DEFECT REDUCTION IN COATING PROCESS OF ALUMINIUM COMPOSITE PANEL

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การลดข้อผิดพลาดในกระบวนการเคลือบสีบนแผ่นอะลูมิเนียมคอมโพสิท

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วิทยานิพนธ์ฉบับนี้มีจุดประสงค์ เพื่อลดของเสียที่เกิดขึ้นในกระบานการเคลือบสีของแผ่นอะลูมีเนียมคอมโพสิท

จากการศึกษาข้อมูลพบว่า ของเสียที่เกิดนั้นมีอยู่จำนวนมาก ซึ่งมีผลต่อการผลิต ในหลายขั้นตอน เนื่องด้วยจาก การผลิตเป็นการผลิตแบบต่อเนื่อง ซึ่งเป็นการเสียเวลา และต้นทุนเป็นอย่างมากต่อการทำการผลิต ผู้วิจัยจึงได้ทำการดำเนินการ โดยการหาสาเหตุ การวิเคราะห์หาสาเหตุ การหาวิธีแก้ไขปัญหาการลดปัญหาและควบคุมกระบวนการในขบวนการเคลือบสีซึ่งเริ่มจากการทำการศึกษาขบวนการเคลือบสีบนแผ่นอะลูมีเนียมและหาปัจจัยที่ส่งผลกระทบต่อขบวนการเคลือบสี ของเสียที่มีปริมาณเยอะที่สุด คือ สีไม่เท่ากัน และได้ทำการออกแบบการทดลองกับปัญหาที่เกิด โดยมี 2 ปัจจัยที่เกี่ยวข้อง คือ อุณหภูมิในเตาอบ และ ความห่างของลูกกลิ้งเคลือบสี และได้ทดสอบข้อมูลทางสถิติและหาปัจจัยที่เกิดขึ้น และ ได้ทำการใช้แผนภาพแสดงวิเคราะห์สาเหตุและผลกระทบ เพื่อหาสาเหตุที่แท้จริงที่เกิดจากปัจจัย พบว่า อุณหภูมิในเตาอบนั้น เป็นปัจจัยสำคัญที่ทำให้เกิดของเสียในการเคลือบสีไม่เท่ากัน และได้หาวิธีแก้ไขปัญหาและลดของเสียในขบวนการเคลือบสีบนแผ่นอะลูมีเนียม หลังได้ทำการทดสอบอีกครั้ง ในช่วงบริเวณต้นของคอยล์อะลูมิเนียมและท้ายของคอยล์อะลูมิเนียมและได้ทำการเทียบข้อมูลก่อนและหลังการปรังปรุง

จากการปรังปรุงแก้ไขในขบวนการเคลือบสีพบว่าจำนวนของเสียที่เกิดในกรณีสีไม่เท่ากันนั้น ได้ลดลง จากเดิม 23.99% เป็น 2.45% ซึ่งลดลงจากเดิม 21.54% ซึ่งเปรียบเทียบกับข้อมูลเดิมคิดเป็น 87.78%หลังจากการทำการปรับปรุง

ศูนย์ระดับภูมิภาคทางวิศวกรรมระบบผลิต ลายมือชื่อนิสิต ....

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This objective of this thesis is to reduce the defect in coating process of aluminium composite panel.

From the research, Defect has the large amount. That is affected to production process in many activities. Due to continuous production process, it wastes time and cost from defect that affected production seriously. Researcher operated by cause definition, cause analysis, improvement, reduction and control in coating process. This research studied in detail of coating process of aluminium composite panel and found the factor that affect coating process. The most quantity of defect is colour unlikeness. Design of experiment is created with 2 factors. There are temperature inside oven and roller Gap. Experiment is tested by statistical method and found significant factor. Cause and Effect Analysis Diagram uses for defining the real cause and effect. Temperature inside oven is the significant factor. Researcher found related method and reduced defect in coating process. After adjustment, researcher checks the result by checking on top of aluminium coil and tail of aluminium. Before adjustment data and After adjustment data are compared and analysed

After improvement of coating process, it found that defect from colour unlikeness case; reduce from 23.99% to 2.45%. It reduces to 21.54%, which compares with before improvement data. It can be calculated 87.78% after improvement.

The Regional Center for Manufacturing System Engineering Student's Signature ....

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Introduction

1.1. Background Information

Thailand is the developing country. There are a lot of companies in Thailand which have the technical knowledge. Many counties in the world choose Thailand as base production. Thailand is expanding industry and economic. Thailand is making product for export and supply in many international companies. Production and lead-time will be planed for production. It makes the objective and target for company. Some product has high technology. It needs the labour skill, experience, and technical processes, etc. But, SME business has the limitation about cost. So, lack of technology, knowledge, Human Factors, These factors is the affective factors. Training for employee, defects, and lack of experience will be cost the business. Many SME businesses cannot control perfectly. They can only adjust cost and gain profit for still in the market. Factory process improvement has to create optimally for business.

In architectural product, this type of business uses design of product to drive business. It will be hard for company to have exact amount for production system, because of uncertainty from customer. They have to provide the good information inside organization. It will be helpful for factory. Overdo quantity of products, defects, etc. from production process will be cost for business. Company will pay maintenance cost, damage cost, and so on. If company has bad production system management, it will increase costs.

In this research, Production customise base on customer's need. Factory must plan stock of raw material in production process. Production should ready all the time. Thus, factory need consider production plan. Production plan is the forecast for manufacturing and Capacity planning. It affects to cost, lead-time. These factors are important and indicate the business. Factory process should be improved more efficiency to reduce cost and time. It will be helpful for business. Production planning should be clean for operator.

Defect Reduction is the activity for optimising the production process. In architectural product, it needs high technology. This activity will make factory to define, Waste from production line, Production Capacity, Lead-time, Amount of resources (Man, Machine, Material, etc.).

1.2. Company Profile

Case Study Company is the group company, which produces architectural product in many type of product. There are steel, metal-ceiling, and Aluminium-Composite panel (Interior-Exterior construction product). Case company is the industry leader in metal ceiling and panelling. Case study Group Company expands and separates production section. Case company A is the one of company which produces aluminium composite panel. Case Company A use name for product as “K”. K’s production process is produced and manufactured under one roof and controlled by experienced engineers. Case Company A uses all strength and knowledge to produce the high-quality product K. Aluminium-Composite panel is low weight and high durable for exterior and interior design.

Product K, the aluminium composite material is fabricated from high technology production line. Product K is utmost satisfy by domestic and worldwide design constructions. Product K is aluminium composite panel, thermoplastic polyethylene core sandwiched with two sheets of aluminium, has high strength, rigidity, smoothness, monolithic surface as well as exceptional lightweight.

Sound Insulation and Vibration Damping

With its core composed of a low density viscoelastic and high molecular polyethylene, K has an excellent sound reduction and has resonance lower than other aluminium sheets.

Heat Insulation

K provides an excellent heat insulating and inflammable capability up to 100 degree Celsius. Their bending strength and deflection capacity are outstanding.

Cleaning and Maintenance

K is easy to clean and save huge cost in maintenance. K uses only soft sponge and mild detergent with water to clean the surface.

Figure 1.1: Reference Project [Case Study Company A]

As figure 1.1, Product K has many features and good for interior and exterior design in current world. Nowadays, many projects in Thailand and other countries use aluminium-composite panel for their construction. In psychical features, it has many advantages, such as low weight, easy maintenance, and so on.

Moreover, it costs lower than other material. Aluminium-Composite panel is the new and high technology in this 21st century, which Many Architect uses for modern exterior and interior design in construction work or project.

1.2.1 Product Feature

- Light Weight
- Easy Fabrication
- Easy Maintenance
- Heat Insulation
- Weather Proof
- Environmental-Friendly
- Non-toxic Product

1.2.2 Product Specification

Product K, Aluminium Composite panel is consisting of Polyethylene or High mineral filled core, which is the core of panel. Top of panel uses the high grade aluminium alloy, Primer, Poly-vinylidene Difluoride (PVDF) Paint and Protect Film. Bottom of panel use high grade aluminium and rear side coating. Product size, product mechanic features is shown in table 1.1 and table 1.2.

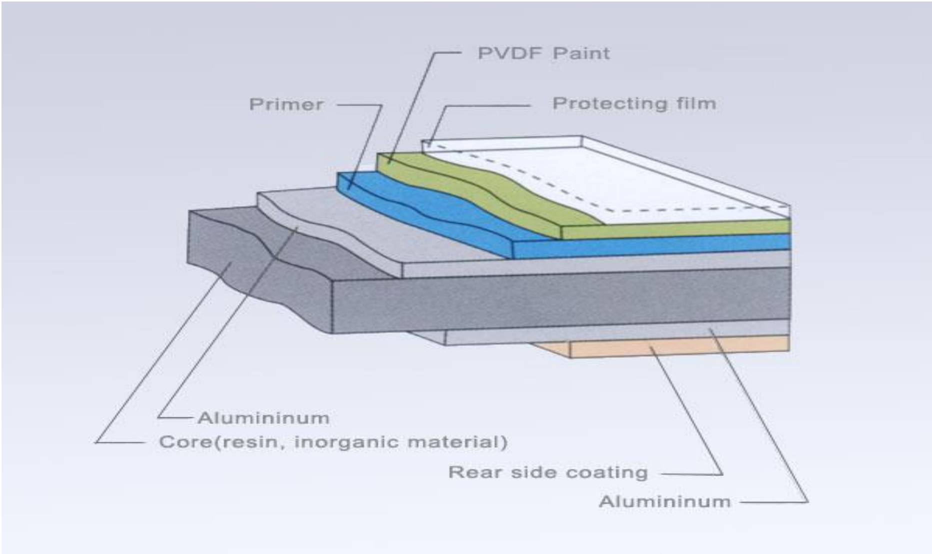


Figure 1.2: the component of Aluminium Composite panel

[Case Study Company A]

Table 1.1 Product Size

The Standard Thickness and Dimension of Panel		
Thickness	4 mm.	6 mm.
Width	1,250 mm.	1,575 mm.
Length	2,440 mm.	3,150 mm.
	3,150 mm.	

Special Size			
Thickness	4 mm.	6 mm.	Minimum Order
Width	850-1,575 mm.		1,500 sqm.
Length	Max 5,000 mm.	Max 8,000 mm.	150 sqm.

K has many tests and quality standard before distribute the product to customer. Case Company A would like to send the High-Quality product to customer. High- Quality product property is the important for in construction business. Product specification, aluminium composite panel, is the new technology and high-gen product in construction industry. Test is the important to approve product for installation and construct into project. Many tests use for checking product quality and safety installation. Safety is the important factor for construction. Moreover, Construction law is the one important factor for construction. K, there are many test for approving product standard. It is shown in table 1.3.

K has the fire test (UK, Germany, and USA standard). Case study Company A concerned about construction Law. So, Fire test is the safety and quality approve for exterior or interior installation. A fire testing, the process consists of the condition of product by weather, temperature, and wind in 25 minutes.

Table 1.2 Mechanical Features

Product K Rigidity And Weight						
Rigidity	**Product K**		**Aluminium**		**Steel**	
	Thickness	**Weight**	**Thickness**	**Weight**	**Thickness**	**Weight**
0.240 kN m^2/m	4 mm	5.5 kg/m^2	3.3 mm	8.9 kg/m^2	2.4 mm	18.7 kg/m^2
0.590 kN m^2/m	6 mm	7.3 kg/m^2	4.5 mm	12.2 kg/m^2	3.2 mm	25.2 kg/m^2

Table 1.3 Property of Product K

TECHNICAL PROPERTY OF "Product K"					
No.	**Property**	**Unit Weight**	**Product K**		**Standard**
			4mm	**6mm**	
1	Density	g/cm^3	1.37	1.22	ASTM D792
2	Weight	kg/m^2	5.48	7.34	
3	Thermal Expansion (-20 - 60 ˚C)	$10^{-6}/^{\circ}C$	24	25	ASTM D696
4	Thermal Conductivity (Appearance)	w/m • k	0.15~0.19		GB10294-88
5	Temperature for Thermal Deformation	˚C	113		ASTM D648
6	Acoustic Insulation	dB	26	27	ASTM E413
7	Tensile Strength	MPa	48	38.2	ASTM D638
8	Yield Strength	MPa	44.2	30.4	ASTM D638
9	Extension Rate	%	14	17	ASTM D638
10	Transverse Modulus	$X10^4MPa$	4.2	2.8	ASTM D393
11	Impact Resistance	kg	1,670	2,120	ASTM D732
12	Adhesive Strength	Kg/cm^2	85		ASTM D638
13	Peel Strength	kg • f/25 mm	18		ASTM D638
14	Flexural Rigidity	Kg/cm^2	1,150		ASTM D638
15	Test for Toxic Gases Cause by Fire	-	GOOD		-

Next, coating process, Product K has the test in paint and colour. Product K is coated by PDVF. Case Study Company A guarantees for 10 years under normal outdoor condition. PDVF coated product can withstand long term erosion of wind, rain (normal, acid), UV light and chemicals. Test is checked by coating thickness and roller coating. In table 1.4, A Case Study Company A uses many standards (ASTM, NCCA, and AAMMA**)** for coating test. Mostly, standard is based on international standard by USA.

Table 1.4 PDVF Coating Test

PVDF COATING TEST		
1	Hardness	ASTM D-3363-74(NCCA II-12)
2	Flexibility (T- bend)	ASTM D-4145-83(NCCA II-19)
3	Adhesion	ASTM D-3359-87(NCCA II-5)
4	Adhesion (Falling sand)	ASTM D-968-81
5	Mortar Resistance	AAMA 605 , 2-91 ,TEST # 7.7.2
6	Detergent Resistance	dBASTM D-2248-73
7	Acid Resistance	ASTM D-1308-87 AAMA 605 , 2-91 , TEST # 7.7.3.1
8	Alkaline Resistance	ASTM D-1308-87
9	Salt Fog	ASTM B-117-85(NCCA III-2)
10	Humidity	ASTM D-2247-87 , D-714-87
11	Colour Retention	ASTM D-2244-85
12	Chalk Resistance	ASTM D-659-86

1.3. Objective

The purpose of this research is to study about Aluminium-Composite panel and reduce defects in coating process which is based on a Case Study Company A.

1.4. Scope of research and Assumption of research

- Defect reduction
- Study and Research in coating process only
- Design the sustainably problem solving plan and operation
- Enhance production process and improvement in coating process
- Formulate an implementation plan for production improvement and defect reduction
- Reducing cost, time and related factor
- Finding solution and optimal tool for implement and solve this problem effectively and efficiency
-

1.5. Expected Benefit

This research will provide optimal solution for Case Study Company A. It will focus on defect reduction based on coating process. It should benefit to Case Study Company A. The research will cover and mention by using and applying tools, techniques, and so on. Expected Benefit will be defined as following:

- Reducing related costs (Raw material, maintenance, overhead cost and etc.)
- Gaining profit by defect reduction.
- Reducing Defect from coating process.
- Defect can be controlled.
- Better production plan and improvement
- Machine Problem can be controlled (Maintenance, Setup, etc.)
- Find solution for long-term problem solving, especially coating process.

1.6. Expected results

The result of this research is the sustainable problem solving, management in defect reduction for Case Study Company A. Optimal tool, technique is provided for solving defect reduction. It will improve the efficiency of coating process which can reduce defect, time, and related cost.

1.7. Methodology

This research will focus on coating process. Researcher would like to improve and find the optimal solution for this company. Research will concentrate on creating the implementation plan for Defect Reduction by:

- Conducting Data and analyse for reducing defect
- Improving production process sustainably, especially in coating process
- Cause & Effect Diagram
- DMAIC (Define-Measure-Analyse-Improve-Control) concept
- Design of Experiment (DOE)
- Or related method

This research uses to apply this research. This framework will make the research systematically. In each phase, there are the tools and techniques to find the solution. DMAIC technique is integrated technique. There are many tools that use in this technique for identify the problem step by step. Cause & Effect diagram (Fish bone diagram) is the tool to generate the idea and identify the cause of the problem. Cause & Effect is the measurement tool of the problem and use for prioritise the cause and effect which occur in the process. Design of Experiment is the statistic tool for Factor analysis. It will help researcher that see the effect and find the problem.

1.8. Research Procedure

The research procedures of finding the solution for Case study Company A will focus on Coating Process .It will divide into following steps:

1. Study the related literatures
   1.1 Finding related information
   1.2 DMAIC (Define-Measure-Analyse-Improve-Control) concept
   1.3 Cause & Effect Diagram
   1.4 Design of Experiment (DOE)
   1.5 Product specification
   1.6 Company profile
2. Study the existing Coating Process
3. Collect and assess the existing information
4. Analyse the cause of problem with the consultancy of supervisor, manager and operators
5. Create solutions
6. Apply tools, techniques, etc.
7. Formulate the operation procedure
8. Summarize and evaluate the result
9. Prepare and Establish implementation plan
10. Implementation action
11. Prepare thesis report
12. Attend the thesis examination

Chapter II

Literature Review

In this chapter, researcher finds contents, journal, method, or theory, which these involve or relate to research. They consist of as following:

2.1 Aluminium coating process

Aluminium Coating Process, There are processes as following:

2.1.1 Aluminium coil, it is uncoiled and cleaned stain by Alkali solution at 80 C. Then, it is cleaned by clean water again.

2.1.2 Aluminium is coated Chromate solution at thickness 2-3 µm, temperature 70 C for dry baking. Colour adheres with the aluminium surface. When it coils again, colour will be coated on the surface.

2.1.3 Coat Primer Coating Colour at thickness 20-22 µm. Then, bake at 224 C. 2.4 minutes, speed line 10m/minute

2.1.4 Coat Top coat Colour at thickness 10-12 µm. Then, bake at 224 C. 2.4 minutes, speed line 10m/minute

2.2 DMAIC Process

DMAIC process is one part of Six Sigma. There are the five main principles. These fives principles is very famous in current quality system. As following:

- Define Phase
- Measure Phase
- Analyse Phase
- Improve Phase
- Control Phase

Six sigma steps	Key processes
Define	Define the requirements and expectations of the customer Define the project boundaries Define the process by mapping the business flow
Measure	Measure the process to satisfy customer's needs Develop a data collection plan Collect and compare data to determine issues and shortfalls
Analyze	Analyze the causes of defects and sources of variation Determine the variations in the process Prioritize opportunities for future improvement
Improve	Improve the process to eliminate variations Develop creative alternatives and implement enhanced plan
Control	Control process variations to meet customer requirements Develop a strategy to monitor and control the improved process Implement the improvements of systems and structures

Figure 2.1 Key steps of six sigma using DMAIC process [Young Hoon Kwaka, 2006]

As figure 2.1, Fives principles have the process with inside and outside organisation. DMAIC has many requirements in each principle. So I will describe in each principle as following.

2.2.1 Define Phase

This step focuses on problem in project. It creates the project scope, problem statement, goal, and objective of this research. They identify propose of project. They are defined the direction of project scope and problem solution. Hence, process activity is the next one that researcher think in this principle. We define the process in many terms, which find the way for solving problem and finding the solution. It means that we create the process for understand and solve the problem.

2.2.2 Measure Phase

This principle focuses on process definition and measurement. Researchers have to collects data and set the plan for collection and implement the data. Firstly, "How to collect the data", it is the question to ask for this step. Researchers need to make or create the data collection plan. Type of data& measure, what to measure, Sampling, and specification; all of them are the factor for set the data plan.

Next, after gathering the information or data, Researcher needs to calculate the data and find the defect of process. The data will be analysed in the next phase.

