Research Article

Reduction of Scrap in Anodization Process: A Case Study in a Cosmetic Packaging Industry

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Abstract

According to the production process conditions in the company case study, in particular the operation of anodization department for coating of the packaging, the defects of the process have been found significantly. Referring to the primary analysis, the defects are caused from inappropriate chemical parameters in anodization process and also inappropriate packaging wash after the anodizing process when the highest amount of paint losses is found in scrap. The scrap value of both matte coating process and glossy coating process is about USD 2,800 per month. The objectives of this research are to study aluminium alloy metal coating process with sulfuric acid under particular conditions and to determine appropriate conditions for material surface coating. The appropriate level of the turbidity is 12.4242 NTU and the concentration is 220 g/L for matte coating process. Glossy coating process can be reduced to the appropriate level of the turbidity at 3.4040 NTU and the concentration is 303.33 g/L. In addition, this can reduce defect on the paint loss packaging from anodizing process, and coating process condition in matte coating process up to 67.77% and glossy coating process is also reduced by 66.02%.

Keywords: Anodization process, Aluminium alloy metal coating process, Experimental plan, Sulfuric acid

1 Introduction

The company case study is a plastic and aluminum cosmetic packaging manufacturer. According to the exploration of general conditions based upon the primary analysis, the defects are from 1) anodization process that has some inappropriate chemical parameters and 2) inappropriate color parameter measurement process. The total defect cost is about USD 2,800 per month. The manufacturing data was collected from January–August 2016. After brainstorming to seek causes of problems, the primary factors affecting paint losses are identified. Quality equipment is applied to brainstorm and identify possible causes of problems. The researchers asked experienced people including engineers, manufacturing, coating, automotive and perfume lid assembling staff and operational staff who are familiar with anodization process in the company case study to analyze and propose interesting solutions. Figure 1 illustrates sample of matte packaging (left) and glossy packaging (right) that are used in this research.

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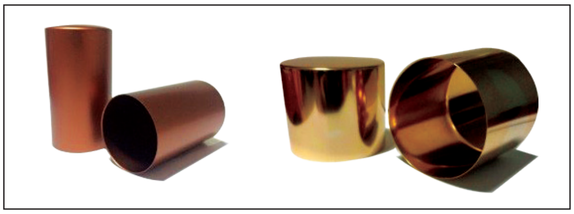

Figure 1: Sample of Matte packaging (left) and Glossy packaging (right).

2 Literature Review

In this section, we present 3 main ideas that consist of aluminum sulfuric acid with process coating metal alloy or anodizing process [1] and design of experiment based on the relevant theories (2^k factorial design) [2], [3] that are related to identify proper conditions for 3^k factorial design [4]–[9].

2.1 *Anodizing process*

Generally, anodizing process or oxidation process at anodes of aluminium metals in electrolyte solutions is the process of generating anodic oxide films on electrode poles [10]. Film layers consist of outer layer of fairly thick porous materials growing from the inner metal layer. Porous holes of materials are basically with constant distances. This layer is usually thin without porous holes around connective joints between metals and oxide. Therefore, when anodizing time is increased, metals will turn into oxide at subjected joints. Those porous holes will become outer film of next layer. General porous oxide material layers are in the form of hexagonal crystal structures with constant arrangement. Inside each crystal embraces a cylinder porous hole. Anodizing process can be done in various ways. It is mostly conducted in solution system by applying electrolyte solution with sulfuric acid, oxalic acid, and phosphoric acid. Alternatively, it can be implemented through the process of magnetron sputtering in vacuum chamber. Figure 2(a) and (b) present an example of a simulated model of aluminum film anodizing process and process tracking with the utilization of electricity.

