Weight-loss Percentage Improvement of PVC Artificial Leather Products in Automotive Part Industry by Six Sigma

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Abstract—The purpose of this research was to improve the weight-loss percentage of PVC artificial leather products manufactured by the calendering process. It was noticed that the weight-loss percentage was greater than 5% which did not pass the specification given by the Original Equipment Manufacturer (OEM). Hence, the DMAIC Six Sigma methodology was applied to improve the situation. The cause-and-effect matrix and the Failure Mode and Effect Analysis (FMEA) were adopted to identify the potential factors that affect the quality of the products. After that, the design of experiment (DOE) was used to determine significant factors and optimal parameter settings for the production process to prevent a recurrence. The result shown that the average weight-loss percentage was reduced to only 0.9% after applying new parameter settings.

Index Terms—Automotive part, Calendering process, PVC leather, six sigma

I. INTRODUCTION

Six Sigma is a rigorous, focused, and highly effective implementation of proven quality principles and techniques [1]. This technique applies the DMAIC (Define, Measure, Analyze, Improve, Control) methodology to analyze the process to root out sources of unacceptable variation and develop alternatives to eliminate or reduce errors and variation [2]. The business excellence in the auto part industry assumes the management commitment to develop and deliver perfect solutions, products or services and to promote the Zero Defects [3].

From 2018 until now, the case study factory has founded problems from the calendering process, which was the major problem of PVC artificial leather product crack after using car did not more than 100,000 kilometres. The tested result shown that some lot of weight-loss percentage was more than a specification of 5%. Hence, this research aims to improve the weight-loss percentage value of PVC artificial leather products in the calendering process [4] by using the Six Sigma approach which comprises five phases as follows.

II. METHODOLOGY

A. Define Phase (D)

This phase is focused on problem identification.
1) Problem statement: OEM complained about PVC artificial leather product crack problem as shown in Fig. 1.
2) Project metrics: Primary metric is the weight-loss percentage of PVC artificial leather product. The consequential metric is production cost.
3) Objective statement: Improvement the weight-loss percentage of PVC artificial leather product after testing to pass at 5% maximum by using Six Sigma.
4) Project scope: Study on PVC artificial leather product of A model only.

B. Measure Phase (M)

This phase consists of two main steps, including measurement method and measurement system analysis.
1) Measurement method

After clarifying problem identification, the weight-loss percentage value of PVC artificial leather product required to improve in this research. The weight-loss percentage value can be detected by the analytical balance and equation shown in (1).

\[
\text{Weight – loss (\%)} = \frac{\text{Mass before heating} - \text{Mass after heating}}{\text{Mass before heating}} \times 100
\] (1)

Figures 1. PVC artificial leather product crack after using the car at most 100,000 kilometers
Weight-loss test: Take 3 specimens of precisely 10 x 10 cm. Measure the mass to g. and hang three specimens whose masses were measured for 100 hours in a Geer oven aging tester at a temperature 120±2 °C. After removal, let them stand for at least 1 hour at a temperature 20±2 °C and relative humidity of 65±5%. Measure the masses again.

2) Measurement system analysis (MSA).
Measurement system analysis [1], [5]. In this measurement system analysis, there is a need to analyze the accuracy of the measurement system. According to the test results show in Fig. 2 which consist of 3 staff analyze, 10 samples and 2 replicates of repeatability and reproducibility of the weight-loss percentage of PVC artificial leather products.

![Gage R&R (ANOVA) Report and measurement system variance components result.](image)

The results of measurement system variance components [6], [7] shown that the part-to-part variability is 99.94% and total gage R&R is 0.06%. It was clear that 3 staff were passed by testing criteria of MSA, which concluded that the measurement is acceptable.

C. Analyze Phase (A)
The purpose of analyzing phase is to determine the root cause of the problem from PVC artificial leather product of the weight-loss percentage of greater than 5% after understanding all process and clarifying the problem definition. All possible causes were addressed by brainstorming with team members who have experiences in the calendering process shown in Fig. 3.

The next step of root cause analysis shown in Fig. 4 is to determine the high related factors which directly affect to PVC artificial leather product of the weight-loss percentage greater than 5% by using Failure Mode and Effect Analysis (FMEA) [8].

![Figure 3. Cause and Effect diagram [1] of PVC artificial leather product of the weight-loss percentage of greater than 5%](image)

The design of experiment (DOE) [9] is applicable in the last step of analysis phase to verify that selected factors from FMEA [5] are statistically significant effect to the weight-loss percentage value of PVC artificial leather. To find the optimal parameter setting for improvement and control the next step. The 2 factors selected from the FMEA to experiment are listed in Table 1 including the production temperature of the calendering process and plasticizer type.