2.2.3 Analyse phase

This step follows from measure phase. So, Researcher sees the result and analyse the data that collect. It can be found the defect or the process. What are the causes that make the defect? It will be discussed with the team. Then, Researcher will know the causes that make the defect or problem in the process.

2.2.4 Improve Phase

Improvement is the action of development in the process. This step is elimination of defect that occurs in the process. Researcher has data analysis and gets rid of the defect. Then, they will develop and make the alternative plan for improve the process. In the define step can utilise and make this step to create the alternative plan effectively.

2.2.5 Control Phase

This is the last step in DMAIC cycle. Control step is the step to improve continuously. It means that organisation will maintain their quality to achieve satisfaction. Researchers have to evaluate the solution and plan that create from above four steps. Plans or actions that choose for alternative plan, researcher should maintain and monitor the standard of the process. Implementation plan creates and maintain the improvement.

2.3 Cause & Effect Analysis

Cause and Effect analysis is the tool, which find the problem and cause relation. These affect process. It can called “Fish Bone diagram”. It seems like the skeleton of fish. That’s the reason, why it called “Fish bone”. Cause & effect analysis was called “Ishikawa Diagram”. It was invented and developed in 1943 by Professor Kaoru Ishikawa, The University of Tokyo. According to Professor Kaoru Ishikawa, There are 3 type of cause and effect diagram. They consist of as following;

- Dispersion Analysis
- Process or Production Process Analysis
- Cause Enumeration

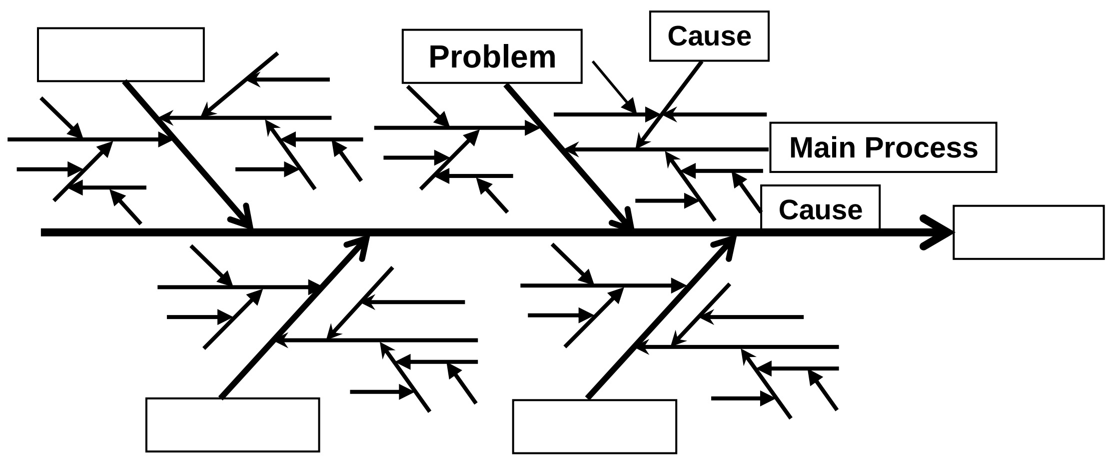


Figure 2.2 Dispersion Analysis Type

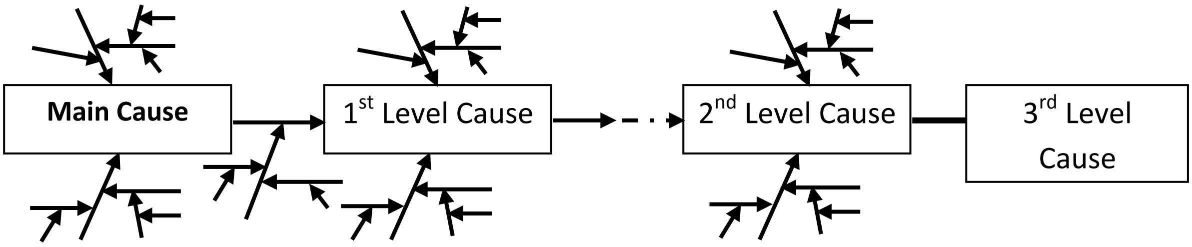


Figure 2.3 Process or Production process Analysis Type

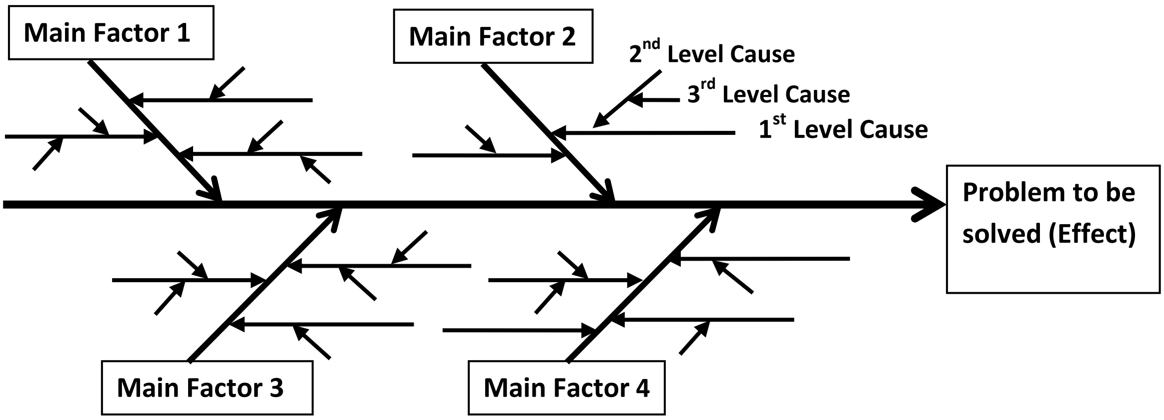


Figure 2.4 Cause Enumeration Type

In figure 2.2, figure 2.3 and figure 2.4, every type of Cause & Effect Diagram, they consist of 2 main parts. They are Problem or Effect part, which is located right side or fish head, and Causes part, which are separated into many factors that affect to problem. Cause is located on each skeleton of fish. It prioritise into level of cause that affect the problem.

2.3.1 Cause & Effect Diagram Instruction

The important for Cause & Effect Diagram is the process flow. It defines the problem, effect and cause. So, Brainstorming is the important tool for finding the factor that affects cause and problem. Finding factor has to prioritise the level of cause and problem. It will be optimal alternative for necessary implementation.

2.3.1.1 Problem that will be solved, it should be defined clearly and possibly. If it is not clear initially, time will be spent a lot for finding cause. Problem definition should be "Defect, Working time, Inefficiency People, Cost, or etc." Mostly, problem should be the negative situation. Brainstorming is the one of important tool for defining problem in cause& effect diagram. It should find the origin of cause, and why it occurred.

2.3.1.2 Factor categorisation, it can categorise in group. Factor can be anything that affect to problem or effect. Factor should define the cause systematically and clearly. Normally, factor can separate into 4M principle. They consist of Man, Machine, Method, and Material.

a.) Man is the operator, worker or Human resource, such as operator has not enough knowledge, no motivation, and no skill, etc.

b.) Machine is the factor that involved with machine, such as machine position, machine installation, machine does not optimise with method or material, etc.

c.) Method is the way or direction of work process, such as unsuitable method, complex method, etc.

d.) Material is the raw material or parts that using in the work process, Such as material size does not optimal, Colour unlikeness of material, etc.

2.3.1.3 Brainstorming for defining cause in each factor is the tool and technique that create cause & effect diagram perfectly. In each skeleton of fish, it is the factor that involved with the problem of effect of the process. In the right side, it is the problem or effect to be solved. In the middle, they are the skeleton of fish. In each one is the main factor of problem or effect. The main factor, there are cause in each level as figure 2.4.

2.4 Design of Experiment (DOE)

Design of experiment or DOE is the one statistical tool for data analysis. It is the science process or method that uses statistical theory for data analysis. Design of experiment objective is the control of variables or factor in the process. Design of experiment collects the data, based on input and output of experiment. Input is the factors that involve and affect the process. Output is the response from the factor in the experiment process. DOE can analyse and summarise the data systematically and reasonably.

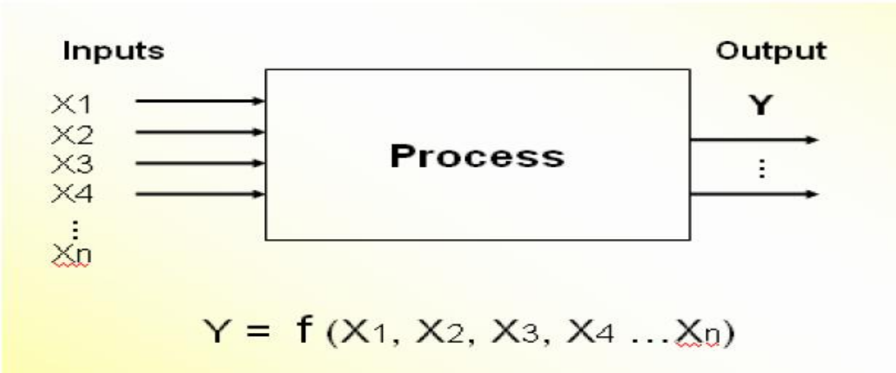


Figure 2.5 Input (Factors), Output (Response), Process [Montgomery, 2005]

According to Figure 2.5, there are variables or factor in the process, which is "Input" (X_1, X_2, X_3, $X_{4...}$ Xn) and "Output" is the response (Y). Design of experiment is the design of X and Y statistical relationship. It is designed with process knowledge for improvement.

Factorial design is the one of DOE technique that design or crate for two or more factor that each complete trial or replicate of the experiment all possible combinations of the levels of the factors are investigated. The observations and replicates may be described by the linear statistical model as equation 2.1 [Montgomery, 2005].

$$Y_{ij} = \mu + \tau_i + \beta_j + (\tau\beta)_{ij} + \epsilon_{ijk} \begin{cases} i = 1,2, \dots, a \\ j = 1,2, \dots, b \\ k = 1,2, \dots, n \end{cases} \quad (2.1)$$

Where Y_{ij} = Total Reservation in i and j

μ = is the overall means effect

τ = the effect of the i^{th} level of factor A

β = the effect of the j^{th} level of factor B

$(\tau\beta)$= the effect of the interaction between Factor A and B

ϵ= is a random error component having a normal distribution with mean zero and variance

There are Factor A, B and AB testing hypothesis as followings:

For Factor A, as equation 2.2

$$\mathbf{H_0: \tau_1 = \tau_2 = \ldots = \tau_a = 0}$$

$$\mathbf{H_1: \text{at least one } \tau_i \neq 0} \qquad (2.2)$$

For Factor B, as equation 2.3

$$\mathbf{H_0: \beta_1 = \beta_2 = \ldots = \beta_b = 0}$$

$$\mathbf{H_1: \text{at least one } \beta_j \neq 0} \qquad (2.3)$$

For Factor AB, as equation 2.4

$$\mathbf{H_0: (\tau\beta)_{11} = (\tau\beta)_{12} = \ldots = (\tau\beta)_{ab} = 0}$$

$$\mathbf{H_1: \text{at least one } (\tau\beta)_{ab} \neq 0} \qquad (2.4)$$

The sum of square of two-factor ANOVA formula is computed as Equation 2.5, 2.6, 2.7, 2.8 and 2.9 (Montgomery,2005)

SS_T=

$$\sum_{i=1}^{a}\sum_{j=1}^{b}\sum_{k=1}^{n} y_{ijk}^2 - \frac{y^2}{abn}$$

(2.5)

SS_A=

$$\sum_{i=1}^{a} \frac{y_i^2 \dots}{bn} - \frac{y^2 \dots}{abn}$$

(2.6)

SS_B =

$$\sum_{j=1}^{a} \frac{y_i^2 . j .}{an} - \frac{y^2 \dots}{abn}$$

(2.7)

SS_{AB}=

$$\sum\sum \frac{y_{ij}^2 \dots}{n} - \frac{y^2 \dots}{abn} - SS_A - SS_B$$

(2.8)

SS_E= SS_T-SS_{AB}-SS_A-SS_B

(2.9)

Source of Variation	Sum of Squares	Degree of Freedom	Mean Square	F_0
A treatments	SS_A	a-1	$MS_A=\frac{SS_A}{a}-1$	$\frac{MS_A}{MS_E}$
B treatments	SS_B	b-1	$MS_B=\frac{SS_B}{b}-1$	$\frac{MS_B}{MS_E}$
Interaction	SS_{AB}	(a-1)(b-1)	$MS_{AB}=\frac{SS_{AB}}{(a-1)(b-1)}$	$\frac{MS_{AB}}{MS_E}$
Error	SS_E	ab(n-1)	$MS_E=\frac{SS_E}{ab(n-1)}$	
Total	SS_T	abn-1		

Table 2.1 ANOVA Table (Montgomery, 2005)

In table 2.1, it is the analysis of variance table or ANOVA for two-way with two factors.

2.5 Temperature Measurement

Case study Company A uses the equipment from "DataPaq Company". DataPaq is the company, which produce and distribute the measurement tool and equipment. Measurement Equipment, which indicates for this research, has a little pin that set and measures the temperature on the surface of material. Then, each pin, there is the line that are connected to the device as figure 2.7. The data visualise data measurement graph as figure 2.6.

According to DataPaq, this equipment indicate and temperature data in every 0.05 second. After finish measurement, device is connected to computer for reading data. Data is shown as graph. Researcher can know temperature inside oven.

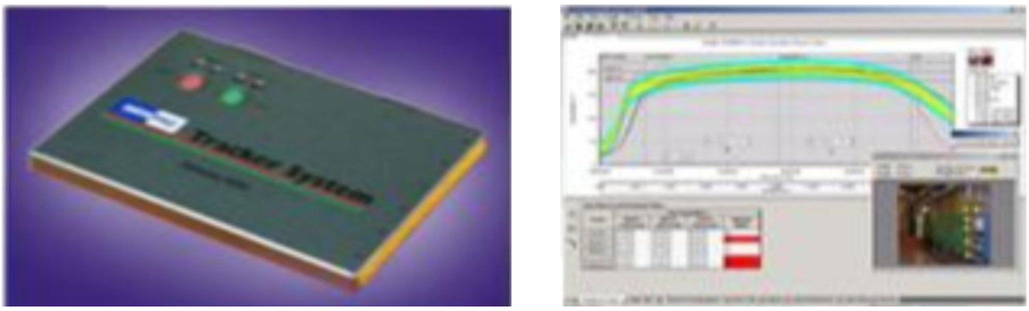


Figure 2.6 DataPaq Equipment and Computer Programme [DataPaq Website, 2012]

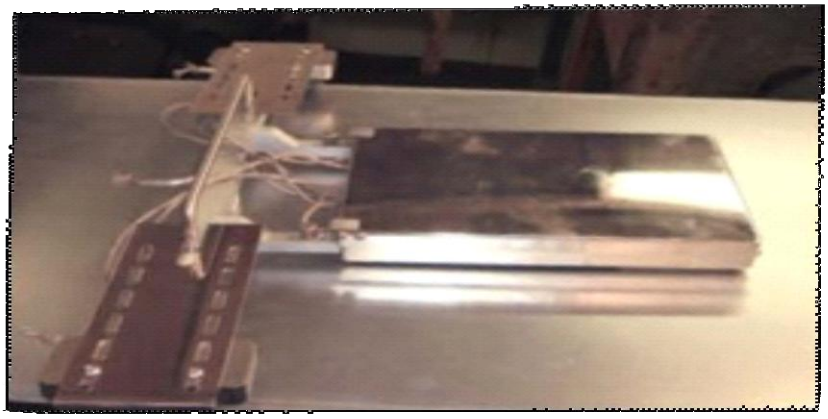


Figure2.7 Equipment Installation on the Surface tracker [DataPaq Website, 2012]

According to the case study company A, they use as colour supplier for baking. Company use temperature 224C. The range of acceptable temperature is 224-232C.

Another measurement equipment is Paperthermo label both left and right side surface of coating Surface. On Paperthermo label as figure 2.8, there are all white squares. When the white square changes to Black square, temperature is read as that scale. Different scale is 8 Celsius degree. If it exceeds little, it will change to upper or lower scale immediately.

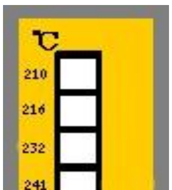


Figure 2.8 Paperthermo Label [Case Study Company A]

2.6 Colour Measurement

According to Human colour vision, Caused occurred by light reflection from the object. Reflection is light into eye and the brain. Human Brain translates into colour vision. So, there are 3 factors, which are Light origin, Colour Object, and Human Vision.

When the light from the light origin is illuminating the object with the incident, it is reflected into the eye. Human eye sight is sensitive to three primary colours of light are red, green and blue.

The Human Eye sight, it can indicate colour object into three types (R.W.G. Hunt)

- Colour Vision, such as red, green or blue is called “*Hue*”.
- Colour Brightness, which is a reflection of the light that is different, is called “*Lightness*”.
- A vibrant intensity and purity of colour called “*Chroma*”.

Human Colour vision, there is 3 factors as following; are Light origin, Colour Object, and the eyes sight.

2.6.1 Light origin

The origin of light, they can separate into 2 type; natural origin and Invented origin. Natural origin is sunlight or daylight that light down into earth. Sunlight is transparent light. If it light though prism, it can divide into 7 colours. Each colour has wave range, which is between 400-780 nanometre. Moreover, Sunlight in each region on earth, it has Spectral Energy Distribution (SED) differently. It depends on geography, climate, or period of time. So, Human eye sight, people see the origin of light differently in each place, or climate zone. This is the reason that people will see colour differently.

Invented origin, they are from Light bulb (incandescence), Tungsten Filament Lamp, or Fluorescence Light Bulb, Zeon Arc Lamp, LED or etc. These origins are invented by human.

2.6.2 Colour Object

When light is reflected on the colour object, it will reflect the phenomena of light reflection. It is called “Specula Reflection”. If the surface is not smooth, glossy, while the light is lighted down on object, it will be the phenomena that object absorb the some colour wave and reflect some. This phenomenon is called “Diffuse Reflection”. It will make the eye sight. People will see the colour different from the origin. Moreover, there is the other type of colour object. It is “Diffuse Reflection”.

Light shines thought translucent object and scatter on the object surface. It is called “Diffuse Transmission”. But, if the object is transparent, such as glass, it is called another term. It is called “Regular Transmission”. According to Figure 2.9, it is shown the phenomena of reflection on the surface of Colour Object

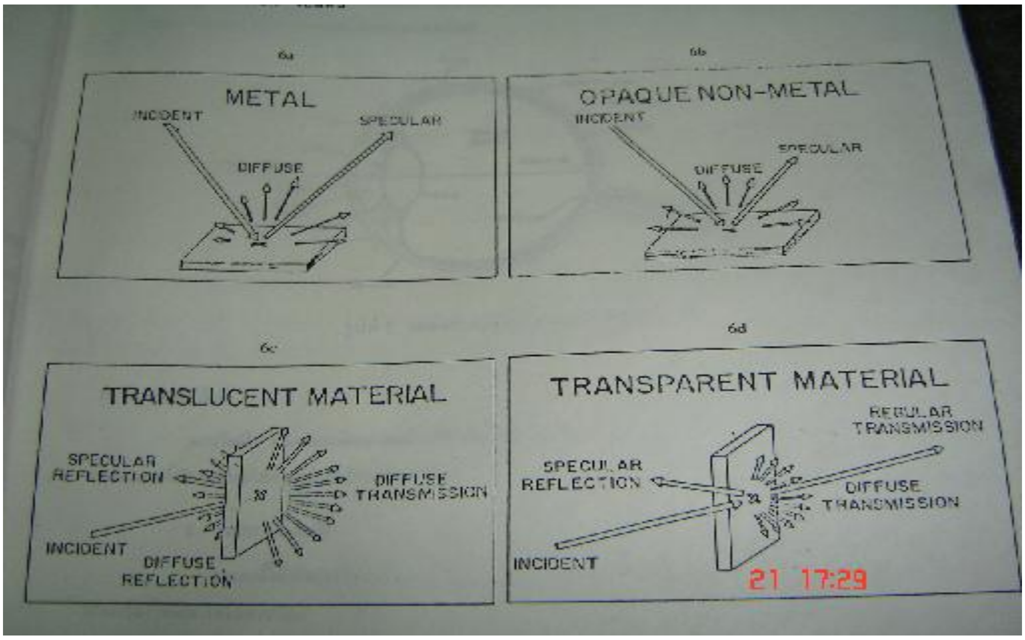


Figure 2.9 the phenomena of reflection on the surface of Colour Object [Case Study Company A]

2.6.3 Human Vision

Human Vision, This phenomenon is occurred, when light is reflected on the Colour object. Colour of object illuminate into eye. Retina is the sensitive organism. It receives illumination. According to figure 2.10 Retina, there is 2 cell parts, which consist of Rods cell nerves and Cones cell nerves.