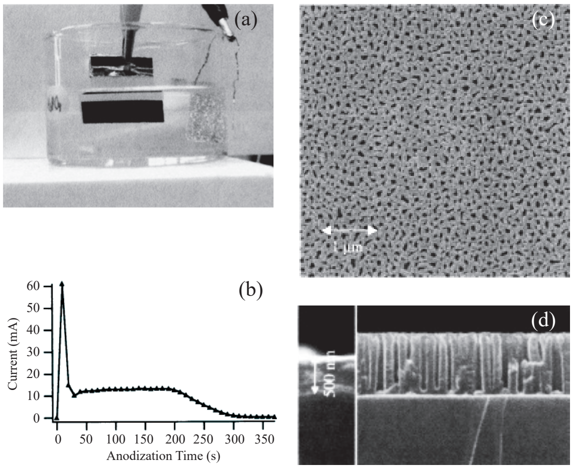

Figure 2: The simulated model of aluminium film anodizing process in phosphoric acid solution; tracking the process with the utilization of electricity; and the physical appearance of porous film [10].

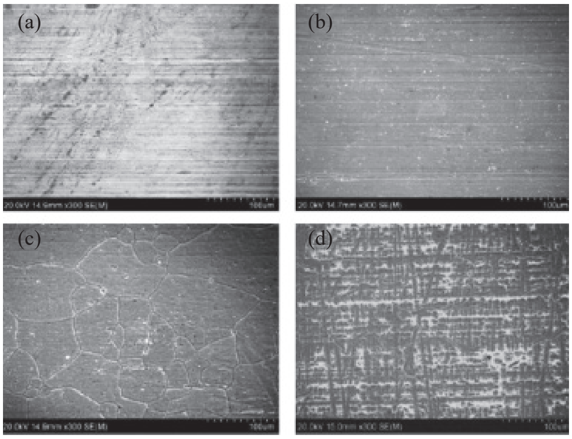

Figure 3: Time of extension the following changes [11].

Aluminium pretreatment process for higher adhesion are basically comprise of the step of surface adjustment by removing the layer of natural oxide film. By doing so, chemical changes or planes of surface roughness might occur. From the study of [11] concerning aluminium pretreatment process with the concentration of NaOH at 0.1 molar, surface changes were found when time extended as demonstrated in Figure 3. After the procedure, the surface was investigated and analyzed by different techniques.

The average thickness of film produced by the process is measured to be about 6 μm. For the cross section micrographs, specimens were wire-cut in the middle and were polished up to 2,400 grit SiC abrasive papers using standard metallographic technique [12].

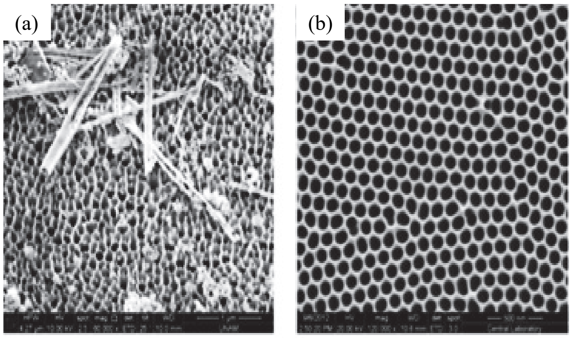

Figure 4: Examples of the anodized film from 1 step anodizing process (left) and from 2 step anodizing process (right) [15].

Values of the turbidity are good indicators that can imply impurities as well as water quality. They are also applied for quality control in food industry pharmaceutics, semiconductors, drinks, and hydrocarbons. And thus values of the turbidity can be manipulated to measure amounts of water in contaminated [13], [14].

The nanopores were then widened in an aqueous chromic acid solution at room temperature for 22 min in Figure 4 [15].

2.2 2^k *Factorial design*

This research was to explore numbers of factors influencing defect on packaging. The research designed the analysis of the experiment [16], [17] to find causes with 2^k factorial design technique in order to reduce happened defect and to be able to find other proper conditions later. It begins from problem analysis to recognize dependent and independent variables. The critical thing is objectives of the experiment must be set correctly. Then, set up factors and scope(s), along with the application of experiences and knowledge of theories in terms of how to apply them to the experiment with the main aims to discover potential factors; to control them according to theories; and to utilize them in real situations. Later on, choose a pattern of the experiment that is appropriate for the problems, followed by drawing numbers of repetition considered from degree of freedom (*df*). The last step is to analyze and summarize the result in order to analyze information from the results, they would be accepted with reference to hypotheses only when residues in normal distribution were estimated.