The experimental design conducts 2 influenced factors with 3 level listed in Table 1 by applying the face-centered central composite design (CCF), the response surface methodology and optimize response variable from several influenced factors [9]. Then finding the optimal parameter for improvement. The response variable of this experiment is the weight-loss percentage measured by analytical balance.

| Factors and Levels for Face-Centered Central Composite Design (CCF). |
|---------------------------------------------------------------|
| Factors          | Level |
|------------------|-------|
| Production Temp  | -1    | 0    | 1    |
| Calendering temp  | 100   | 173  | 178  |
| Plasticizer Type | 1     | 2    | 3    |

The design selection for the experiment is in place to analyze the following list in Table 1. The experimental result has been done and analyzed statistically by Minitab in Fig. 5. The test result from ANOVA [9] represents 3
main effects of influenced factors are significant including a plasticizer, temp. 1 (calendering roll temp. 1) and temp. 2 (calendering roll temp. 2) observed by P-value less than 0.05 in Fig. 5. Regarding the two-way interaction, it shows that interaction of Plasticizer*Temp 1, Plasticizer*Temp 2, Plasticizer*Temp 3 and Temp 2*Temp 4 are also significant. The interaction plot shown a middle level of plasticizer (type 2) and increasing temperature (temp. 1, 2 and 3) in production can be decreased weight-loss percentage. The interaction plot of Temp 2*Temp 4 shown a middle level of temp. 2 (168 °C) and increasing temp. 4 in production can be decreased weight-loss percentage. On the other hand, the weight-loss percentage can be decreased when a high level of temp. 2 (173 °C) is applicable whereas temp. 4 is a middle level (152 °C). There are four residual plots shown in Fig. 5, including residuals are normally distributed, residuals are statistically independent and residuals have a constant variance which can be observed by the normal probability plot, residual versus order plot and fitted plot respectively.

**Analysis of Variance α = 0.05**

| Source          | DF | Adj SS    | Adj MS    | F-Value | P-Value |
|-----------------|----|-----------|-----------|---------|---------|
| Model           | 10 | 70.8767   | 7.0877    | 127.37  | 0.000   |
| Linear          | 5  | 11.9594   | 2.3919    | 42.98   | 0.000   |
| Plasticizer     | 1  | 5.5869    | 5.5869    | 100.43  | 0.000   |
| Temp 1          | 1  | 5.3901    | 5.3901    | 96.86   | 0.000   |
| Temp 2          | 1  | 0.8493    | 0.8493    | 15.26   | 0.001   |
| Temp 3          | 1  | 0.0220    | 0.0220    | 0.40    | 0.536   |
| Temp 4          | 1  | 0.1089    | 0.1089    | 1.96    | 0.176   |
| Square          | 1  | 54.8592   | 54.8592   | 985.82  | 0.000   |
| Plasticizer*Plasticizer | 1 | 54.8592   | 54.8592   | 985.82  | 0.000   |
| 2-Way Interaction | 4 | 4.0583   | 1.0146    | 18.23   | 0.000   |
| Plasticizer*Temp 1 | 1 | 3.1329   | 3.1329    | 56.30   | 0.000   |
| Plasticizer*Temp 2 | 1 | 0.8364   | 0.8364    | 6.05    | 0.023   |
| Plasticizer*Temp 3 | 1 | 0.2809   | 0.2809    | 5.05    | 0.036   |
| Temp 2*Temp 4   | 1  | 0.0380    | 0.0380    | 5.54    | 0.028   |

**Model Summary**

- R² = 0.71
- R² (adj.) = 0.61
- R² (pred.) = 0.56

![Figure 5. ANOVA, residual and interaction plots.](image)

**D. Improve Phase (I)**

According to the result from ANOVA in Fig. 5, three factors significantly influence the weight-loss percentage of PVC artificial leather product including a plasticizer, temp. 1 and temp. 2. In finding the optimal setting for minimum weight-loss percentage, further data analysis is required to be done by the same experimental design of 5 factors to reduce weight-loss percentage and improve the calendering process. The result of the experiment was statistically analyzed that can be demonstrated the new optimal setting for 5 parameters shown in Fig. 6. Therefore, the calendering process should set up optimal conditions for solving the issue as follows: setting the plasticizer of PVC artificial leather product to be type 2 and setting production temperature including calendering roll temp.1 at 173 °C, calendering roll temp.2 at 168 °C, calendering roll temp.3 at 159 °C and calendering roll temp.4 at 157 °C.

![Figure 6. Optimal parameter setting for the calendering process.](image)

**E. Control Phase**

After applying new condition into production. In this phase will represent the process capability (Cpk) [5], [10] result of weight-loss percentage after improvement compares with before improvement in Fig. 7. After improved found that process capability increase to be 7.66 by reducing the mean of weight-loss percentage and variation of the process.
Figure 7. Process capability comparison before and after improvement.

From result monitoring of new lots after setting a new condition is shown in Fig. 8. This can be a conclusion that the weight-loss percentage of PVC artificial leather product in the calendering process less than 5% all lots, which it pass significantly as OEM specification all lots. Also, update the control plan and train operator as new condition setting for control of the critical point to ensure adequate controls are in place to prevent recurrences.

III. CONCLUSION

The case study company founded that the weight-loss percentage of PVC artificial leather product produced by the calendering process was greater than 5% which did not pass the specification of original equipment manufacturer (OEM) given at 5% maximum. The major problem came from the PVC artificial leather product was cracked before the warranty period of cars was ended (less than 100,000 kilometres). The five phases (DMAIC) of Six Sigma were adopted to reduce the weight-loss percentage of PVC artificial leather products and improve the production process. The design of experiment (DOE) was used to find significant factors and optimal parameter setting for the improvement and control in the calendering process. After the improvement of the weight-loss percentage of PVC artificial leather product by setting appropriate parameters and implementing the control plan to the calendering process, the result shown that the weight-loss percentage reduced to 0.9% in average (less than 5%).

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Ruttanaporn Leruk design experiment, conducted the research, analyze the data and wrote the full paper. Prof. Parames Chutima, Ph.D. (corresponding author) assisted in discussion part of this research and the writing stage of the full paper. All authors had approved the final version.

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