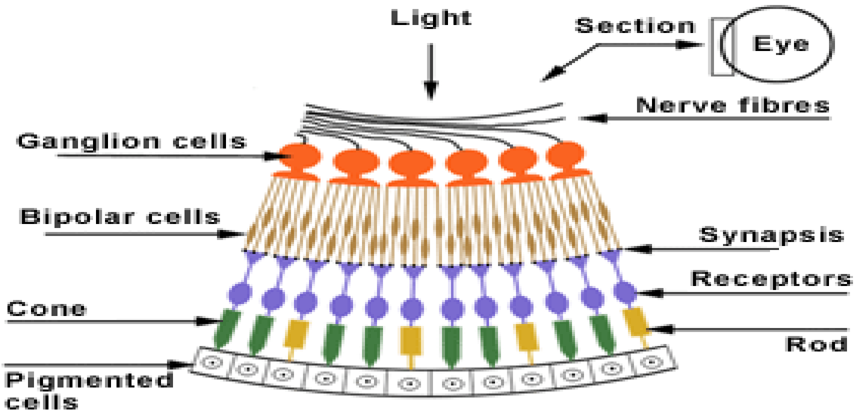


Figure 2.10 Human Vision Structure [One-Minute Astronomer's Website]

According to Department of Physics, Rajamagala University Website, Rod cell nerves receives monochromatic vision and Cones cell nerves receives colour vision. Rods and Cones cell nerves, they can classify into three levels of visibility. (Department of Physics, Rajamagala University's Website)

- Scotopic Vision: Rods cell nerves receive the only visible objects are white - black. The received light is between 10^{-6}- 10^{-2}fl.

- Mesopic Vision: Rods and Cones work together to identify the monochromatic object and colour object. But they can not specify exactly what colour is. The received light is between 10^{-2}- 1fl.

- Photopic Vision: Cones works only at this level. The visible objects is identified the colour clearly. The received light is 1 fl or higher.

Normally, Human vision response and simulate the object at wavelength 510nM (Scotopic Vision) and 555 nM. (Photopic Vision). Sensitive colour, which these cell nerves is affected, are Red, Green and Blue. They are shown in figure 2.11, 2.12 and table 2.2.

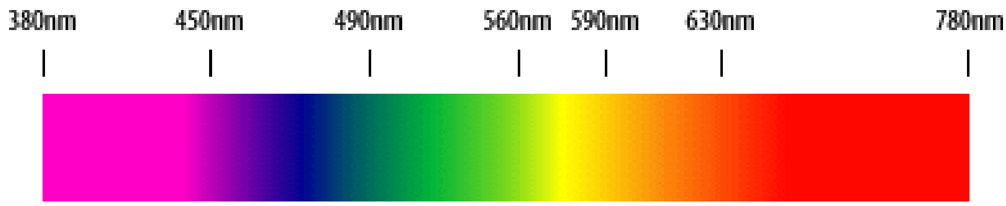


Figure 2.11 The wavelength of Colour

[Department of Physics, Rajamagala University's Website]

Table 2.2 Wavelength of Colour

[Department of Physics, Rajamagala University's Website]

Colour	Wavelength (nM.)
Red	780 - 630

Orange	630 - 590
Yellow	590 - 560
Green	560 - 490
Blue	490 - 440
Light Blue	440 - 420
Purple	420 - 380

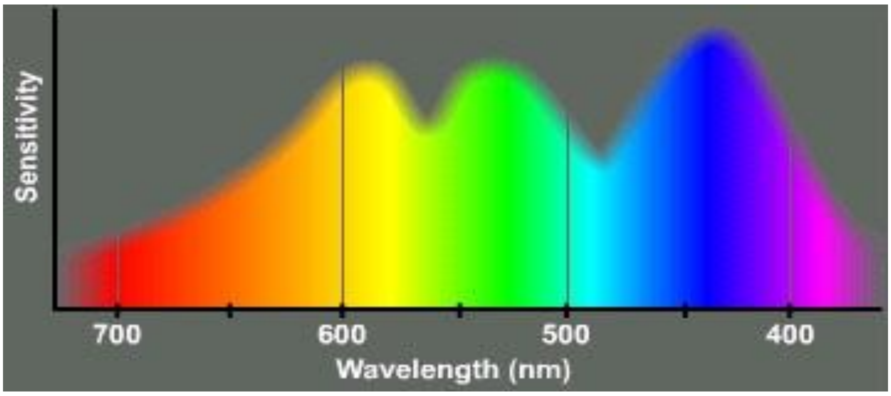


Figure 2.12 Sensitivity of Wavelength

[Department of Physics, Rajamagala University's Website]

Human Vision, people response and simulate the sight differently. So, industry, it should have International standard. It should be accepted from manufacturer and end-user. International Standard for Colour measurement. Standard System, there are many method and systems. Munsell and CIE is the international colour standard, which accept in many countries. Case study Company use CIE Standard for colour measurement. They use CIELAB or CIEL*a*b (1976) [CIE Publication 15.2]

CIE stands for “Commission Internationale de l’ Eclairage”. CIE is the institution, which develop standard system for illumination measurement. CIE standardise by numerical measurement. Colour is calculated into number. It can define as colour value.

Colour measurement use wavelength of colour for defining the exact colour. It reflects into human eye sight. Colour is measured by this measurement tool. It is called “spectrophotometer” in figure 2.13. Case study Company A uses BYK Company.

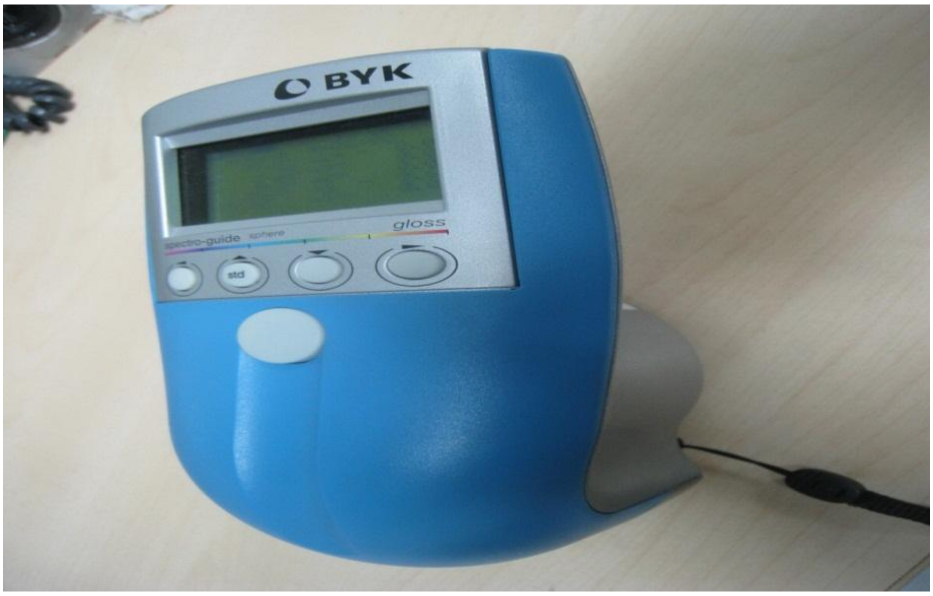


Figure 2.13 spectrophotometer [Case Study Company A]

So, CIELAB set the standard, which is categorised as followings (CIE Publication)

- Illuminant A : it represents the light and colour temperature about 2848 K, light power similar as tungsten light bulb or Incandescence
- Illuminant B: it represents the light and colour temperature about 4900K, It similar as noon light.

- Illuminant C: it represents the light and colour temperature about 6700K, it similar as daylight.
- Iluminant D: it represents the light, but colour temperature is different. It depends on standard, which user choose, such as D65, or D75
    - D65: it represents as light with colour temperature 6500K.
    - D75: it represents as light with colour temperature 7500K.

In generally, industry uses D65 standard for illumanant D measurement. Spectrophotometer uses this standard as reference measurement. It indicate object by illumination on object surface. It is compared with reference reflectance curve. Each Colour object has different wavelength. It is shown in figure 2.11. Three sensitive colour is Blue (Wavelength 440-490 nM), Green (Wavelength 490-560 nM), Red (Wavelength 620-780 nM) in table 2.1 and figure 2.12.

In figure 2.14 CIELAB (1976), it is calculated into 3 values, there are *L,*a and *b value. These values define the colour value or Chromaticity coordinate. It is the colour identification method. Each *L,*a,*b, they identify Lightness, Red or Green, and Blue or Yellow respectively. L*axis is measure reflect diffusion or Lightness (Black or White). Zero represents black and 100 represent as white. *a axis and *b axis can be positive or negative value. *a positive is Red. *a negative is Green. *b positive is yellow and *b negative is blue.

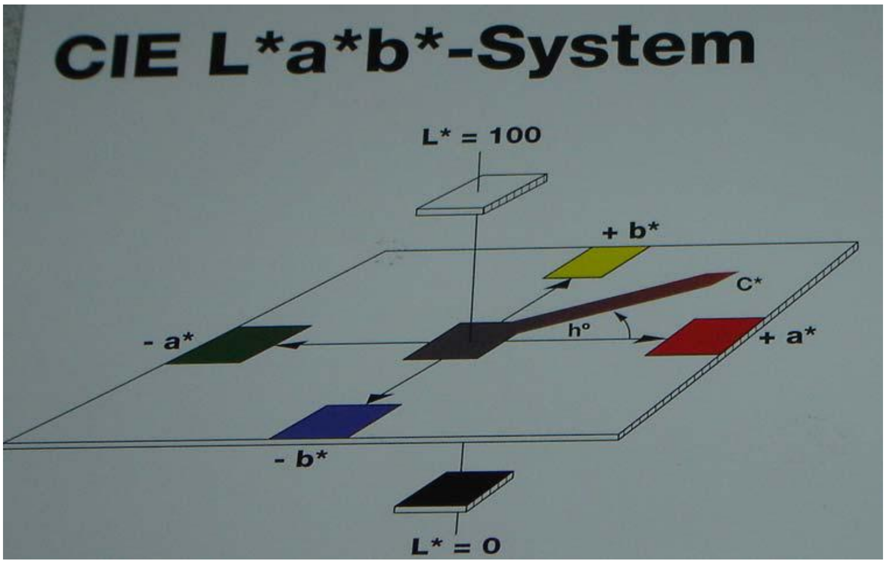


Figure 2.14 CIELAB 1976 System Colour space [CIE Publication 15.2, 1986]

L* is the Lightness, which is between 0-100

*a positive	Colour is represented as Red
*a negative	Colour is represented as Green
*b positive	Colour is represented as Yellow
*b negative	Colour is represented as Blue

So, each calculation, colour difference is measure as numeric value. Difference is indicated by comparing the standard and sample value from each *L,*a, and *b. The difference value for each axis, are the colour identification value. It defines as delta value of each axis. Delta value will represent the tolerance of colour for each axis. For example, Δ *a is positive. It means redder than standard.

The total colour difference is represented as ΔE. ΔE is calculated as formulas 2.10. It is the difference from sample and standard. ΔE is the single value. [CIE Publication 15.2, 1986]

$$\Delta E = \sqrt{(L_1^* - L_2^*)^2 + (a_1^* - a_2^*)^2 + (b_1^* - b_2^*)^2} \quad (2.10)$$

In general, Human Vision can see the colour, measure, and indicate colour by 3 factors (Light origin, Colour object and Colour Measurement). But Human Eye sight does not stable measurement. Each person has each standard. So, spectrophotometer is the tool or equipment, which indicates colour accuracy. It standardise the quality of colour measurement as industry international standard. It can globalise the product standard.

2.7 Project Financial Analysis

2.7.1 Net Present Value (NPV)

Net Present Value (NPV) is total of net return that the project period has been adjusted already, which is used to consider that return gained from the conducted or considered project is worthwhile or not. In case that calculated NPV is more than zero, this means that investment of that project is worthwhile. On the other hand, if the result of NPV is zero or negative, this means that investment of that project is not worthwhile. Therefore, NPV is used to be the criterion to make decision for acceptance or rejection of projects. In conclusion, NPV is the rate of return that makes the present value of the net benefit of the investment should be greater than zero. The NPV can be calculated by following equation 2.11 [Chatchai, Patchapon, 2004]:

$$NPV = \sum_{t=1}^{n} \frac{b_t - c_t}{(1+r)^t} \tag{2.11}$$

Which
NPV = Net Present Value
b_t = Return at year t
c_t = Cost at year t
r = Interest rate
t = Year period, which t=1,2,3,...,n
n = Project period

2.7.2 Internal Rate of Return (IRR)

Internal Rate of Return (IRR) is method to measure the return of the project that will provide worthwhile return on investment or not by using discount rate that affect the present value of cash flows expected to be paid to equal to the present value of cash flows expected to be received over the project period or the net present value is equal to zero. For example, there is investing 100 Baht at the beginning of the year and then gaining 140 Baht at the end of the year, which means that return on investment is 40% because discount rate at 40% affecting the present value of cash flows received equal to the present value of cash flows paid, which is 100 Baht or the present value of rate of return is equal to zero. In conclusion, rate of return on investment is rate of return that affects the net present value equal to zero.

Calculation of return on investment starts with estimation of costs and incomes for project operation. This calculation should test to determine discount rate by trial and error technique until achieving discount rate that affect the difference between the present value of cash flows received and the present value of cash flows paid is zero. The result of this calculation will be a real rate of return on investment. Internal Rate of Return can be calculated by following equation 2.12 [Chatchai, Patchapon, 2004]:

$$IRR = \sum_{t=1}^{n} \frac{b_t - c_t}{(1+r)^t} = 0 \qquad (2.12)$$

Which

IRR = Internal Rate of Return
bt = Return at year t
ct = Cost at year t
r = Interest rate
t = Year period, which t=1,2,3,...,n
n = Project period

2.8 Journal and Related Textbook

1) **Design and Analysis of Experiments : Classical and Regression Approaches with SAS, Leonard C. Onyiah, USA, 2009**

This Text book is the handbook about descriptive data analysis, probability, statistical distribution and method, Factorial design, Regression method and so on by using computer programme. This text book describes the way to define and design the experiment step by step with case and example. It based on SAS programme.

2) **Total Quality Management : Text with Cases, John S. Oakland, UK, 1995**

This text has technique in TQM method. The tools, which use in this research, are Cause & Effect Analysis (fish bone diagram), Pareto analysis diagram, Process Flow chart, etc. These are the tool and technique for quality Improvement and also can apply into this research. It uses for defining the problem, solving, and find the solution, implementation for this research.

3) **Introduction Statistical Quality Control, Douglas C. Montgomery, USA, 2005**

This text has the statistical method in many tools and techniques, such as SPC (statistical process control), ANOVA (analysis of variance), DOE (design of experiment), etc. All of statistical tools and techniques concern about process improvement and quality control. In this research, Design of experiment (DOE) is the one of tool that researcher choose for this research.

4) **Engineering Economy, Chatchai Aksadonsak, Dr.Patchapon Niummanee, Thailand,1st edition, 2004**

This text book has the project financial analysis method. For example, Net Present Value (NPV), Internal Interest Rate (IRR), Payback period calculation, they are the tool for financial analysis. These tool and technique help researcher to analyse value of project. Project should be invested or not.

5) **Analysis and Control of quality factors for automotive painting, Suwit Klampheng, Thailand, 2000**

This research will focus on solving the problem in automotive painting. Defining the problem, this thesis chooses and defines the priority the problem and analyse data by using experimental design and cause& effect diagram. Problem is discovered, which are dust and dirty in the painting room, in this thesis.

6) **Manufacturing Process Improvement By Analysis Factors that Influencing on The Carton's Friction, Suchart Saetae, Thailand, 2005**

This research focuses on manufacturing process control management. This thesis describes about continuous manufacturing process. Carton manufacture is similar the aluminium composite process, which have continuous manufacturing process. This research concerns about defect reduction by using design of experiment (DOE) methodology. Moreover, this research uses Cause & Effect diagram for defining problem and using statistical process control for controlling factor in manufacturing process.

7) **The Reduction of Defects in cold Rolled Process of Stainless Steel Pipe, Urakin Polnikorn, Thailand, 2007**

This research has manufacturing process which similar this research. DOE is the tool for design experiment and analyse the factor on coil. Defect is always occurred on the welding process and cold process. Moreover, F.M.E.A, Fish-bone diagram and brainstorming are the tool and techniques for define factor and seek the affected factor in the process.

8) **Design of experiments in thermal spraying: A review,Christel Pierlot, Lech Pawlowski , Muriel Bigan, Pierre Chagnon, France, 2008**

This journal relate to the coating process. It relates to study of this thesis. DOE is the tool for see the coefficient factor and analyses the critical factor in the coating process. This journal discuss the application of different designs to determine the response equations with the responses related to microstructure, mechanical, electrical and other properties of coatings deposited using different thermal spray and post-spray processes.

9) **Improvement of Degumming Process to Reduce the Unleveling Dyeing of Silk Yarn through the Design of Experiment, Anchulee Manitsakul, Thailand, 2006**

This journal relate to the degumming process in silk industry. This research uses design of experiment for factor analysis. Author uses 2 level-factorial design for analysis. Experiment is designed for finding the factor that response the goods surface. Experiment optimise for optimal production settings plan. The experiment indicates temperature in the production, time and pH value. Temperature is 85 celcius, time is 45 minutes and pH- values is 8.6. After adjustment, Defect reduces from 57.2% into 10.8%

10) Defect analysis and loss reduction in corrugated paper box board process, Kraikul Liggachai, Thailand,2007

This journal relate to color of printing machine with analysis statistic data, process capability of process color in offset printing system. Author analysed and improved by using DOE with 2^K with 3 centerpoints with 2 replicates. Author analyses 4 factors. Research is found 2 factors, which are Dampening temperature and Ratio of Isopropyl Alcohol in dampening solution. After adjustment and implementation, the data of process capability after improving the process is between fair to good criteria level include the control plan action it can reduce a defect from 11.41 to 5.90% of all defect.

11) Design Of experiment for Analysing Factor in Corrugated Box Production Process. Parichart Natasan, 2010

This journal ralate to reduce the glue gap in corrugated box production. Author applied design of experiment (DOE) method. The glue gap of top side and bottom side is 66.61±1.69 and 5.50±1.4 mm respectively. In cause and effect, author use Cause and Effect diagram or Taguchi Method to define cause of production process. Experiment is 3^k factorial design experimental design. The significant factor is running speed. As the result, the running speed was fixed 120 boxes/min. The average corrugated boxes glue gap on the top side and bottom side were 6.05±0.74

and 5.93±0.70 and process capacity value on top side and bottom side were 1.77 and 1.87 respectively.