2.3 3^k *Factorial design*

This step describes experimental plan to find proper conditions for material surface coating. From the design of experiments (3^k factorial design) is consisted of k factor and the level for experimental that is determined the level divide into 3 levels. The results of the ANOVA are presented in an ANOVA table which can find the main factors influencing the amount of paint losses packages significantly when p-value < 0.05. After that we conclude the result of response with Contour Plot and Surface Plot. This both forms can lead to determining the appropriate level of factors. Thus applying the tool Response Optimizer with a statistical program can analyze the experiment and leads to a reliable response.

3 Research Methodology

3.1 *Phase 1: Data collection*

According to Figure 2, The experimental results are from the real manufacturing process to analyze if it is accorded to hypothesis or not. In this phase, there are three steps which are 1) study of the factory's operation of the case study; 2) study of researching works and related theories; and 3) Cause analysis, in order to specify factors for consideration. The purpose is to reduce defect from several factors that may happen to packaging. As for the case analysis, the team brainstormed to review the cause, using statistical tool, Fishbone Diagram or Cause and Effect Diagram, to summarize the related causes of problems.

- Step 1, This step explains the operation of the case study factory. The research studied to identify the major cause that damages the works, considering manufacturing process and operational process.
- Step 2, To study related theories and researching works about steel coated with aluminium alloy, applying analytical design method and statistical technique to test and search for the cause in order to reduce the damages and adapt for the operation.
- Step 3, The result from cause analysis can proceed to find factors that affect to the test in order to receive the appropriate level. The team brainstormed to consider the causes and apply Fishbone Diagram or Cause and Effect Diagram [18] with Failure Mode and Effects Analysis (FMEA) to screening the primary root cause

and consider the comment from a team to brainstorm ideas. This principle is used for weighting to prioritize problems and to summarize the major problems [19].

3.2 *Phase 2: Two-level factorial design and determining appropriate level of experiment*

Phase 2 includes steps of appropriate design of experiment with related factors and summarize for analysis. There are 2 steps as follows:

- Step 1, To search the appropriate level of factors, design 2^k factorial design.
- Step 2, To search the appropriate condition for the experiment and to search the appropriate level of factors, according to the design of 3^k factorial design (the beginning experiment would be repeated to find the mean; the total experiments are $3 \times 3 \times 3\ldots \times 3 = 3^k$).

3.3 *Phase 3: Summary*

The experimental results are applied in the real manufacturing process to analyze whether it is according to hypothesis or not.

4 Results and Discussion

4.1 *Phase 1: Data collection*

After studying of the general condition of the case study factory and the operation process to search for the true cause of the problem, the data are below.

Table 1: Factor and level of factor during control process in 2^k factorial design

Factor	Level of Factor				Unit
	Matte		Glossy		
	Low (–)	High (+)	Low (–)	High (+)	
Specific Gravity	23	27	24	27	$(kg/m^3)/(kg/m^3)$
Grab	13	15	13	15	mm.
Turbidity	10	20	3	7	NTU.
Free H_2SO_4 Concentration	220	240	270	330	g/L

4.2 *Phase 2: Two-level factorial design and determining appropriate level of experiment*

According to Table 1, it presents 4 factors during control process in 2^k factorial design.

