (%)

WL	Concentration (%)										
(nm)	99.99	75.00	50.00	25.00	12.50	5.00	2.50	1.25	0.625	0.315	0.156
400	0.235	0.406	2.044	11.375	22.622	35.588	42.757	50.132	56.689	56.496	59.792
410	7.466	7.927	10.445	18.527	28.144	39.419	45.112	53.199	58.106	57.983	60.894
420	0	0.082	3.048	12.73	24.662	37.963	46.322	55.219	61.27	60.999	64.834
430	6.859	7.066	9.444	17.62	27.795	40.098	47.522	55.487	61.825	61.665	65.338
440	1.756	2.145	3.97	11.778	22.223	35.173	43.098	52.283	59.478	59.14	63.72
450	5.143	5.216	6.525	12.832	22.206	34.318	42.363	51.607	59.144	58.887	63.801
460	3.499	3.571	4.436	9.595	18.153	30.044	38.62	48.183	56.305	56.155	61.718
470	3.767	3.848	4.314	8.48	16.067	27.685	36.479	46.495	55.169	54.988	61.127
480	3.454	3.525	3.604	6.72	13.188	23.573	32.137	42.506	51.542	51.382	58.114
490	2.859	2.9	2.803	5.088	10.583	20.406	28.917	39.266	48.982	48.877	56.328
500	3.694	3.76	3.543	5.22	9.78	18.796	26.783	36.801	46.368	46.251	53.941
510	2.59	2.707	2.309	3.538	7.393	15.551	23.323	33.478	43.618	43.517	51.644
520	3.697	3.887	3.286	3.896	6.548	12.871	19.837	29.214	39.033	38.961	47.104
530	3.003	3.23	2.382	2.606	4.619	10.034	16.301	25.378	35.379	35.29	43.798
540	4.035	4.297	3.292	3.369	5.232	10.417	16.567	25.584	35.379	35.294	43.856
550	3.789	4.09	3.01	3.061	4.967	10.341	16.578	25.653	35.595	35.515	43.988
560	4.42	4.741	3.514	3.384	5.345	10.583	16.836	25.871	35.845	35.797	44.297
570	4.638	4.978	3.695	3.884	6.358	12.526	19.332	28.816	38.989	38.911	47.241
580	4.875	5.254	4.42	6.117	10.947	19.812	27.837	38.103	47.92	47.809	55.397
590	5.026	5.626	6.132	11.331	19.71	31.037	39.22	49.011	57.411	57.255	63.078
600	5.439	6.467	9.599	19.707	31.059	42.997	50.072	58.388	64.55	64.331	68.308
610	7.559	9.463	15.825	30.164	42.357	52.952	57.799	63.975	68.048	67.785	70.411
620	11.532	14.714	23.439	39.673	51.219	59.674	62.268	66.771	69.666	69.378	71.443
630	18.364	22.736	32.011	47.973	58.076	64.249	65.214	68.735	71.113	70.822	72.525
640	25.599	30.553	39.178	53.478	61.971	66.428	66.462	69.485	71.541	71.262	72.891
650	32.028	37.057	44.628	57.106	64.361	67.695	67.242	69.993	71.865	71.558	73.142
660	36.074	41.023	47.896	59.18	65.75	68.5	67.802	70.464	72.345	72.016	73.566
670	38.94	43.772	50.018	60.512	66.582	68.962	68.034	70.611	72.523	72.186	73.764
680	40.7	45.411	51.261	61.166	66.91	69.08	67.977	70.52	72.363	72.026	73.629
690	42.564	47.291	52.908	62.442	67.933	69.896	68.782	71.296	73.116	72.758	74.315
700	43.899	48.535	53.855	62.778	67.94	69.734	68.568	70.981	72.84	72.467	74.028

Table B22 Spectrum reflectance of acrylic paint primary color “Violet” at different concentration (%)