12) Improving The Manufacturing Process quality of Biscuit tiles using Design of experiment method, Teerayut Yoksew, 2009

This journal is related to improve the manufacturing process of Biscuits tiles using design of experiment (DOE). The factorial variables were title size 8 inch in breadth and 10 inch in length. Author crated experiment with 2^{k-p} factorial design. There are 4 factors which were Feeder setting, 2^{nd} Stroke Pressure, Burner Modulation and Firing Temperature. There 3 factors that concern in next experiment; Feeder Setting, 2^{nd} stroke pressure and Firing Temperature. Author found that feeder setting is not significant impact on size of tiles. After that 2^{nd} stroke pressure was fixed at 240bar and firing temperature was fixed at 1,130 C. After improvement, the defects were 8196 and 1378 DPPM in 8 inch size and 10 inch respectively.

13) Wrinkle Defect Reduction of Plastic Sheet in the Calendering Process, Sumeth Karnpakdee, 2004

This journal related to reduce defect of the plastic sheet in the calendering process. Author created design of experiments. Author uses 2^k factorial design for this research. From experiment, the main factor is longitudinal direction stretching of the take-off unit at 2.50, temperature of the calendar roll at 175, 177, 175, 173 'C and temperature of the take-off llnit & emboss roll at 175 c. The result was found that the shrinkage rate in two directions (wrinkle rate) decreased by 75.77% from 8.46% to 2.05%, the wrinkle defects in the plastic sheets decreased by 2.17 % from 3.01 to 0.84%

14) A study of optimal factors to reduce colour cracking problem of expansion tank using design of experiments, Thutthong Tainuei, 2010

This journal is related to analyse factor and finding level of factor in expansion tank production process. The objective is to reduce cracking on product's surface. Defect quantity before adjustment is 203 pieces per month or cost about 75.075 baht. By the analysis of significant factors that affect to colour crack, there are four factors namely Brush diameter, polishing cycle, baking temperature, and Caulking pressure. The author conducted a 2^4 factorial experiment design with 95%. The result shows that Brush diameter and Polishing cycle have significantly affected to the colour crack problem and the optimal factor levels to reduce this problem is to set the Brush diameter at 35 mm., 2 cycles of Polishing, 200°C of temperature, and 0.6 Mpa. For baking pressure, this setting is then performed to the real process. The result shows that the total number of colour cracks can be reduced to 107 pieces per month which generate the saving cost of 33,696 baht per month or 404,352 baht per year.

Chapter III
Problem Statement

In chapter 3, researcher describes and defines problem from current situation of Case Study Company A. Researcher will categorise step by step. They consist of 8 parts.

3.1.Current Statement of Problem

This report will use information from Case Study Company A. Case Study Company A provides architectural products in Aluminium-Composite panel. Raw materials are aluminium alloy, galvanized steel and Poly-vinylidene Difluoride polymer plastics. These raw materials have high cost and also design of product will affect the cost of product. Defect affects production line. It affects cost which has to pay for raw material cost.

Table 3.1 The amount of production and defects from coating process.

Month	Mar 11	Apr 11	May 11	Jun 11	Jul 11	Aug 11	Sep 11	Total
Production (m^2)	71,775.2	103,183.4	123,387.3	110,757.8	174,203.3	59,490.0	79,896.2	722,693.1
Defect (m^2)	4,996.9	5,823.6	4,509.7	9,174.3	8,129.5	4,542.7	2,968.5	40,145.4
Percentage (%)	6.962	5.644	3.655	8.283	4.667	7.636	3.715	5.55

In manufacturing process, Product K, there are 2 main processes (Coating process, Lamination Process). 2 processes are manufactured respectively. Current Problem is occurred in coating process, which affect to lamination process, because it is the continuous process. If one of them has the problem, it will affect to the other process. Coating process has long manufacturing process and continuous process. Some station or process has problem. Other station can’t run or drive the process, while problem station has being fixed. It is the main factor for fixing and maintenance in the coating process.

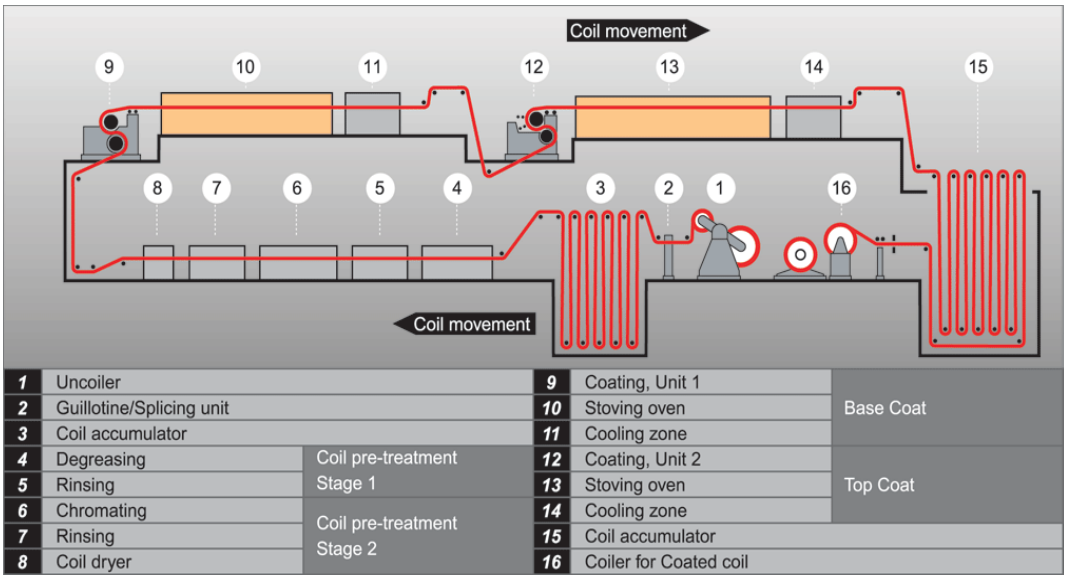


Figure 3.1: Coating Process [Case Study Company A]

In current situation, the coating process is the first process in production process. Aluminium Composite panels are not small amount when company produce in one time for one customer. They have to uncoil and coil back which have to use time and long manufacturing process. Coating process is the one of important problem of Case Study Company A. Every decision is made base on the experience of factory manager in manufacture process. Each station uses many knowledge and experience very much. The problem should solve as fast as possible to drive business smoothly and reduce cost and time. Defect reduction is the indicator and measurement. Type of defects will be divided in Table 3.2. Bar chart is shown in figure 3.2, and Pareto Chart is shown in figure 3.3.

Defects in the coating process, there are 9 main defects;

- Dot, Dust
- Scratch
- Colour thickness
- Colour Stain

- Colour mark
- Scrap from stopping
- Colour Disappearance
- Edge wave
- Unlike
- Unlike
- Others

Table 3.2: Category of Defects from Coating Process in 7 months (March 2011-September 2011)

Type	**Defect** (m^3)	**Percentage (%)**
Unlike	12,721.00	31.69
Colour mark	7,324.72	18.25
Scarp from Stopping	6,872.87	17.12
Dot, Dust	5,762.91	14.35
Colour Thickness	2,103.7	5.24
Colour Disappearance	1,799.98	4.48
Scratch	1,757.54	4.38
Colour Strain	782.1	1.95
Edge wave	576.96	1.44
Others	443.6	1.10
Total	**40,145.38**	**100**

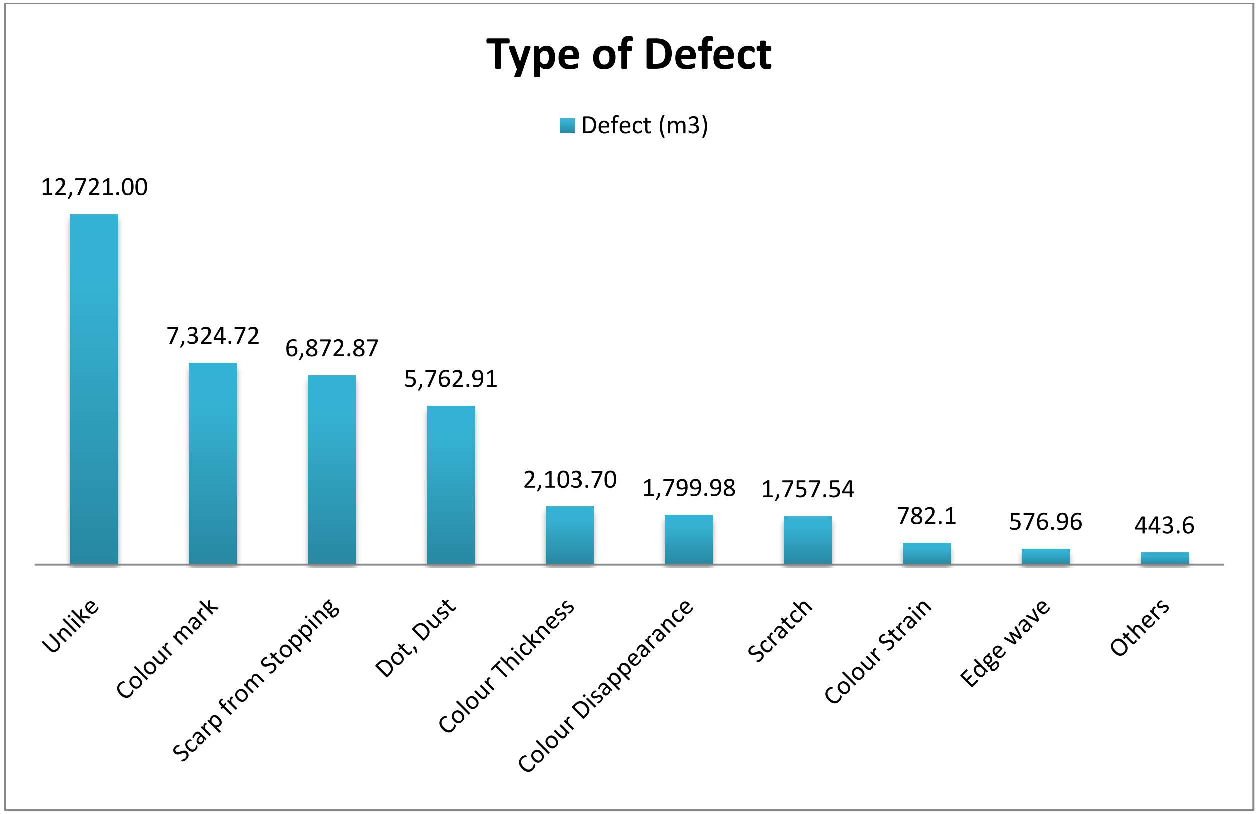


Figure 3.2: Defects from Coating Process in 7 months (separated into group and plot into bar chart)

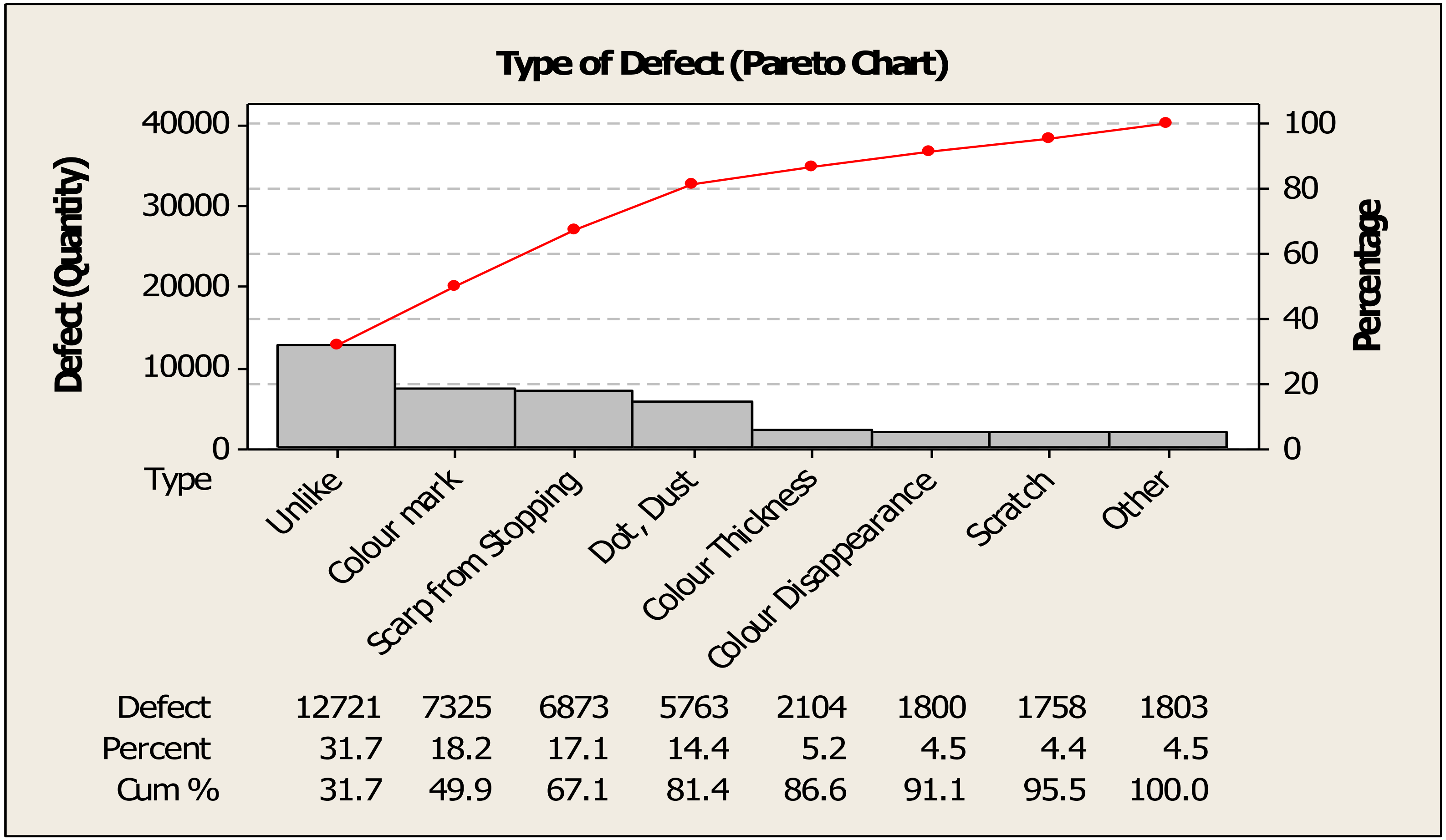


Figure 3.3 Defects Comparisons (Pareto Chart)

Coating process has many activities. In each activities has own technical manufacturing process. Operators are trained for each station. However, defects will occur anytime. Production line is continuous process. When defects are occurred, Production process cannot stop immediately. They are not separated process which can control in each station. Defect elimination is the cutting the defect area. It will be cut as small amount as possible. It will be affect the whole process. When machine down, it has to set temperature to run the manufacturing, Because of Coating. It wastes the time. Moreover, it affected to lamination process.

Cause of this problem could be defined as:

- Lack of awareness of operator
- Work environment
- Customer need (Colour; Especially concern, Size, Etc.)
- Work process (Technical Tool or Method, Machine, Etc.)
- ETC.

Above list might affect for long term. If Case Study company A will not solve, It will be affected the whole process.

Therefore, this research will focus on improving and developing production system for this company. Coating process is the process that should have high awareness. It does not only the aluminium material process. It has the knowledge about coating technology.

In Factory manager opinion, he thinks defect come from Coating Room and Oven. They are the part of process for coating the colour into aluminium surface. If one of defect is occurred on surface, it will waste the time and affect many processes. Problem always occurs in this station. He said it can control in the short term and also it affects to lamination process while customer want the product in the expected time. Before it used to occur on mixture in coating material. It has solved alrerady. However, It can only solve problem initialy. Factory manager would like to solving defect reduction for long-term. Basicly, He thinks Dust and metalic objective in colour mixture material is the main reason. Sometimes, defect occurs when operator does near machine as figure 3.4.

Figure 3.4 Coating Rollers

Figure 3.5 colour tank with screen filter and colour stirring motor

In Figure 3.5, Screen filter and colour stirring Motor are the basic problems solving tool for short-term. It can reduce some defect, such as dot, colour marks. But it will not reduce for some defect. It is the problem for this factory and affects many processes in the factory. Moreover, it affects cost and time which are the main factor for manufacturing process.

Figure 3.6: Operator in Coating Room

3.2. Current Problem Analysis

Researcher analyses from the information from the case study company A. According to Figure 3.2, 3.3, Most of defect is "unlike" case. Quantity is 12721 m^2. It is very high amount. Researcher considers about this colour unlike case.

So, Researcher decides to think in colour unlike case and find the solution plan. Firstly, researcher and factory manager discussed about this issue. Defect comes from colour unlike case a lot. The effected process should be from oven and coating room. Oven and coating room is the involved process with colour Researcher creates and design experiment for test hypothesis. Researcher use statistical method for finding the variance of factor.

Researcher observes the coating process by asking sample from factory. Researcher chooses the cream pearl (SC-104) with 4 mm thickness for experiment. For colour measurement, researcher uses spectrophotometer for colour measurement. This equipment indicate the Δ E –value. That is the standard value, which based on CIELAB standard. Researcher makes experiment initially from coating process.