Hypothesis Setting

1. Hypothesis 1: Influence of Specific Gravity.
   H_0: $\tau_1 = \tau_2 = 0$ $i = 1,2,\ldots.a$
   H_1: τ_1 or $\tau_2 \neq 0$ At least one τ_i
2. Hypothesis 2: Influence of Grab.
   H_0: $\beta_1 = \beta_2 = 0$ $j = 1,2,\ldots.b$
   H_1: β_1 or $\beta_2 \neq 0$ At least one β_j
3. Hypothesis 3: Influence of the turbidity.
   H_0: $\gamma_1 = \gamma_2 = 0$ $k = 1,2,\ldots.c$
   H_1: γ_1 or $\gamma_2 \neq 0$ At least one γ_k
4. Hypothesis 4: Influence of free H_2SO_4 concentration.
   H_0: $\delta_1 = \delta_2 = 0$ $l = 1,2,\ldots.c$
   H_1: δ_1 or $\delta_2 \neq 0$ At least one δ_l
5. Hypothesis 5: Treatment interactions, the specific gravity and grab.
   H_0: $(\tau\beta)_{ij} = 0$ for all i and j
   H_1: $(\tau\beta)_{ij} \neq 0$ At least one $(\tau\beta)_{ij}$
6. Hypothesis 6: Treatment interactions, the specific gravity and the turbidity.
   H_0: $(\tau\gamma)_{ik} = 0$ for all i and k
   H_1: $(\tau\gamma)_{ik} \neq 0$ At least one $(\tau\gamma)_{ik}$
7. Hypothesis 7: Treatment interactions, the specific gravity and free H_2SO_4 concentration.
   H_0: $(\tau\delta)_{jl} = 0$ for all i and l
   H_1: $(\tau\delta)_{jl} \neq 0$ At least one $(\tau\delta)_{jl}$
8. Hypothesis 8: Treatment interactions, grab and the turbidity.
   H_0: $(\beta\gamma)_{jk} = 0$ for all j and k
   H_1: $(\beta\gamma)_{jk} \neq 0$ At least one $(\beta\gamma)_{jk}$
9. Hypothesis 9: Treatment interactions, grab and free H_2SO_4 concentration.
   H_0: $(\beta\delta)_{jl} = 0$ for all j and l
   H_1: $(\beta\delta)_{jl} \neq 0$ At least one $(\beta\delta)_{jl}$
10. Hypothesis 10: Treatment interactions, the turbidity and free H_2SO_4 concentration.
    H_0: $(\gamma\delta)_{kl} = 0$ for all k and l
    H_1: $(\gamma\delta)_{kl} \neq 0$ At least one $(\gamma\delta)_{kl}$
11. Hypothesis 11: Treatment interactions, The specific gravity, grab and the turbidity.
    H_0: $(\tau\beta\gamma)_{ijk} = 0$ for all i, j and k
    H_1: $(\tau\beta\gamma)_{ijk} \neq 0$ At least one $(\tau\beta\gamma)_{ijk}$
12. Hypothesis 12: Treatment interactions, The specific gravity, grab and free H_2SO_4 concentration.
    H_0: $(\tau\beta\delta)_{ijl} = 0$ for all i, j and l
    H_1: $(\tau\beta\delta)_{ijl} \neq 0$ At least one $(\tau\beta\delta)_{ijl}$
    Hypothesis 13: Treatment interactions,
13. the specific gravity, the turbidity and free H_2SO_4 concentration.

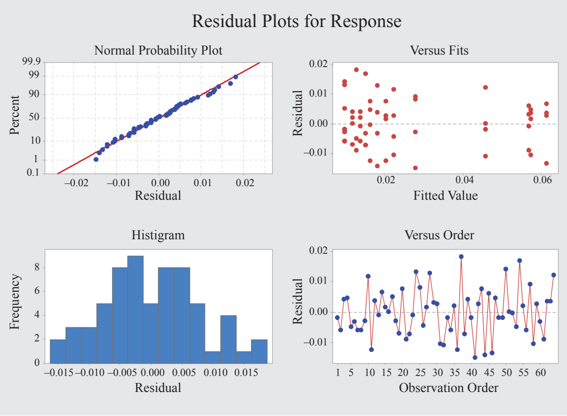

Figure 5: Analysis of Variance Design Expert Output for 2^k Factorial Design (matte coating).

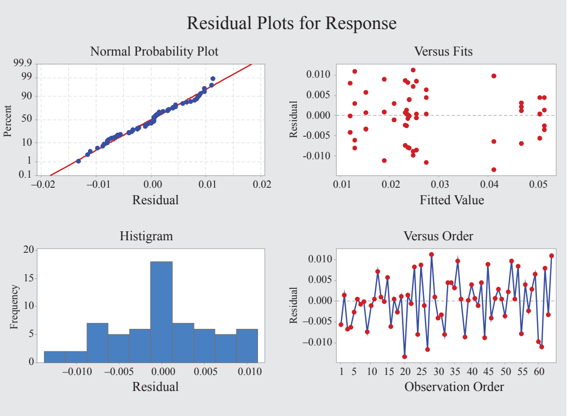

Figure 6: Analysis of Variance Design Expert Output for 2^k Factorial Design (glossy coating).