WL	Concentration (%)										
(nm)	99.99	75.00	50.00	25.00	12.50	5.00	2.50	1.25	0.625	0.315	0.156
400	4.13	3.663	3.197	3.412	5.62	10.853	17.796	25.721	34.838	42.357	53.776
410	5.463	5.099	3.734	3.948	5.241	9.389	15.639	22.844	31.95	39.861	52.891
420	5.056	4.684	3.5	3.413	4.734	8.485	14.442	21.403	31.033	39.352	52.018
430	5.101	4.727	3.169	3.185	4.229	7.477	13.161	20.221	29.735	38.421	51.241
440	6.139	5.659	4.094	4.045	5.07	8.325	13.833	21.565	30.584	39.286	52.062
450	5.992	5.535	4.007	4.013	5.137	8.567	14.918	22.231	31.339	39.848	52.66
460	5.684	5.362	3.874	3.866	5.058	9.551	16.099	23.891	33.652	42.41	55.039
470	5.538	5.17	3.924	3.966	5.366	9.793	16.49	24.405	34.149	42.931	55.813
480	5.728	5.445	4.055	4.12	5.749	10.633	17.823	26.14	35.91	44.718	57.499
490	6.002	5.855	5.131	5.488	8.08	14.581	22.935	31.777	41.687	50.28	62.051
500	7.033	7.481	8.571	9.744	14.932	24.487	34.539	43.662	53.071	60.423	69.925
510	9.851	11.637	17.247	19.891	28.715	40.475	50.929	58.999	65.906	70.61	76.412
520	16.619	20.676	32.997	36.922	47.94	58.985	67.266	71.876	75.162	77.074	79.912
530	27.811	33.312	50.009	53.682	63.753	71.284	76.011	77.605	78.579	79.255	80.961
540	41.496	47.307	63.407	65.778	73.312	76.8	79.333	79.465	79.63	79.933	81.339
550	52.657	57.485	70.173	71.396	76.7	78.151	79.931	79.677	79.66	79.821	81.188
560	60.08	63.709	73.36	73.984	78.043	78.658	80.213	79.85	79.739	79.854	81.157
570	63.441	66.295	74.518	74.926	78.55	78.898	80.327	79.861	79.716	79.842	81.119
580	65.766	68.126	75.311	75.634	79.03	79.233	80.663	80.141	79.986	80.114	81.417
590	67.335	69.149	75.554	75.678	78.987	79.105	80.533	79.996	79.817	79.849	81.185
600	68.891	70.228	75.932	75.917	79.187	79.28	80.687	80.079	79.845	79.923	81.311
610	70.413	71.389	76.346	76.239	79.426	79.436	80.808	80.197	80.035	80.125	81.495
620	71.548	72.207	76.496	76.409	79.528	79.489	80.886	80.32	80.235	80.356	81.749
630	73.495	73.936	77.503	77.15	80.163	80.181	81.579	80.989	80.784	80.83	82.209
640	74.885	75.162	78.265	77.837	80.857	80.917	82.3	81.718	81.515	81.575	82.971
650	75.763	75.857	78.621	78.173	81.172	81.222	82.573	81.961	81.74	81.831	83.254
660	76.592	76.562	78.877	78.345	81.343	81.298	82.763	82.099	81.925	82.018	83.593
670	77.214	77.098	79.175	78.588	81.42	81.428	82.779	82.2	81.988	81.983	83.433
680	77.644	77.469	79.347	78.769	81.594	81.571	82.957	82.366	82.196	82.22	83.674
690	78.204	78.006	79.835	79.221	82.046	82.069	83.378	82.784	82.607	82.69	84.131
700	78.73	78.555	80.267	79.695	82.585	82.539	83.888	83.287	83.132	83.186	84.632

Table B23 Spectrum reflectance of acrylic paint primary color “Black” at different concentration (%).