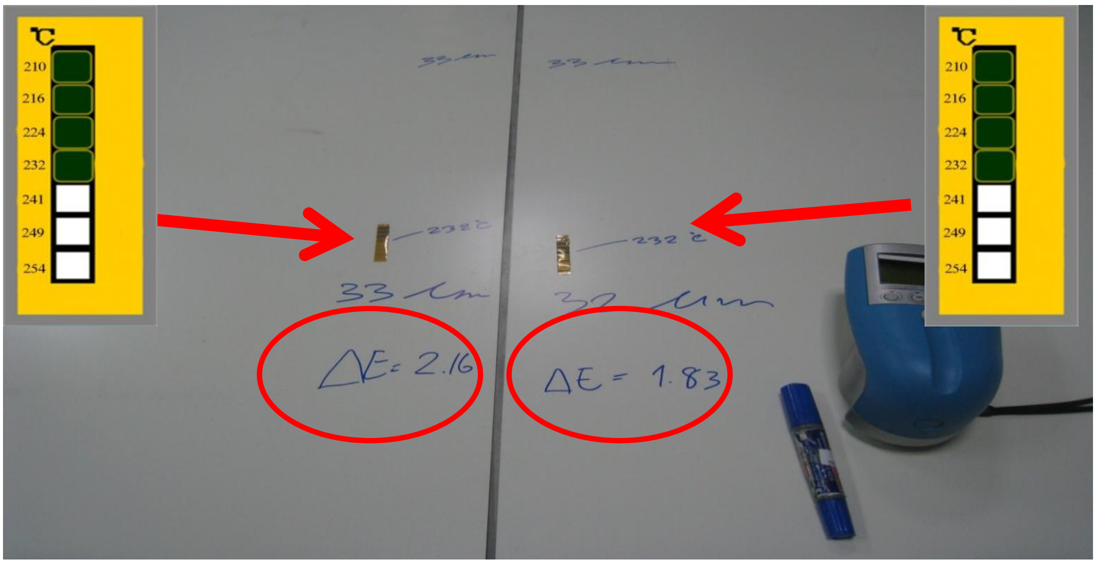


Figure 3.7 Production process 1^{ST} time

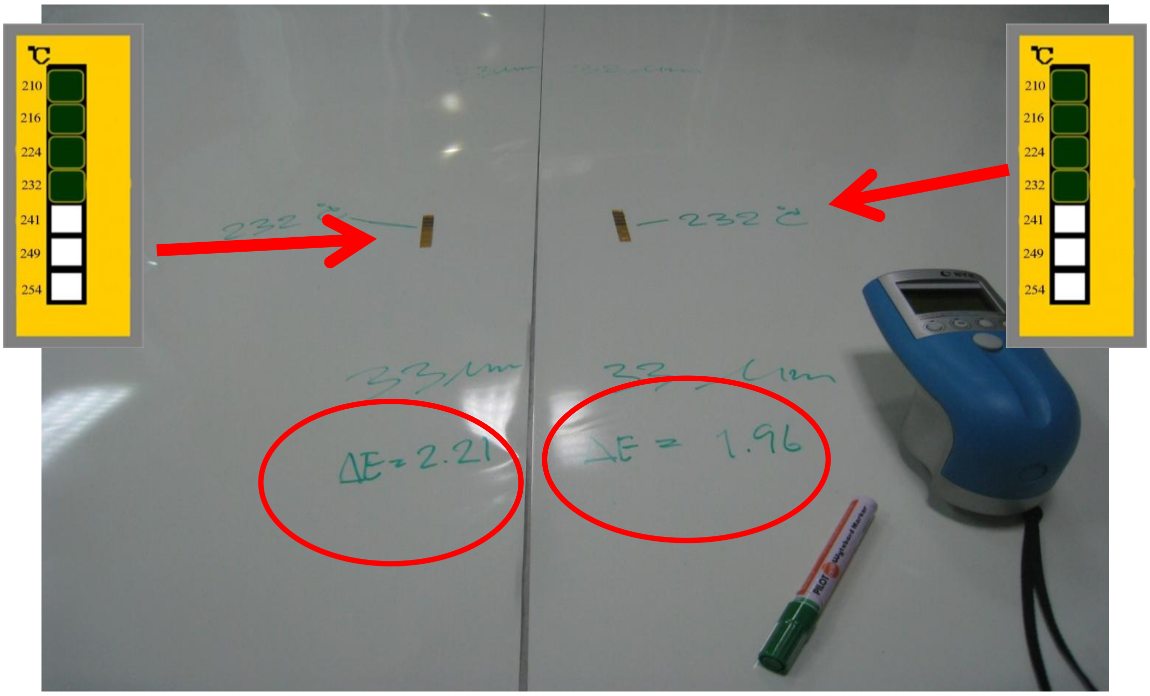


Figure 3.8 Production Process 2nd time

The sample is collected as following 1st sample from the top of aluminium coil and 2nd sample from the tail of aluminium coil. From the Figure 3.7 and Figure 3.8, The Current data is shown, that Left side and Right Side are not similar while Thickness and Temperature does not different much.

From measurement is follow as quality standard and production condition. In Reality, the colour does not the both side. Acceptable Δ E -value should not exceed 1, but 1st time measurement data is 2.16 and 1.83. 2nd time measurement data is 2.21 and 1.96. From data, the difference of Δ E -value is too much.

3.3 Cause & Effect Analysis

From Figure 3.9, it is shown the analysis of cause and effect in coating Process which is shown the colour unlikeness case.

3.3.1 Material

The problem is not enough time for colour stirring and Colour Viscosity Rate, which is unstable. Colour from Supplier is not stable colour viscosity. It depends on colour lot. Process will spend more time. Researcher gives weighed-score is 10%

3.3.2 Man

Operator does not enough experience and knowledge in production process. According to Aluminium-Composited Panel, this product manufactures with new and high-gen technology in coating process. Operators have no technical experience. Training for operator is not enough for all. Researcher give weighed score is 15%

3.3.3 Machine

Temperature might be the main effect factor for colour unlikeness case. So, Researcher concern and think the cause from machine. Left-Right temperature might be the main cause for colour unlikeness case. Baking Oven cannot control Temperature, because there are no temperature equilibrator and Temperature measurement and indicator tool. Moreover, roller gap for coating in the coating room is involved about colour thickness, which is related to colour reflection. Researcher give weighed score is 50%.

3.3.4 Method

Colour Thickness unconformity might be the main problem for colour unlikeness case. The reason is the settings of rolling speed incorrectly and uncontrolled colour thickness. Roller speed is affected to coat colour on surface and colour thickness. Roller speed and Roller gap, they are dependent factor.

Next, Wind pressure inside oven, which is unbalance and low-pressure it might be main cause of problem. Researcher give weighed score is 25%

From Cause & Effect Analysis, There are many factors that involved with colour unlikeness defect. K product is the high-gen technological product and new product in this industry. Operator has to train about technical production process. However, factory has not enough for time. Moreover, training has high cost. It might be not optimise for training operator. It cannot guarantee that after training, operator can solve this problem effectively. It depends on operator performance. Next, Method is the one of cause that researcher concern. Roller settings, Wind Pressure, Baking Temperature, Colour thickness conformity, they are the cause of current problem. Each of them is affected the coating process, because of lack of skill and knowledge of operator. Factory manager must set everything together with supervisor and operator. That is the reason. Nevertheless, machine has weighted-score50%. Most of them involve with temperature, such as "No temperature equilibrator, left-right temperature unbalance, etc."

Researcher concerns current problem, based on cause and effect diagram. Method and Man, they must spend time and cost, such as Training cost, Time for training. Factory manager and Researcher discussed about colour unlikeness case. Problem should be solved in machine. It can improve and implement sustainably than man. So, Researcher and Factory Manager focus on machine. Factor, which might come from machine, they are ***"Temperatures inside oven, Roller Gap in coating room"***.

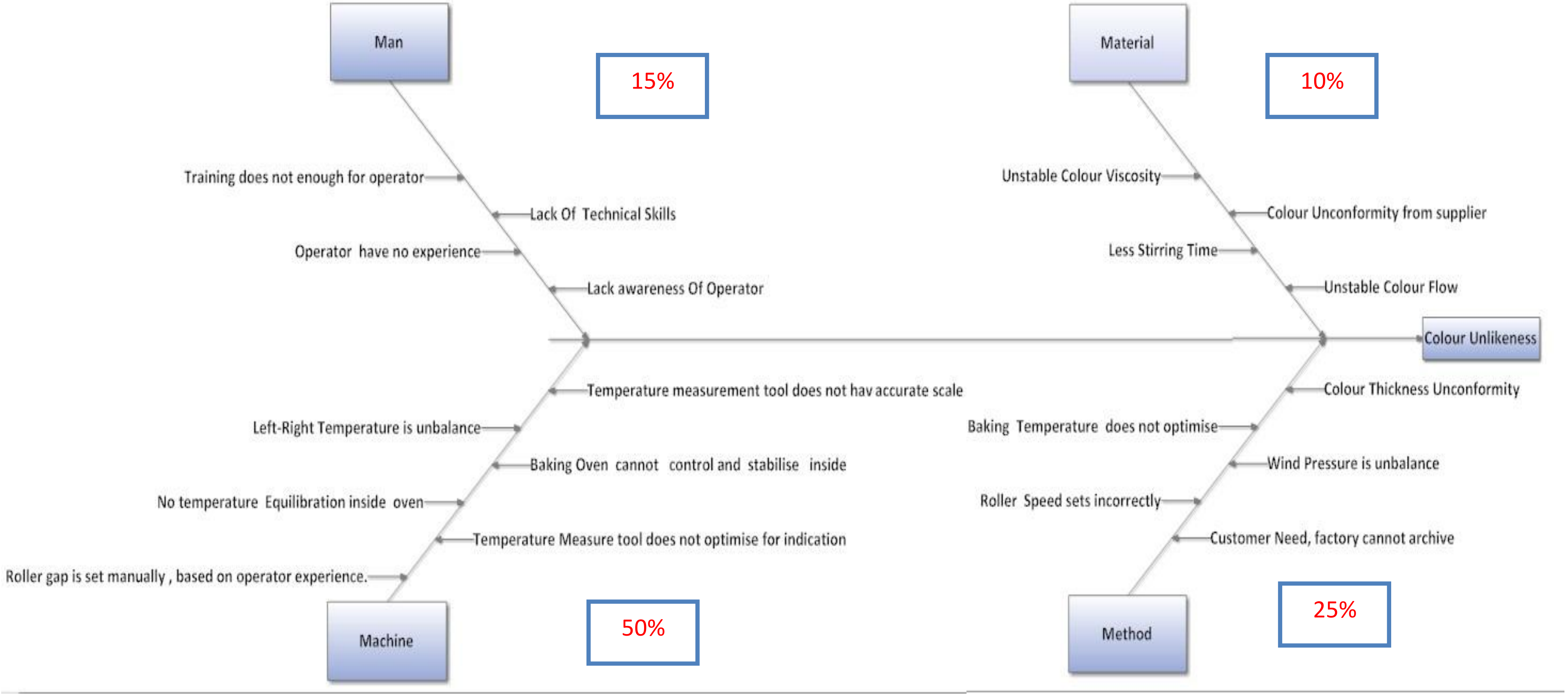


Figure 3.9 Cause & Effect Analysis Diagram for Colour Unlikeness

3.4. Experiment of Current Problem Analysis

3.4.1. The Reason of Factor Selection

From Cause and Effect Diagram, researcher can define the factors, which involved with colour unlikeness case. They should be Temperature for baking, and Roller gap in the coating room. Colour on surface is the measurement for defining that which colour is similar all on surface. Colour thickness, Colour reflection is the indicator for solving this current problem.

Reason for selecting temperature as Factor A

- Colour mixture for each colour, there is different temperature for baking. It depends on colour supplier recommendation.
- Temperature inside Oven. It might be the cause of colour unlikeness.
- The temperature range, which is between 242-232 C. Currently, factory cannot control and stabilise temperature inside oven along the process. Even If, machine is set temperature.
- Temperature can check initially. If temperature is the main factor. Factory can buy equipment for measurement. It can be evidence or approval for purchasing equipment for temperature measurement.
- Unbalance wind pressure and no temperature equilibrator can be the cause of problem.

Reason for selecting roller gap as Factor B

- Colour thickness is affected on coating surface panel.
- Colour Coating and colour thickness has effect on this factor. If roller gap set incorrectly, it might be affected on colour thickness. Moreover, it will be affected on roller speed for coating colour on panel surface.
- Colour viscosity can be effect on roller. If it has high viscosity, Colour for coating does not coat on the surface. Roller gap can be adjusted with each colour viscosity. Stirring motor and painting tank, which set beside Roller, can solve some defect currently. If Roller Gap is main factor for colour unlikeness. Researcher and Factory manager can develop this tool or find implementation.
- Unstable colour flow, if it might be this cause, Roller gap can be affected for colour flow and colour viscosity. It will be affected on colour coating on surface.
- Roller Gap, it will be effected on compression in colour thickness and colour on coating on panel surface.

According to Current Problem, Factor A is “Temperature” and Factor B is “Roller Gap”. Baking Temperature range is between 224 up to 232 Celsius, which is the recommendation from colour supplier. In the coating room, roller gap is the important factor for colour thickness. Colour thickness of Aluminium composited panel affected for illumination and light reflection. Human vision will receives different colour from them. This is the one of factor that researcher and factory manager concern in this research. Roller gap range is 3mm.-5mm.

Hence, Colour unlikeness is the main problem. There is large amount of defect. Factors, which researcher and factory manager concern, are temperature and Roller gap. Researcher creates experiment for process observation. DOE (Design of Experiment) is the statistical tool for checking the interaction between each treatments. The main effect can be found in this experiment test.

3.4.2. Design of Experiment for Colour Unlikeness

3.4.2.1. Factor and Level

In Colour Unlikeness case, Researcher concerns and defines factors. There are 2 main factors that concerned. Temperature, researcher sets parameter, based on colour supplier. Temperature range is between 224-232 Celsius degrees. Roller gap is between 3mm.-5mm. They consist of "Temperature", "Roller Gap". Each factor, there is 3 levels as table 3.3. This experiment tests in coating process. Temperature, they separate into 3 levels. Low level is 224 C. Medium level is 228 C and High level is 232 C. For Roller Gap, Low level is 3 mm. Medium level is 4mm and High level is 5mm.

Table 3.3 Experiment Factor and Level

Factors	**Levels**		
	Low	Medium	High
Temperature (C˙)	224	228	232
Roller Gap	3mm	4mm	5mm

3.4.2.2. Type of Design and Response

This experiment is tested by the factorial design with 2 factors and 1 response. In each level of factor, this experiment is collected and run 2 replicates as following table 3.4. This experiment is design with factorial design method. This experiment is 3^2 factorial design. There are 2 factors with 3 levels. So, this experiment has 18 test data. The output or response of this experiment is the colour tolerance or Δ E –value. This experiment has 2 factors with 3 levels.

3.4.2.3. Prepare Experiment

This experiment collects data from Cream Pearl colour (SC-104) coating process in 18 experiment tests .There are 2 replicates for each level of experiment.

3.4.2.4. The limitation of experiment

According to Case study Company A policy, Factory has continuous production process. There are many colours for coating for delivering finished goods to customer on time. Next, Time for Temperature settings and roller, it spends much time. It depends on colours that run production before experiment test. Oven has to cool down or warm up temperature. It might be affect for actual production schedule. Temperature settings in 3 levels, it can indicate immediately after machine setting. Moreover, researcher has to wait Cream Pearl Colour production. Factory manager notices researcher about data collection. So, researcher can collect only 2 replicates for each experiment test level.

3.4.2.5. Hypothesis of this Experiment

There are 2 factors in this experiment. The analysis of variance can be used to test hypotheses about the main factor effects of and the interaction. There are 3 hypothesises for this experiment. The hypotheses of the experiment are

- For Factor A H_0: There is no main effect in Factor A(Temperature)
  H_1: At least one in Factor A
- For Factor B H_0: There is no main effect in Factor B(Roller Gap)
  H_1: At least one in Factor B
- For Interaction H_0: There is no main effect in Interaction Factor (Temperature*Roller Gap)
  H_1: At least one in Interaction Factor

3.4.2.6. Experiment Data

Table 3.4 Experiment Data

Δ E –value (Response)	Run Order	Temperature (Factor a)	Roller Gap (Factor b)
1.25	1	224	3
0.75	2	224	3
0.56	3	224	4
1.21	4	224	4
2.15	5	224	5
1.77	6	224	5
1.45	7	228	3
1.76	8	228	3
1.30	9	228	4
1.11	10	228	4
1.33	11	228	5
1.25	12	228	5
1.79	13	232	3
2.25	14	232	3
2.04	15	232	4
1.98	16	232	4
2.19	17	232	5
2.05	18	232	5

3.4.2.7. Result of Experiment

Researcher use MINITAB for ANOVA Creation. ANOVA shows each factor and interaction between factors. ANOVA is shown the result of factor analysis. Output is the tolerance of colour or Δ E –value. MINITAB is the statistical computer programme for statistical analysis. The result of experiment is shown in Figure 3.10

ANOVA: DeltaE versus Temp, RollerGap

Source	DF	SS	MS	F	P
Temp	2	2.11934	1.05967	15.99	0.001
RollerGap	2	0.53854	0.26927	4.06	0.055
Interaction	4	1.04616	0.26154	3.95	0.041
Error	9	0.59660	0.06629		
Total	17	4.30064			

S = 0.2575 R-Sq = 86.13% R-Sq(adj) = 73.80%

Figure 3.10 ANOVA data from MINITAB

According to the ANOVA table analysed by MINITAB, the P-value of Factor A is less than significance level of 0.05 (P-value<0.05). It is 0.001 as figure 3.10. The Null hypothesis (H_0) of factor A is rejected. Researcher can decided that Factor A or Temperature is the significant factor, which affect the unlike case. Researcher would like to confirm this ANOVA analysis. Residual analysis is the statistical tool for ANOVA Check.

3.4.2.8. Residual Analysis

According to Montgomery, Errors are normally and independently distributed with mean zero and constant but unknown variance (σ_e^2). Residual analysis is the testing of ANOVA assumption. In Figure 3.11, it shows the residual data. There are normal probability plot. If the plots will resemble straight line, Error will be normal distribution. Next, the pattern of versus fits values plot is non-structure which means the errors have a constant variance. this ANOVA has satisfied all the assumptions that mean this tested is adequate to determine the result. Researcher can decide that “temperature” is the significant factor.

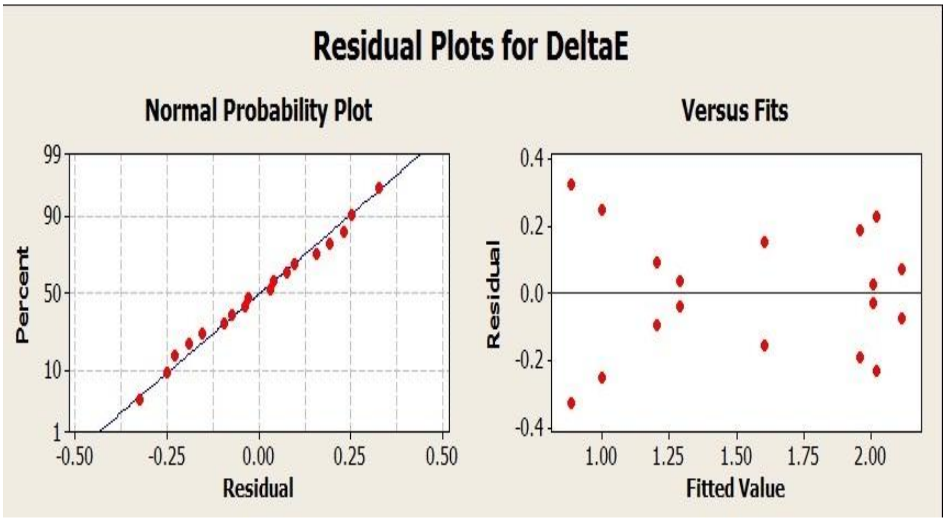


Figure 3.11 Residual Plots

For Colour unlikeness case, temperature is the most significant factor. So researcher will focus and reduce defect in colour unlike case. Next, researcher will find and analyse the cause, which affect and involve with temperature. In initial, Researcher and Factory manager discuss about this problem. Defect might be from oven, because of temperature. From this experiment, it can confirm that oven is making defect in coating process. It should be adjusted and reduce defect as this researcher objective. In next chapter, it will be described the way of problem solving.

Chapter IV

Research Methodology

From Chapter3, researcher concern and consider problem from current situation of Case Study Company A. Researcher found that Temperature is the main effect factor for colour unlikeness case. In chapter 4, researcher uses the tool and equipment for analysing and solving this problem, which is defined from chapter 3. So, researcher will categorise step by step.

4.1 Production Process Observation (Coating Process)

Researcher has found the theories and method, which involve and relate to case study company A. The main problem in Colour unlikeness is the "Temperature" in oven. Researcher uses data from Cream Pearl Colour (SC-104) coating.

So, Researcher will focus on Colour Unlikeness case only in this research. Research predicts and analyses in this problem from the Case study Company A Factory as following;

4.1.1 Production Process Observation

4.1.1.1 Aluminium Coil is cleaned by Alkali solution at 80 Celsius. Then, Clean the aluminium coil, again.

4.1.1.2 Coat Chromate and Bake at 70 C by dry method.

4.1.1.3 Coat Primer with thickness 20-22 µm

4.1.1.4 Bake in oven at 224 C-232 C

4.1.1.5 Coat Top Coat with thickness 10 – 12 µm.

4.1.1.6 Bake in Oven 224 C-232 C again

4.1.1.7 Check quality, good parts will be sent for Aluminium-Composited Panel lamination process. For Defect, if it exceeds 150kg, it will be produced as Aluminium-Composited Panel as Backside. For less than 150 kg case, it will be sold as scrap.