H_0: $(\tau\gamma\delta)_{ikl} = 0$ for all i, k and l
H_1: $(\tau\gamma\delta)_{ikl} \neq 0$ At least one $(\tau\gamma\delta)_{ikl}$

14. Hypothesis 14: Treatment interactions, grab, the turbidity and free H_2SO_4 concentration.
    H_0: $(\beta\gamma\delta)_{jkl} = 0$ for all j, k and l
    H_1: $(\beta\gamma\delta)_{jkl} \neq 0$ At least one $(\beta\gamma\delta)_{jkl}$
15. Hypothesis 15: Treatment interactions, the specific gravity, grab, the turbidity and free H_2SO_4 concentration.
    H_0: $(\tau\beta\gamma\delta)_{ijkl} = 0$ for all i, j, k and l
    H_1: $(\tau\beta\gamma\delta)_{ijkl} \neq 0$ At least one $(\tau\beta\gamma\delta)_{ijkl}$

where τ is influence of the specific gravity, β is influence of grab, γ is influence of the turbidity, δ is influence of free H_2SO_4 concentration [20].

The research repeated the experiment four times. The total experiments are $2\times2\times2\times2\times4 = 64$ experiments. Setting α at 0.0c5, using a statistical program to analyze the experiment as follows:

1. Normal Distribution: According to the data in the table after the analysis, the residuals distribute in horizontal meaning that the distribution is non - normal.

2. Independent examination of residuals: According to the data in the table after the analysis, the distribution of residuals is independent, no fix form, representing that they are independent to each other.

3. Variance Stability of σ^2: According to the data in the table after the analysis, the diagram of residuals' distribution can be compared to Fitted Valued as they have similar result and no bending moment representing variance stability. The output from 2^k factorial design is presented in Figures 5 and 6 and Table 2.

Table 2: The result of the ANOVA are presented in an ANOVA table for 2^k factorial design for matte coating (Above) and glossy coating (Below)

Factorial Regression: Response versus Specific gravity, Grab Turbidity, Concentration					
Analysis of Variance					
Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Model	15	0.020807	0.001387	17.48	0.000
Linear	4	0.015898	0.003975	50.09	0.000
Specific gravity	1	0.000036	0.000036	0.45	0.504
Grab	1	0.000127	0.000127	1.60	0.123
Turbidity	1	0.004658	0.004658	58.71	0.000
Concentration	1	0.011078	0.011078	139.61	0.000
2-Way Interactions	6	0.004601	0.000767	9.67	0.000
Specific gravity* Grab	1	0.000053	0.000053	0.66	0.420
Specific gravity* Turbidity	1	0.000008	0.000008	0.10	0.759
Specific gravity* Concentration	1	0.000077	0.000077	0.96	0.331
Grab* Turbidity	1	0.000064	0.000064	0.81	0.374
Grab* Concentration	1	0.000240	0.000240	3.03	0.088
Turbidity* Concentration	1	0.004160	0.004160	52.43	0.000
3-Way Interactions	4	0.000290	0.000073	0.91	0.464
Specific gravity* Grab* Turbidity	1	0.000225	0.000225	2.84	0.099
Specific gravity* Grab* Concentration	1	0.000030	0.000030	0.38	0.540
Specific gravity* Turbidity* Concentration	1	0.000012	0.000012	0.15	0.696
Grab* Turbidity* Concentration	1	0.000023	0.000023	0.28	0.596
4-Way Interactions	1	0.000018	0.000018	0.23	0.635
Specific gravity* Turbidity* Concentration	1	0.000018	0.000018	0.23	0.635
Error	48	0.003809	0.000079		
Total	63	0.024616			
Model Summary	S 0089075	R-sq 84.53%	R-sq(adj) 79.69%	R-sq (pred) 72.49%	