WL	Concentration (%)										
(nm)	99.99	75.00	50.00	25.00	12.50	5.00	2.50	1.25	0.625	0.315	0.156
400	0.332	0.391	0.396	3.382	0.395	1.911	7.101	17.076	28.548	40.246	50.771
410	6.004	6.336	6.191	4.417	7.686	10.651	16.153	22.894	32.418	42.9	52.23
420	0	0	0	3.32	0.048	3.727	9.207	18.084	30.798	42.906	54.44
430	5.818	6.102	5.938	4.197	7.606	11.059	15.941	23.67	34.578	45.559	55.753
440	1.155	1.315	1.222	3.559	2.902	6.707	12.068	20.232	31.526	43.327	54.252
450	4.593	4.914	4.692	4.016	6.405	10.07	15.312	23.286	34.298	45.988	56.782
460	3.307	3.68	3.455	3.968	5.111	8.759	14.043	21.86	33.009	44.391	55.015
470	3.801	4.198	3.947	3.967	5.601	9.279	14.678	22.435	33.458	45.111	55.873
480	3.805	4.238	4.012	4.028	5.609	9.211	14.755	22.37	33.144	44.515	55.371
490	3.288	3.733	3.468	3.928	5.127	8.909	14.447	22.148	33.347	45.235	56.194
500	4.224	4.671	4.403	4.071	5.997	9.683	15.084	22.777	33.762	45.315	55.979
510	3.204	3.645	3.36	3.957	4.999	8.852	14.453	22.49	33.755	45.652	56.701
520	4.153	4.627	4.337	4.081	5.886	9.622	15.313	23.169	34.148	45.582	56.337
530	3.029	3.539	3.21	3.979	4.818	8.693	14.471	22.388	33.72	45.504	56.532
540	3.77	4.278	3.945	4.072	5.524	9.39	15.148	23.032	34.242	46.069	56.995
550	3.397	3.927	3.577	4.046	5.147	9.062	14.857	22.806	34.13	45.853	56.848
560	3.736	4.275	3.889	4.066	5.44	9.351	15.231	23.29	34.626	46.353	57.331
570	3.547	4.095	3.714	4.079	5.248	9.227	15.011	23.06	34.477	46.281	57.298
580	3.653	4.214	3.822	4.088	5.355	9.392	15.256	23.383	34.889	46.709	57.786
590	3.71	4.293	3.902	4.129	5.423	9.468	15.307	23.366	34.826	46.582	57.624
600	3.56	4.162	3.765	4.115	5.291	9.388	15.312	23.487	35.006	46.908	58.034
610	3.921	4.543	4.153	4.164	5.653	9.744	15.668	23.893	35.364	47.148	58.213
620	3.662	4.301	3.895	4.157	5.393	9.538	15.56	23.846	35.352	47.21	58.357
630	3.942	4.596	4.167	4.19	5.651	9.814	15.82	24.043	35.613	47.459	58.613
640	3.69	4.349	3.91	4.179	5.369	9.558	15.59	23.933	35.508	47.373	58.56
650	3.955	4.626	4.183	4.198	5.621	9.82	15.873	24.229	35.718	47.532	58.685
660	3.798	4.478	4.018	4.197	5.46	9.709	15.887	24.267	35.876	47.786	59.086
670	3.964	4.663	4.177	4.227	5.603	9.881	16.06	24.321	35.953	47.843	59.134
680	3.889	4.613	4.118	4.237	5.538	9.844	16.063	24.402	36.053	47.985	59.305
690	3.808	4.571	4.06	4.214	5.479	9.837	16.139	24.642	36.38	48.399	59.832
700	4.073	4.869	4.35	4.271	5.729	10.099	16.389	24.863	36.571	48.507	59.914

VITA

Nawarat Kaew-on received her MSc. in Imaging Technology from the Faculty of Science, Chulalongkorn University in 2001, she graduated her Bachelor of Photographic Science and Printing Technology from the same faculty. After she completed her Master's work, Nawarat worked in the printing and packaging industry for fourteen-years, three years in an Asian packaging company and eleven years of services at Target Corporations, the second largest retailer in the world. As the key personnel in Target's Packaging Operations located in Southeast Asia, Nawarat worked well in cross-functional and cross cultural teams, which strengthened her skills, not only in the fields of printing and packaging, but in communicating, collaborating and training. In addition to her experience in the professional field, Nawarat is extremely interested in art. She spends most of her time learning and teaching art, especially in acrylic color painting. She teaches decorative painting class at her home studio routinely.

In 2014, Nawarat was awarded the fellowship by the Thai Research Fund for the Doctorate of Philosophy in Imaging Science. She decided to pursue her education as she found that it is a perfect opportunity to merge her background in science and her skill set in art to support the Thai traditional art conservation.

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