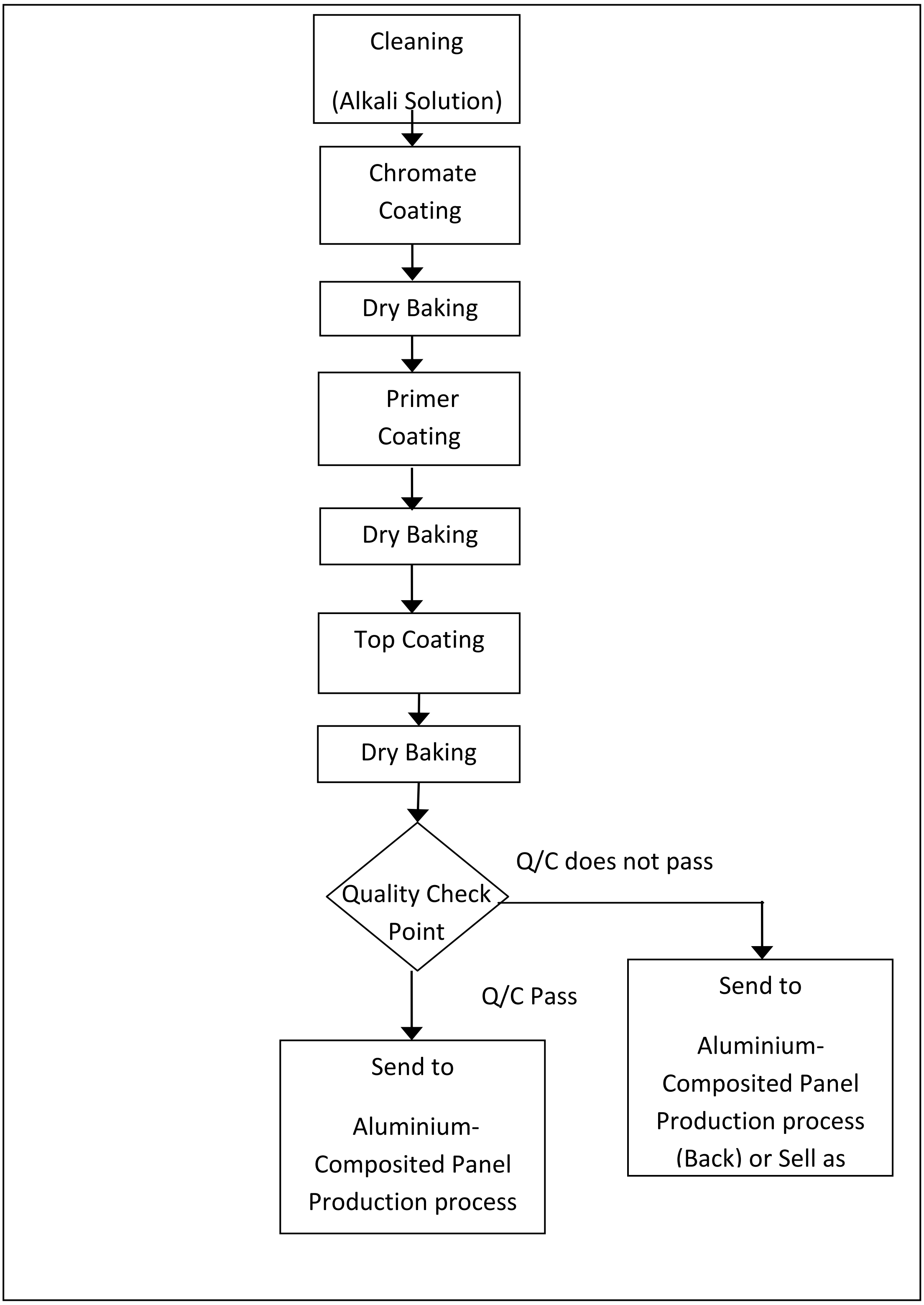


Figure 4.1 Aluminium-Composited Panel Production Process

4.2 Improvement and Implementation

Researcher sets Paperthermo label both left and right side surface of coating Aluminium Coil. On Paperthermo label, there are all white squares. When the white square changes to Black square, temperature is read as that scale. Different scale is 8 Celsius degree. If it exceeds little, it will change to upper or lower scale immediately. That is the reason. It cannot analyse the temperature difference accurately.

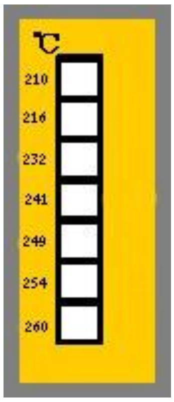
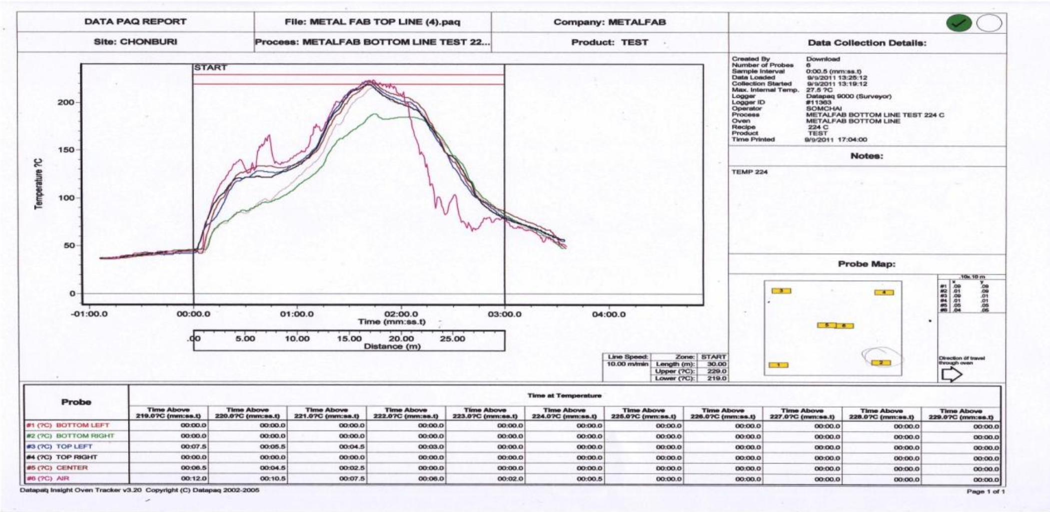


Figure 4.2 Paperthermo Label

So, the problem can be from the tool or equipment that can indicate roughly. Research has to find the measurement tool, which have more accuracy scale. Tool or equipment is called "DataPaq". Temperature is the main effect factor for this case. Factory has approval for purchasing the DataPaq equipment for accurate temperature measurement.

DataPaq, Indicator is set on the surface of Aluminium-Composite Panel. Setting Position is Left-Side, Right-Side and Middle of the Aluminium-Composite Panel. Next, DataPaq set on the surface and go into oven. It will indicate temperature all along baking process. Then, indicator is connected into Computer for analysing the data. It can read the temperature all the process time.



Probe	Time at Temperature										
	Time Above 219.0?C (mm:ss.t)	Time Above 220.0?C (mm:ss.t)	Time Above 221.0?C (mm:ss.t)	Time Above 222.0?C (mm:ss.t)	Time Above 223.0?C (mm:ss.t)	Time Above 224.0?C (mm:ss.t)	Time Above 225.0?C (mm:ss.t)	Time Above 226.0?C (mm:ss.t)	Time Above 227.0?C (mm:ss.t)	Time Above 228.0?C (mm:ss.t)	Time Above 229.0?C (mm:ss.t)
#1 (?C) BOTTOM LEFT	00:00.0	00:00.0	00:00.0	00:00.0	00:00.0	00:00.0	00:00.0	00:00.0	00:00.0	00:00.0	00:00.0
#2 (?C) BOTTOM RIGHT	00:00.0	00:00.0	00:00.0	00:00.0	00:00.0	00:00.0	00:00.0	00:00.0	00:00.0	00:00.0	00:00.0
#3 (?C) TOP LEFT	00:07.5	00:05.5	00:04.5	00:03.0	00:00.0	00:00.0	00:00.0	00:00.0	00:00.0	00:00.0	00:00.0
#4 (?C) TOP RIGHT	00:00.0	00:00.0	00:00.0	00:00.0	00:00.0	00:00.0	00:00.0	00:00.0	00:00.0	00:00.0	00:00.0
#5 (?C) CENTER	00:06.5	00:04.5	00:02.5	00:00.0	00:00.0	00:00.0	00:00.0	00:00.0	00:00.0	00:00.0	00:00.0
#6 (?C) AIR	00:12.0	00:10.5	00:07.5	00:06.0	00:02.0	00:00.5	00:00.0	00:00.0	00:00.0	00:00.0	00:00.0

Figure 4.3 Results from DataPaq Equipment

From figure 4.3, Between Green line and Black line, there is different temperature, which is 20-25 Celsius degrees. Red line and Blue Line, there is different temperature 8-10 Celsius degrees.

Research can summarise that the problem in unlike colour case is “Left-Right temperatures do not equal”. It is shown same as paperthermo label test. Researcher analyses this problem, that Oven does not has temperature equilibrator. That will make balance temperature in both sides. Research has to find the solution for this case and find the implementation.

Figure 4.4 Current Appearance of Oven

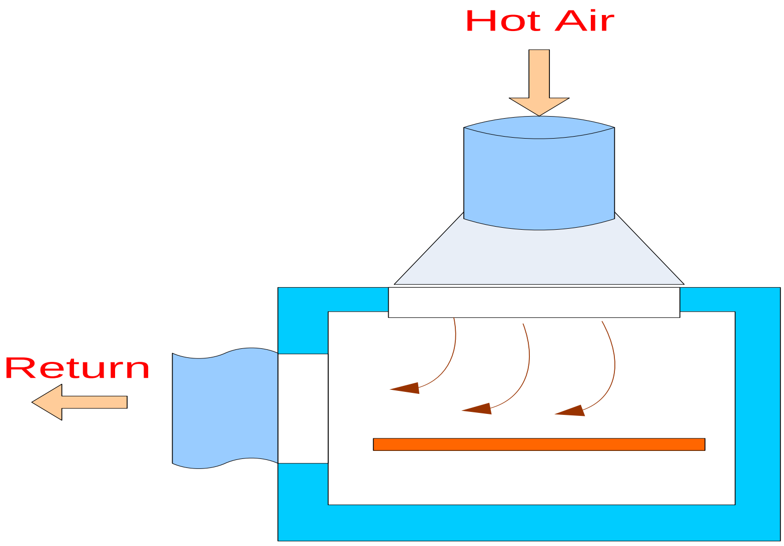


Figure 4.5 Current Situations inside Oven on Coating Process

From Figure 4.5, hot air is flowing into surface from top tube and goes into left-side that has return tube. Return tube flow the air back into the top tube. It is the cause that make right-side temperature lower than left-side. Collected Data matches with DataPaq equipment.

From the current situation, researcher understand that hot air flows in on left- side of aluminium-composited panel surface and flow out into return tube systematically. However, it can control to hot air flowing both side of surface. That is the main problem for this case. Baking Temperature is the main factor for unlike colour case.

From analysis, researcher has discussed with factory manager and engineering department for find the solution and implementation for oven. Air should control and flow into both side of surface in oven. The solution will be described as figure 4.6

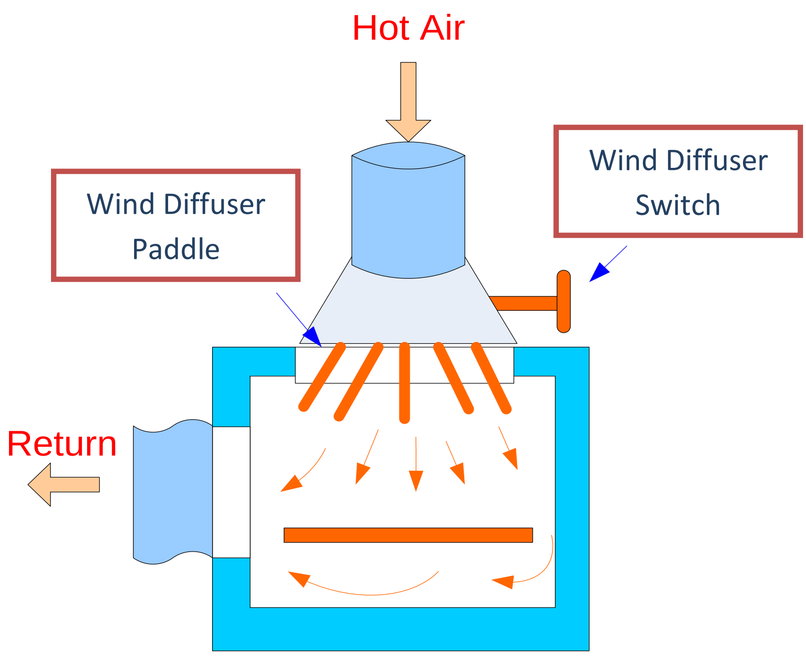


Figure 4.6 Ovens after Adjustment

From figure 4.6, top tube is adjusted. It is installed air equilibrator. Air equilibrator, there is small spread panel and wind diffuser into top tube. It will distribute the hot air equally. It will make the hot air flow all area inside oven. It will solve colour unlikeness case.

From this project, if we have to improve and solve this case, there is expense. Estimated cost is 240,550 baht. Researcher will calculate the break-even point for this project. Research uses financial tool for finding the break-event point of this project. It should be invested or not?

Table 4.1 List of Material for Adjustment

	List	Quantity	Price (1 Unit)	Total (Baht)
1.	Pipe SUS Size 60x40x0.15 cm. Length 2.5 m.	4	11,500	46,000
2.	Pipe SUS 90 Degrees Size 60x40x0.15 cm.	1	14,000	14,000
3.	Pipe SUS size 120x80x0.15 cm Length 60 cm.	1	15,000	15,000
4.	Pipe SUS Taper 60x120x0.15 cm Length 80	1	17,000	17,000
5.	cm.	3	1,200	3,600
6.	Angle Steel 2.5”x2.5 mm.	3	22,000	66,000
7.	Wind diffuser SUS paddle size 8”x1.35 M.	6	4,200	25,200
8.	Heat Heat-Resisting Asbestos Density 150 K	7	3,250	22,750
9.	SUS Cover Thickness 1 mm.	-	5,000	5,000
10.	Other	-	26,000	26,000
	Painting and Installation			
			Total Amount	240,550

So, researcher uses financial tool and engineering economy method. This project should be invested or not?

4.2.1 Project Investment Analysis

This analysis will describe the project in financial term (amount of expense, Revenue after adjustment, etc.). This analysis is the tool that approves the investment. It should be invested or rejected. Researcher set hypothesis as following:

Minimum Attractive Rate of return (MARR) = 8 %

Project Life Time = 3 years

Researcher analyse based on:

Production Quantity 7,735.28 m^2 /Month

Production Cost 145.76 Baht/ m^2

Defect (Before Adjustment) 23.49 %

Table 4.2 Initial Costs and Estimated Revenue

	Year 0	Year 1	Year 2	Year 3
Initial Cost	240,550.00			
Estimated Revenue	-	1,589,121	1,589,121	1,589,121
Estimated Defect Loss Before Adjustment	-	3,178,242	3,178,242	3,178,242
Estimated Defect Loss After Adjustment	-	1,589,121	1,589,121	1,589,121

4.2.1.1 Net Present Value (NPV) Analysis

Net present value (NPV) is the indicator of investment. It describes the value of project at each time of investment. NPV can be negative, zero, or positive value. NPV is calculated as following equation 4.1 and 4.2 [Chatchai, Patchapon, 2004]:

$$NPV = \sum_{t=1}^{n} \frac{B_t - C_t}{(1+i)^t} = 0 \tag{4.1}$$

Or

$$NPV = -K + \frac{B_1 - C_1}{(1+i)} + \frac{B_2 - C_2}{(1+i)^2} + \ldots + \frac{B_n - C_n}{(1+i)^n} \tag{4.2}$$

By

NPV = Net Present Value
K_O = Initial Cost in 1st time
B_t = Revenue in year 1, 2, 3…, n
C_t = Cost in year 1, 2, 3…, n (Which can be include $K_{O \text{ or not}}$)
i = Interest rate
t = Project year 1, 2, 3…, n
n = Project life

4.2.1.2 Project Net Present Value At MARR 8%

Project Cash Flow

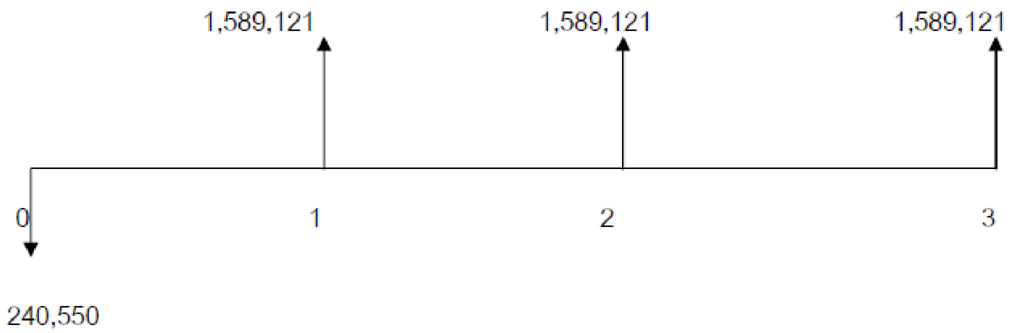


Figure 4.7 Project Cash Flow

Table 4.3 NPV analysis with MARR 8%

Year (t)	Cost (C_t)	Revenue (B_t)	Income (B_t-C_t)	MARR=8% $(1+i)^t$	NPV $(B-C)/(1+i)^t$	Cumulative NPV
0	240,550	0	-240,550	1.0000	-240,550.00	-240,550.00
1	0	1,589,121	1,348,571	1.0800	1,471,408.33	1,230,858.33
2	0	1,589,121	2,937,692	1.1664	1,362,415.12	2,593,273.45
3	0	1,589,121	4,526,813	1.2597	1,261,507.50	3,854,780.95
				Total =	3,854,780.95	

From Table 4.3, Cumulative NPV is 3,854,780.95 baht and NPV value is positive and more than zero. This project should be invested, due to Revenue. It deduct with cost. It will be advantage for project.

4.2.1.3Internal Rate of Return (IRR) Analysis

Internal Rate of Return (IRR) is the discount rate which make project is equal zero (NPV=0). Discount rate is calculated at some number.