Factorial Regression: Response versus Specific gravity, Grab Turbidity, Concentration					
Analysis of Variance					
Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Model	15	0.009805	0.000654	14.16	0.000
Linear	4	0.008641	0.002160	46.80	0.000
Specific gravity	1	0.000068	0.000068	1.47	0.231
Grab	1	0.000025	0.000025	0.54	0.465
Turbidity	1	0.004258	0.004258	92.24	0.000
Concentration	1	0.004290	0.004290	92.95	0.000
2-Way Interactions	6	0.000932	0.000155	3.36	0.008
Specific gravity* Grab	1	0.000004	0.000004	0.09	0.770
Specific gravity* Turbidity	1	0.000002	0.000002	0.03	0.855
Specific gravity* Concentration	1	0.000036	0.000036	0.78	0.382
Grab* Turbidity	1	0.000001	0.000001	0.02	0.884
Grab* Concentration	1	0.000105	0.000105	2.28	0.138
Turbidity* Concentration	1	0.000784	0.000784	16.99	0.000
3-Way Interactions	4	0.000232	0.000058	1.26	0.299
Specific gravity* Grab* Turbidity	1	0.000025	0.000025	0.54	0.465
Specific gravity* Grab* Concentration	1	0.000039	0.000039	0.85	0.362
Specific gravity* Turbidity* Concentration	1	0.000030	0.000030	0.66	0.422
Grab* Turbidity* Concentration	1	0.000138	0.000138	2.99	0.090
4-Way Interactions	1	0.000000	0.000000	0.00	0.971
Specific gravity* Turbidity* Concentration	1	0.000000	0.000000	0.00	0.971
Error	48	0.002215	0.000046		
Total	63	0.012020			
Model Summary	S 0.0067938	R-sq 81.57%	R-sq(adj) 75.81%	R-sq (pred) 67.23%	

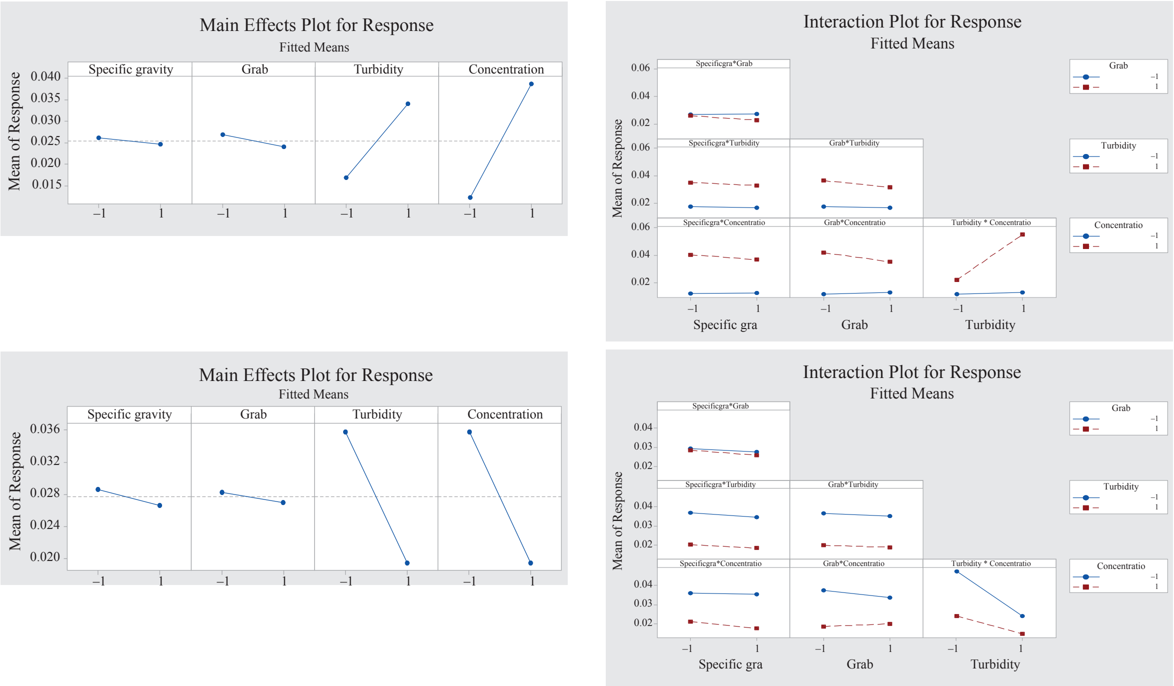

Figure 7: Main effects plot and Interaction plot for response in matte coating (above) and glossy coating (below).