So, IRR calculation is nearly the same as NPV calculation. There is some different point. NPV calculation uses interest rate (i). IRR calculation uses discount rate (r) which forces NPV equal zero. IRR calculation has 2 methods as followings:

Trial and Error Method

IRR is r (Discount rate), which forces NPV = 0 (3.3)

Or

Interpolation Method

$$IRR = [r_L + (r_U - r_L)] * \left[\frac{(NPV_L)}{(NPV_L - NPV_U)}\right] \quad (3.4)$$

By

r_L = Discount Rate from lower

r_U = Discount Rate from upper

NPV_L = NPV from lower

NPV_U = NPV from upper

Researcher uses Trial and Error, which uses discount rate at 659% and 660%. NPV at discount rate 660% as table 4.4

Table 4.4 NPV Calculation at discount rate 660%

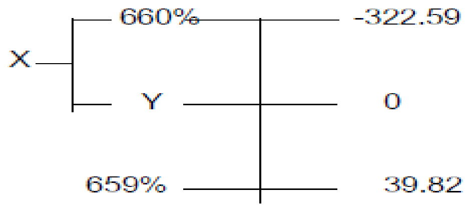
Year	Cost (C)	Revenue (B)	Income (B-C)	$(1+i)^t$	NPV $(B-C)/(1+i)^t$	Cumulative NPV
0	240,550	0	-240,550	1.0000	-240,550.00	-240,550.00
1	0	1,589,121	1,348,571	7.6000	209,094.87	-31,455.13
2	0	1,589,121	2,937,692	57.7600	27,512.48	-3,942.65
3	0	1,589,121	4,526,813	438.9760	3,620.06	-322.59

Researcher uses Trial and Error, which uses discount rate at 659% and 660%. NPV at discount rate 659% as table 4.5

Table 4.5 NPV Calculation at discount rate 659%

Year	Cost (C)	Revenue (B)	Income (B-C)	$(1+i)^t$	NPV $(B-C)/(1+i)^t$	Cumulative NPV
0	240,550	0	-240,550	1.000	-240,550.00	-240,550.00
1	0	1,589,121	1,348,571	7.5900	209,370.36	-31,179.64
2	0	1,589,121	2,937,692	57.6080	27,585.07	-3,594.57
3	0	1,589,121	4,526,813	437.2450	3,634.39	39.82

Interpolation



X = [(660-659) x (0+322.59)]/(322.59+39.82)

= 0.89

Hence, At NPV = 0, IRR is

0 = 660-0.89

= 659.11%

Investment decision of this project is calculated as above. From above, IRR is 659.11%, which are higher than MARR at 8%. It shows that this project should be invested.

4.2.1.4Payback Period Analysis

Payback Period is the period of time that make net cash flow and equal or equal initial cost. This project initial cost is 240,550 and project life time is 3 years as table 4.6

Table 4.6 Net Cash flow with Project Life 3 years

Year	Cost	Revenue	Net Cash Flow	Cumulative Net Cash Flow
0	240,550	0	-240,550	-240,550
1	0	1,589,121	1,589,121	1,348,571
2	0	1,589,121	1,589,121	2,937,692
3	0	1,589,121	1,589,121	4,526,813

From Table 4.6, Cumulative Net Cash flow from year 1 is 1,348,571 baht. Payback period time is calculated by this equation 4.5

$$\text{Payback Period Time} = \text{Initial Cost} / \text{Revenue} \qquad (4.5)$$

This project payback period is calculated as following

240,550/1,589,121 = 0.15 or 1 month and 24 days

Table 4.7 Project Summary Table

List	Amount
Net Present Value	3,854,780.95 Baht
Internal Rate of Return	659.11%
Payback Period	1 month and 24 days

Chapter 5
Research Result

From chapter 4, Researcher observes and analyse cause and effect. Researcher uses that data and information finding implementation for unlike colour. It consists of 3 parts as following:

5.1. Research Result

From chapter 4, Researcher adjusted machine and the result is as following.

Figure 5.1 Before adjustment

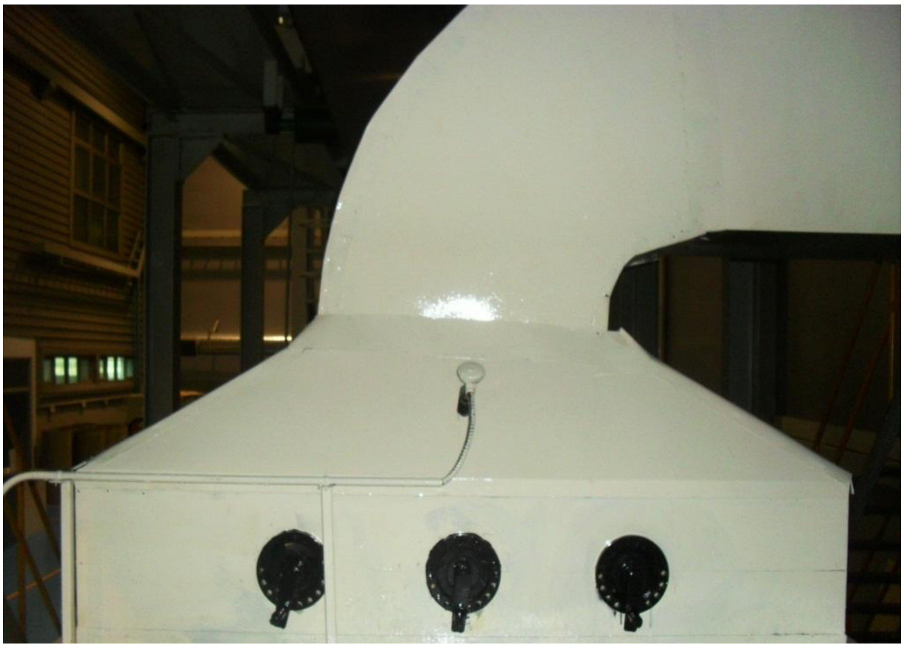
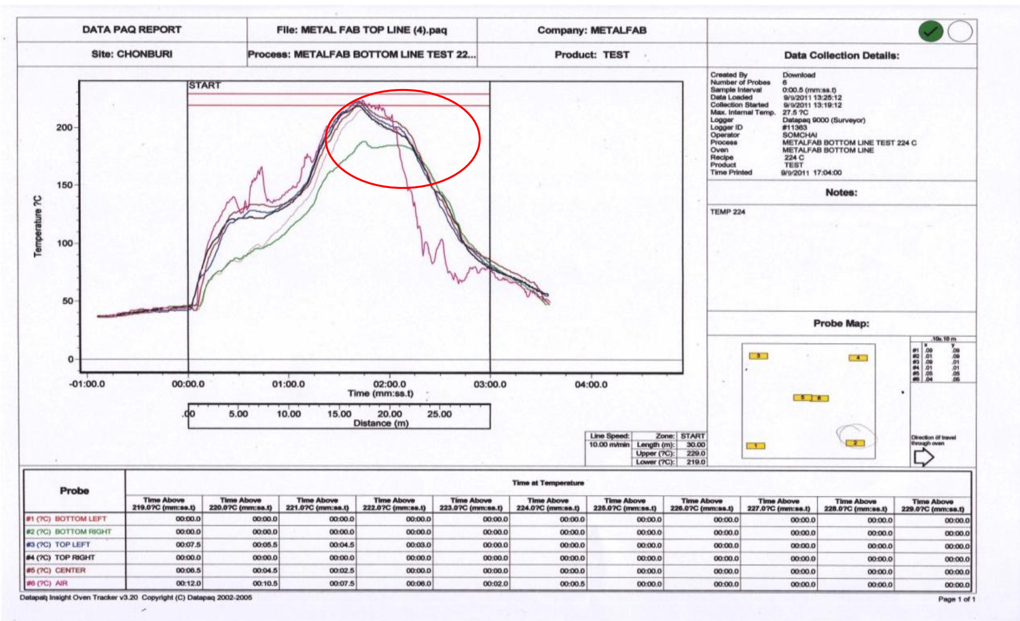


Figure 5.2 After Adjustment

After Adjustment, researcher measure and indicate the temperature in the oven again. Data is compared with before adjustment data. Researcher analysed data as following:



Probe	Time at Temperature										
	Time Above 219.0?C (mm:ss.t)	Time Above 220.0?C (mm:ss.t)	Time Above 221.0?C (mm:ss.t)	Time Above 222.0?C (mm:ss.t)	Time Above 223.0?C (mm:ss.t)	Time Above 224.0?C (mm:ss.t)	Time Above 225.0?C (mm:ss.t)	Time Above 226.0?C (mm:ss.t)	Time Above 227.0?C (mm:ss.t)	Time Above 228.0?C (mm:ss.t)	Time Above 229.0?C (mm:ss.t)
#1 (?C) BOTTOM LEFT	00:00.0	00:00.0	00:00.0	00:00.0	00:00.0	00:00.0	00:00.0	00:00.0	00:00.0	00:00.0	00:00.0
#2 (?C) BOTTOM RIGHT	00:00.0	00:00.0	00:00.0	00:00.0	00:00.0	00:00.0	00:00.0	00:00.0	00:00.0	00:00.0	00:00.0
#3 (?C) TOP LEFT	00:07.5	00:05.5	00:04.5	00:03.0	00:00.0	00:00.0	00:00.0	00:00.0	00:00.0	00:00.0	00:00.0
#4 (?C) TOP RIGHT	00:00.0	00:00.0	00:00.0	00:00.0	00:00.0	00:00.0	00:00.0	00:00.0	00:00.0	00:00.0	00:00.0
#5 (?C) CENTER	00:06.5	00:04.5	00:02.5	00:00.0	00:00.0	00:00.0	00:00.0	00:00.0	00:00.0	00:00.0	00:00.0
#6 (?C) AIR	00:12.0	00:10.5	00:07.5	00:06.0	00:02.0	00:00.5	00:00.0	00:00.0	00:00.0	00:00.0	00:00.0

Figure 5.3 before Adjustment Graph

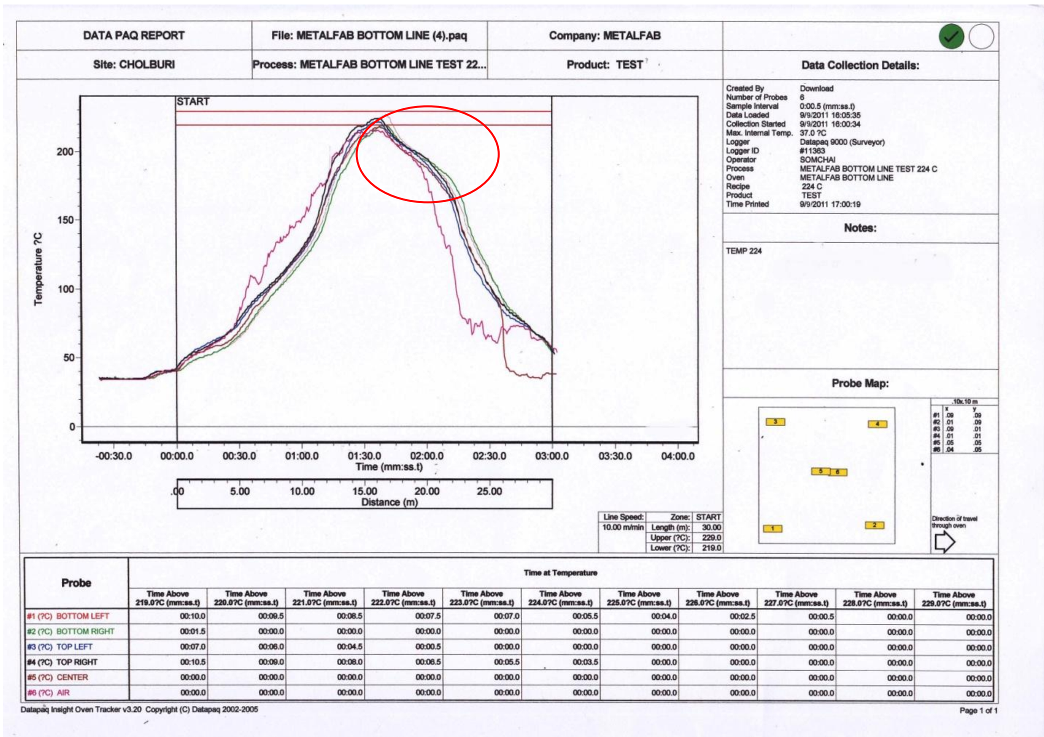


Figure 5.4 After adjustment graph

From DataPaq equipment data, temperature on the surface is nearly same temperature. It can criticise data that if production run process with this adjustment, temperature in each position will be similar. Moreover, left-side and right side colour will be similar, too.

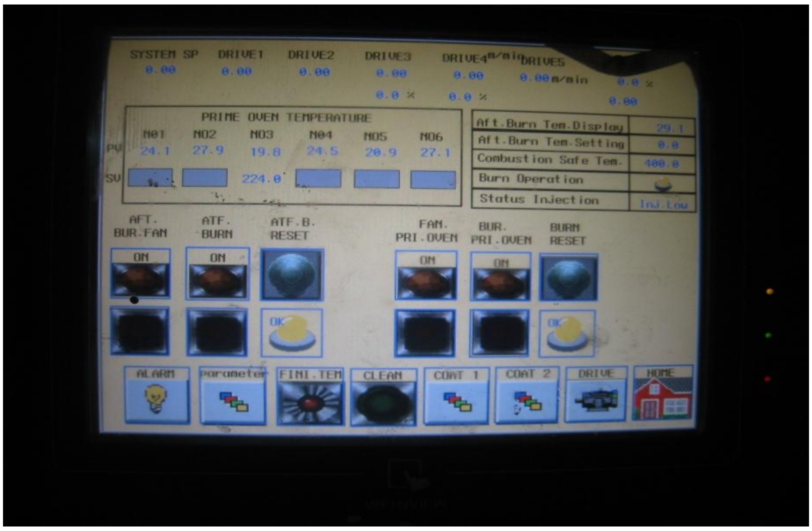


Figure 5.5 Monitor during Production process.

Researcher and Operator test this solution. 2 tons of Aluminium Coil, length 1300 meters is set as experiment. The data was collected on 5th -10th meter from aluminium coil. Sample is indicated and analysed data. Then, researcher collects at 1290th -1300th meters. So, The 2 data sets were compared and summarised the results.

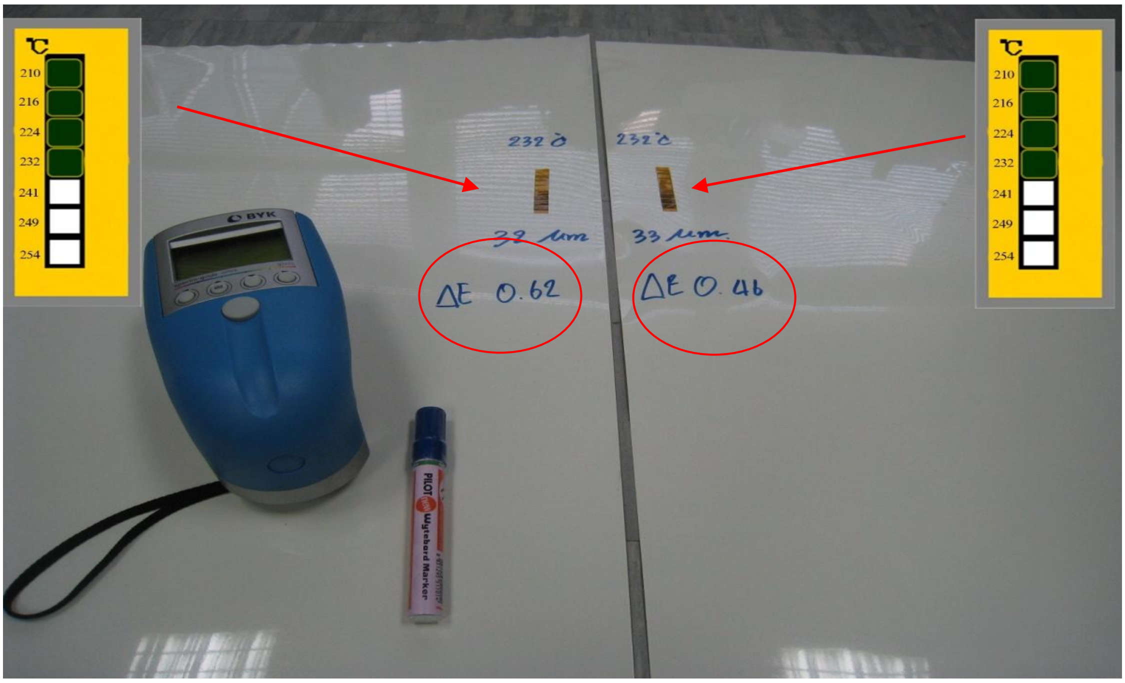


Figure 5.6 Sample from 5th-10th meter from aluminium coil

Table 5.1 the result from Sample from 5th-10th meter from aluminium coil

Test	Left-side	Right-side
Temperature (PMT) 224-232 C	232	232
Colour Thickness 30 – 34 µm	32	33
Δ E (≥1)	0.64	0.44

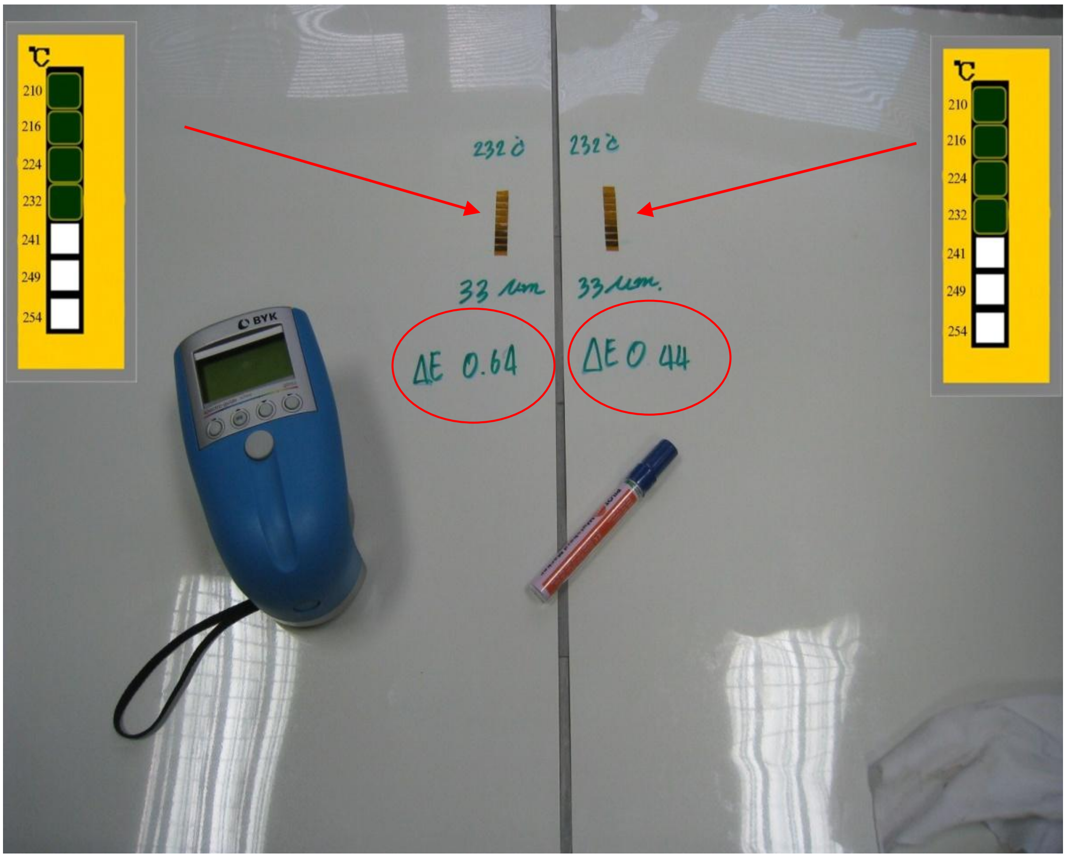


Figure 5.7 Sample from 1290th-1300th meter from aluminium coil

Table 5.2 the result from Sample from 1290th-1300th meter from aluminium coil

Test	Left-side	Right-side
Temperature (PMT) 224-232°C	232	232
Colour Thickness 30 – 34 µm	33	33
Δ E (≥1)	0.64	0.44

For Colour Unlikeness case, the most affected factor is “Temperature”. During Production Process, data is collected. They consist of 6 zones. Each zone has different temperature as followings:

Zone 1 = 190 ºC

Zone 2 = 200 ºC

Zone 3 = 215 ºC

Zone 4 = 224 ºC

Zone 5 = 230 ºC

Zone 6 = 220 ºC

In zone 1-3, it is increased temperature respectively for dry baking and colour will be coated on the surface. In zone 4-5, colour has no moisture with temperature, which is between 224-232 ºC, and flow into zone 6 for cooling.

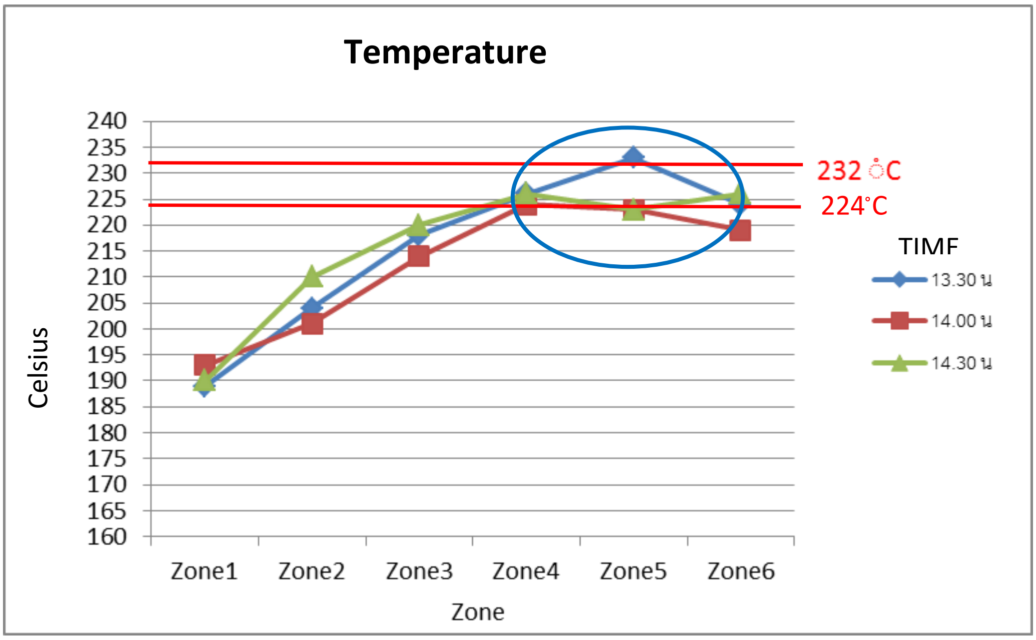


Figure 5.8 Graphs (Temperature and Time)

In figure5.8, temperature measurement is indicated in 3 times. As the result, Temperature is between in the range (224C-232C). It follows colour baking standard.

In zone 5 is the important zone before cooling down. Temperature should be in the range for colour drying. Colour on panel surface will be equal on both sides.

5.2. Research Result Analysis

From table 5.3 and table 5.4, the 1st data set is collected on the 5th-10th meter of the aluminium coil. The 2nd data set is collected on 1290th -1300th meter of the aluminium coil. When researcher compare 2 data sets, the results are similar and Δ E is not exceed than 1.

From Δ E in 2 data sets, they are between 0.44-0.64. Range of 2 data sets is so narrow. It has only 0.2. If production has long period, temperature might change little. Δ E value can be accepted, because it less than 1. The different value is 0.36.

Table 5.3 Result Data Comparison Top of aluminium coil (Before-After adjustment)

Top of Coil	Before Adjustment		After Adjustment	
Test	Left	Right	Left	Right
Temperature (PMT) 224-232 C	232	232	232	232
Colour Thickness 30 – 34 µm	33	32	32	33
Δ E (≥1)	2.16	1.83	0.62	0.46

Table 5.4 Result Data Comparison Tail of Aluminium Coil (Before-After adjustment)

Tail of Coil	Before Adjustment		After Adjustment	
Test	Left	Right	Test	Left
Temperature (PMT) 224-232 C	232	232	232	232
Colour Thickness 30 – 34 µm	33	33	33	33
Δ E (≥1)	2.21	1.96	0.64	0.44

5.3. Research Result Comparison

From result analysis, the result is satisfied. Case Study Company A can solve this problem and implement this project. Data Sets are compared and Defect can decrease. After research and implement this project, which affect to unlike colour case, Researcher collected data after adjustment one month, which is May 55 data.

Table 5.5 the amount of production and defect from coating process from unlike colour case (Before Adjustment)

Month	Sep 11	Oct 11	Nov 11	Dec 11	Jan 11	Feb 11	Mar 11	Total
Production (m^2)	8,636	7,921	8,572	6,983	6,552	6,853	8,631	54,148
Defect (m^2)	1,687	1,253	1,685	2,680	1,324	2,311	1,781	12,721
Percentage%	19.53	15.82	19.66	38.38	20.21	33.72	20.63	23.49

Table 5.6 Defect Reduction Summary (MAY 12)

Month	**May 12**
Production (m^2)	9,436
Defect (m^2)	231
Percentage%	**2.45**

From Result comparisons, which are before adjustment and after adjustment, Average defect per month in 7 months is 23.99% from table 4.5. Defect in May 12 reduce to 2.45%. That decreases 21.54%. This project solves this current situation (Colour Unlikeness Case) and archives this research objective.

Chapter VI

Conclusion and Recommendation

From chapter 5, researcher shows the experiment and result comparison, which are between before and after adjustment. The result approve clearly. This Improvement is the good benefit for Case Study Company A very much. Company can reduce the cost and time, which occur in the production process, and find the solution for sustain implement plan for Defect reduction.

This analysis fulfils the objective of this research which is the reduction of defect in coating process. Data analysis is based on Case Study Company A. Company is improving and developing more effective and efficiency from current problem situation by this research. Left-Right colour unlikeness from coating process is solved and implement by this research suggestion.

6.1. Conclusion

This objective of research is defect reduction in coating process. Researcher defines the factor in the coating process. Design of experiment is the tool for analysing the factor interaction. Researcher creates by using two-factor factorial design method. Researcher creates 3^2 factorial design. There are 2 factors with 3 levels of parameters. Researcher collected 2 replicates for each treatment. ANOVA table shows that Factor A (Temperature) is the significant factor. Factor A or Temperature has p-value lower than significance level of 0.05. It is 0.01. It can confirm that temperature is significant factor. Researcher concern and focus about temperature inside oven especially.

Researcher analysed cause and effect from coating process that affect to Colour unlikeness case. Researcher solved in main problem that is colour unlikeness from coating process. Cause & Effect diagram is created for current situation problem analysis. In the Colour unlikeness cases, the main problem that is “Left-Right colour unlikeness” from coating process.

In the past, Company use only Paperthermo Label equipment for temperature measurement. That cannot find the factor that affect to the colour unlikeness case, because Paperthermo has imprecise scale. It cannot indicate the exact temperature.

So, researcher and factory manager discussed for purchasing the precise scale measurement. DataPaq equipment is the solution. It can measure many point on the surface, while it is in oven. Moreover, it can illustrate the graphs, which compare time and temperature. PaperThermo Label cannot indicate. That time, looking for Real Problem is difficult task.

After Cause& Effect Analysis and ANOVA table, it approved that temperature in oven is the main factor. Researcher found the solution and applied the adjustment. Then, researcher measure and indicate after adjustment. Result from experiment is satisfied. Results analyse and compare from collected data that occurred in real production.

Then, Researcher installs the wind diffuser panel on the top hot air tube. It is the air equilibrator. It uses for distributing hot air equally inside oven. Project is calculated project cost. It costs 240,550 baht. NPV with MARR 8% is 3,854,780.95 baht. It is positive value. IRR is very high is 659.11%.

Researcher measured the process and Data indicated good result. Researcher collected 2 data sets that were measured temperature, colour thickness and Left-Right Colour. For Δ E –value, Top of Aluminium coil is 0.62, 0.46. Tail of Aluminium Coil is 0.64, 0.44. These Δ E-values is acceptable value (Less than 1). Payback period is very short. It is 0.15 year or 1 month and 24days only. It is profitable for factory investment.

Next, Researcher compared data in May 12 data set. In May 12, production quantity 9,436 m^2, defect 231 m^2, Defect can calculated as 2.45%. Average defect per month in 7 months is 23.99%. If this data is compared to May 12 data, this implementation can improve process and archive research objective. It deceased 21.54%. It is calculated 87.78% comparing with before adjustment. It is satisfied and archived objective of this research.

6.2. Recommendation

This research is the research in coating process. This research reduces the defect (Colour Unlikeness Case). Colour unlikeness, some factor cannot improve and control from machine. From research result and analysis, temperature in oven is the main factor. It cannot equalise temperature both left and right side. According to this research, temperature factor can be solved and applied implementation plan.

Nevertheless, coating process, there is other factors that have chance for being problem. That is the roller. Case Study Company A must control and maintain the implementation for roller. Roller has 3 types. They consist of Coating roller, Pick up roller and Scraper Roller. Coating Roller is used for coat colour on aluminium sheet surface. Pick up Roller is used for taking colour into coating roller. Scraper Roller is used for setting colour thickness.

6.2.1 Colour Thickness

It should be less than ±3 µm from range between 30-34 µm. If some side have more than acceptable value, it will be different colour or unlikeness. The acceptable gap is ±0.5 mm. Operator should set and check the roller gap before coating process every time. Now, factory has production settings form for operator. Every production time, operator has to fill the form. Scraper Roller is considered and carefully setting for colour thickness.

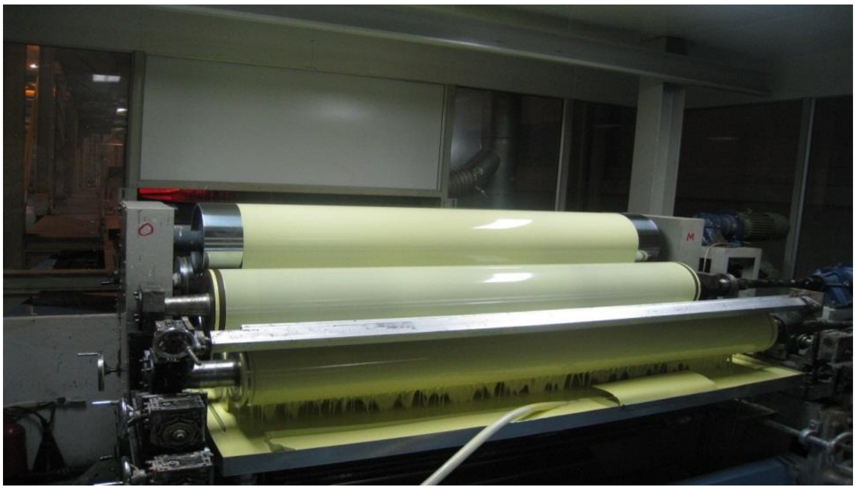


Figure 6.1 Coating Roller after setting

Figure 6.2 Operator is setting Scraper Roller

6.2.2 Roller speed Settings

Factory uses 3 roller application with one rubber blade as figure 6.2. Roller speed is affected to colour thickness. So, the correct setting should be concerned. Factory has work instruction for roller settings.

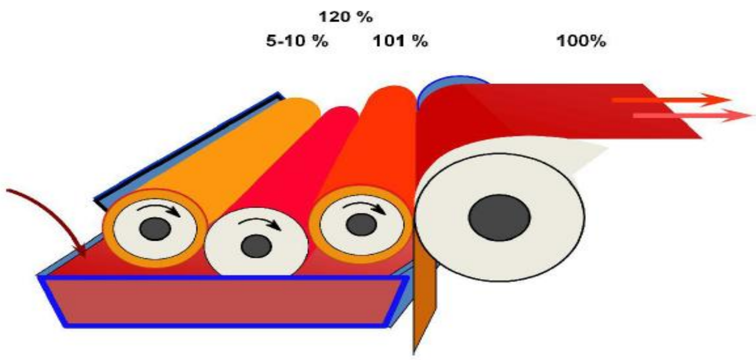


Figure 6.3 Roller Speed Settings

As figure 6.3, Colour viscosity, it is affected for roller setting. Each colour has different colour viscosity. Each roll should be set as figure 6.2. Speed is compared as percentage. According to figure 6.2, if production line speed is 12M/min Coating roller (right) set as 101% from 12M. It is 12.12M/min. Pick up roller (middle) set as 120% from 12 M. It is 14.4M/min. Scarper Roller is 5-10% from 12 M. it is 0.6-0.12 M/min

6.2.3 Roller cleaning

Roller should be polished roller surface. Operator has to polish before coating. It can make dust on the surface of panel. Factory has cleaning form. Operator fills the form. It can check the frequency of cleaning time. Coating Roller should be polished every time after finishing production. Colour will mix or coating to another production. It depends on coating colour material.

6.2.4 Work piece Tension (Aluminium coil)

Aluminium Coil should be levelled both left and right equally, while Coating is under process. 2 operators set both side of aluminium coil equally. If they are not equal for both sides, Colour unlikeness will occur again. It affects to colour thickness, panel surface colour. When aluminium coil feed in, 2 operators stick the yellow on the surface; it will check the aluminium feed in machine both side equally.

Figure 6.4 Two Operators feed in aluminium coil

6.3. Further Research

In this part, Researcher discussed with factory manager about temperature inside oven after production. It might reuse the heat temperature from oven. LPG is used for heating up oven. In factory manager's opinion, LPG cost is the cheapest energy currently. However, LPG increased every month. It cannot predict cost accurately. Temperature for coating in once, it is so high. It is between 224-232C. It spends time for heating up and using large amount of LPG. Finish production, Heat inside oven has just release out and do nothing with that heat. Factory manager would like to reuse that heat. It might be reuse in coating process or lamination process. It can be reduced cost effectively. It might not waste time for setting temperature. It can be faster than actual production. It will help factory to run process faster and spend less time than before.

Then, lamination process, is the continue process from coating process. Current problem, aluminium coil is broken, while production process. In lamination process, there is compress and combine many materials. Operator always lack of awareness in aluminium feeding in and controlling. Moreover, the width size is incorrect size with machine. Currently, Aluminium composited panel have to cut edge. Edge of aluminium sheet, It can be sold as scrap. Factory manager would like to find problem solution. Operators have to aware all production time. Operator should do other job than just looking production process.

Figure 6.5 Operator cut edge of aluminium composite coil

Other problem is the top of lamination process. It is from the plastic melting machine. Plastic grains block up in the melting tube. That is the problem that factory can solve in short-term. Operator use hard wood for stirring. It wastes cost of plastic grain. Factory manager think the long-term implementation plan for lamination process. It should find sustainable solution. It has to analyse and define the cause of problem and find implementation plan in the future.

Figure 6.6 Plastic Melting Machine

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APPENDIX

DATAPAQ®
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the heart of the profiling system

The Datapaq® Q18 data logger has been designed using the latest miniaturized electronic packaging technology, enabling us to combine speed of readings, superb accuracy and high resolution all in one versatile unit. The Q18 is intended for use in profiling applications and is supplied with 6, type K thermocouple input channels.

DESIGNED WITH EASE-OF-USE

The Q18 retains the familiar status indicators and stop/start buttons common to the complete range of industrial temperature data loggers from Datapaq.

READY FOR USE AT ALL TIMES

The Q18 is equipped with an internal NiMH battery and intelligent fast charger circuits. These allow the user to leave the logger permanently on charge with no risk of damage to the battery.

FAST AND EFFICIENT

The fast sampling capability and huge memory for readings enables large amounts of data to be captured. This is transferred in seconds to a PC using a high speed USB interface, ensuring minimal time is lost.

THE Q18 SOLUTION

The Q18 is available in two height and width options, each of which has a range of thermal barriers. This ensures that you can choose the data logger based on the requirements of your process.

FLEXIBLE

The Q18 has the power and flexibility to profile many different industrial thermal processes from electronics packaging and assembly, through food preparation, paint and powder coating to metal heat treatment.

DataPaq Equipment Detail

TECHNICAL SPECIFICATIONS

Q18 RANGE OF DATA LOGGERS

Sample Interval:	0.05 seconds to 10 minutes
Accuracy:	±0.5°C (±0.9°F)
Resolution:	0.1°C (0.2°F)
Maximum Internal Operating Temperature:	85°C (185°F)
Temperature Range:	-200°C to 1370°C (-328°F to 2498°F)
Memory:	18,000 readings per channel
Data collection start:	Start/Stop buttons, time or temperature trigger
Battery:	NiMH rechargeable
Thermocouples:	Type K

DATA LOGGER	PART NUMBER	HEIGHT	WIDTH	LENGTH	NUMBER OF CHANNELS
	DQ1860	12 mm (.47 in)	106 mm (4.1 in)	150 mm (5.9 in)	6
	DQ1862	20 mm (.78 in)	57 mm (2.2 in)	165 mm (6.4 in)	6

The DQ1860 and DQ1862 Q18 loggers can be used with a comprehensive range of different thermal barriers. Contact Datapaq to discuss which thermal barrier is best suited to your specific applications needs.

The Worldwide Leader in Temperature Profiling

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FAMELINE GROUP ALWAYS BEYOND

COATER PROCESS REPORT

Date :

Production No. :

Reportor :

Team Leader :

Coater Check sheet

Coil Lot	Coil Size (W x T)	Line speed (m/min)	Coater Head	Paint code (B/N)	Paint Color (Name)	Open (L)	Return (L)	Open Visc. (Sec)	Run Visc. (Sec)	Solvent Added (litres)	Solvent Clean (litres)	App.roll speed (m/min)	Pick up speed (m/min)	Scracp roll speed (m/min)	Applicator Gap (mm)	Pickup Gap (mm)	Wet Film (um)	Temp.	Prime Oven Zone1	Prime Oven Zone2	Prime Oven Zone3	Prime Oven Zone4	Prime Oven Zone5	Prime Oven Zone6	Prime Oven PMT	Finish oven Zone1	Finish oven Zone2	Finish oven Zone3	Finish oven Zone4	Finish oven Tract	Finish oven Burn	Finish oven Gas	Finish oven PMT
			Prime Coater 1															Set Up	-	-		-	-	-			-		-		-		
			Top Coater 2															Actual			-												
			Bottom Coater 3																														
			Prime Coater 1															Set Up	-	-		-	-	-			-		-		-		
			Top Coater 2															Actual			-												
			Bottom Coater 3																														
			Prime Coater 1															Set Up	-	-		-	-	-			-		-		-		
			Top Coater 2															Actual			-												
			Bottom Coater 3																														
			Prime Coater 1															Set Up	-	-		-	-	-			-		-		-		
			Top Coater 2															Actual			-												
			Bottom Coater 3																														
			Prime Coater 1															Set Up	-	-		-	-	-			-		-		-		
			Top Coater 2															Actual			-												
			Bottom Coater 3																														

System Speed & Tension

No.	Details	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00
1	Speed Drive 1												
2	Speed Drive 2												
3	Speed Drive 3												
4	Speed Drive 4												
5	Speed Drive 5												
6	%Tension Recoil												
7	%Tension Line												

FM-F2-CO-006/Rev.1/01-09-55

Coater Process Report

BIOGRAHPHY

Pongsathorn Sirisukkasem graduated in 2008 with Bachelor's Degrees of Science in Engineering Management from Sirindhorn International Institute of Technology, Thammasat University. He worked as Japanese Factory Coordinator at SSK Co.Ltd for 3 months. He applied to Master's Degree in Engineering Management at Regional Centre for Manufacturing System Engineering, Chulalongkorn University and Master's Degree in Supply and Logistics Management at University of Warwick (United Kingdom).