According to Figure 7, the response to matte coating means that when the turbidity is high, it results in the amount of paint losses. If the concentration is high, this results to the highest amount of paint losses as well. On the other hand, when adjusting the specific gravity and grab, the graph tends to be horizontal meaning that the specific gravity and grab has no influence on the errors on packages. As a result, the turbidity and the concentration are the influencers which need to be analyzed. The response to glossy coating means that when the turbidity is high, it results in the large amount of paint losses. If the concentration is high, it results in the low amount of paint losses similarly. From treatment interactions factors graph has affected to the amount of paint losses in between the turbidity and the concentration in the response to matte coating and glossy coating. The others have no effects on the number of errors on the paint losses packaging from anodizing. The research sets parameters to display factors and levels of factors studied to respond to the surface. The results are presented in Figures 8 and 9 as following.

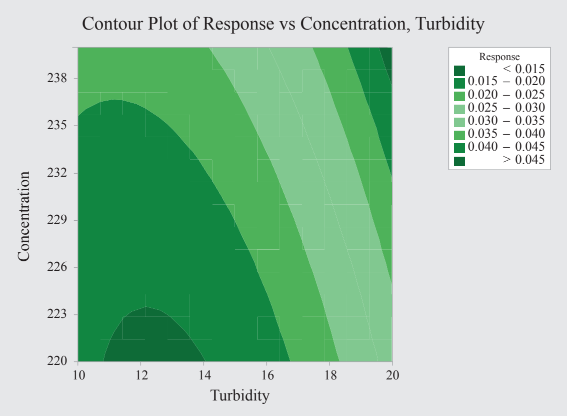

Figure 8: Structure between factors of the turbidity and the concentration for matte coating.

Regarding the variance analysis, the main factors influencing the number of errors on the paint loss packaging significantly with p-value < 0.05 are the turbidity and the concentration.

Moreover, there is treatment interaction among the two factors affecting the damages significantly.

For matte coating as the color gets in darker zone, the response (damage) decreases. The response decreases as the turbidity and the concentration tend to be lower, this results in the low number of damage.

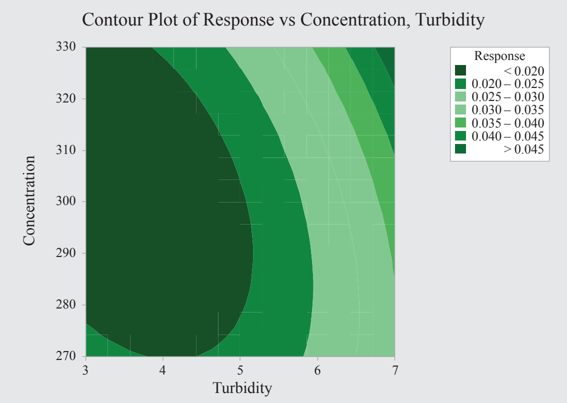

Figure 9: Structure between factors of the turbidity and the concentration for glossy coating.

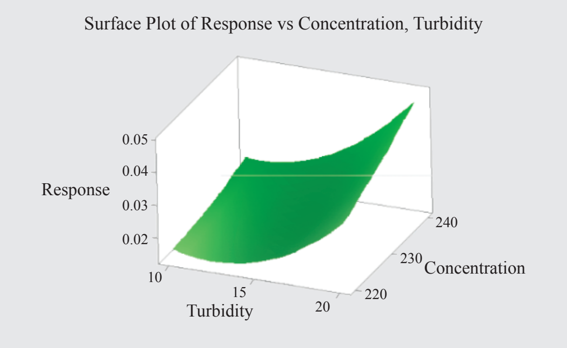

Figure 10: Response surface between factors of the turbidity and the concentration for matte coating.

So the low number of damage in this peak (appropriate level) region is less than 0.015. When adjusting for glossy coating the low number of damage in this peak (appropriate level) region is less than 0.020.

In Figure 10, the structure and response surface graph between factors of the turbidity and the concentration for matte coating has been found and resulted in the low number of damage in anodizing process for the paint losses when the turbidity is low in the horizontal between 11–14 NTU In contrast, when adjusting the concentration between 220–223 g/L, this results in the low number of damage simultaneously.

The structure and response surface graph between factors of the turbidity and the concentration for glossy coating has been found in Figure 11 and resulted in the low number of damage in anodizing process for the paint losses when the turbidity is low in the horizontal between 3–5 NTU. In contrast, when adjusting the concentration between 280–330 g/L, this results in the low number of damage simultaneously.

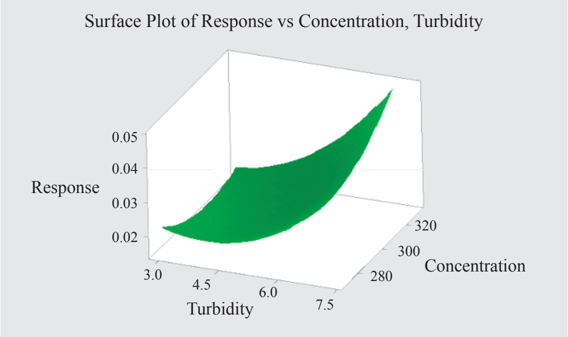

Figure 11: Response surface between factors of the turbidity and the concentration for glossy coating.

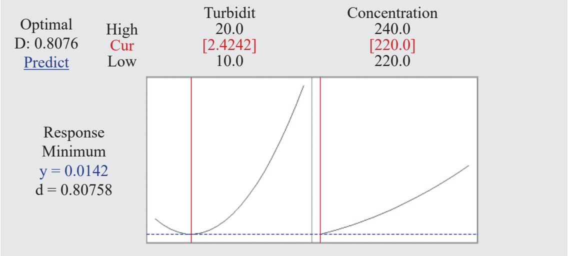

Figure 12: Optimization plot shown the appropriate level of factors for matte coating.

Figure 12 shows the relation between 2 factors which are the turbidity and the concentration. The appropriate level of factors is identified by using 3^k factorial design with optimization plot. The appropriate level of the turbidity is 12.4242 NTU and the concentration is 220 g/L.

Figure 13 shows the relation between 2 factors which are the turbidity and the concentration. The appropriate level of factors is identified by using 3^k factorial design with optimization plot. The appropriate level of the turbidity is 3.4040 NTU and the concentration is 303.33 g/L. The overall parameters are presented in Table 3.

Table 3: Factor and level of factor during control process in anodizing

Control Factor	Matte		Glossy		Unit
	Appropriate Level	Duration of Control	Appropriate Level	Duration of Control	
Turbidity	12.4242	11–14	3.4040	3–5	NTU.
Free H_2SO_4 Concentration	220	220–223	303.3333	280–330	g/L

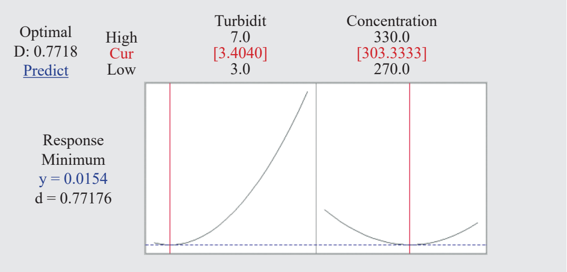

Figure 13: Optimization plot shown the appropriate level of factors for glossy coating.

5 Conclusions

Regarding to the data analysis, the solutions of damaging in matte coating and glossy coating processes for paint loss packages are as follows. For the factors influencing the error on the packages, it applies to use 2^k factorial design in order to synthesize factors and search for the right level of factors. According to 3^k factorial design for the consideration of the responding results and the primary analysis of 2^k factorial design, there are factors of the turbidity and the concentration while the specific gravity and grab of anodizing liquid has no influence on the errors on the packages. According to ANOVA, the relation of treatment interaction between 2 factors which are the turbidity and the concentration, the treatment interaction affects to the errors on the packages significantly. The next step is to find the appropriate level of factors by using 3^k factorial design with Response Surface Methodology. For matte coating the appropriate level of the turbidity is 12.42 NTU and the concentration is 220 g/L. In addition, this can reduce defects in paint loss packaging from anodizing process.

For glossy coating the appropriate level of the turbidity is 3.40 NTU and the concentration is 303.33 g/L. In addition, this can reduce defects in paint loss packaging from anodizing process.

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