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Reduction of Variation in Tensile Strength of Tissue Paper

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Abstract: - This paper presents a method to reduce variation in the tensile strength of tissue paper. The Central Composite Experimental Design with the use of regression and optimization techniques was proposed to determine the optimal setting of the refiner load and the dry strength chemical addition rate. It was found that the target tensile strength of 1950 gf/in^2 could be obtained by setting a refiner load and a dry strength chemical addition rate at 34.12 ampere and 2900 cc/minute respectively. Once the operators knows the optimal setting, the over adjustment is reduced, leading to a lower variation in the produced tensile strength.

Keywords: - *Tensile Strength, Tissue Paper, Variation Reduction, Experimental Design*

I. INTRODUCTION

Tensile strength is the most important characteristic of tissue paper. There were several research works on the improvement of the strength of paper. Adding dry strength chemical such as starch to the stock during the stock preparation process helped improve the strength of paper [1]. Another method was to use refiner machine to press the stock with the plate inside to generate across-link between fibers [2], [3].Wet pressing and drying were proposed as methods to improve the strength of paper since wet pressing pressed the fibers to be closer and generate a cross-link pattern [4].

Previous research presented methods to improve the tensile strength of paper. However, it is common that the tensile strength of products from the production processes has high variation and deviation of the process means from their targets. This fact is due to the improper setting of levels of the process factors. Thus, there is a need to have a systematic method to find the optimal levels of significant process factors. The optimal level can be different at different shop floors. Therefore, the method to determine the proper setting should be studied. In the tissue paper manufacturing processes, there are several process factors which impact the tensile strength. Examples of these factors are the furnish mix ratio, the refiner load, the amount of chemical usage, the crepe ratio, the moisture of tissue paper, and the pressure roll load. However, most factors are not allowed to be adjusted since it is highly possible to negatively affect other properties and also customer satisfaction. In the case study factory, there are two process factors which are adjustable. These factors are the refiner load and the dry strength chemical addition rate. This paper then presents the use of the experimental design with regression and optimization techniques to determine the optimal setting of these two process factors.

II. PROBLEM DESCRIPTION

The problem of tensile strength variation is described via a case study factory. The case study factory produces several kinds of tissue papers. A Jumbo roll tissue, which is used in commercial places for toiletries and bathrooms, had the problem in that the tensile strength of the product had high variation and also the mean tensile strength deviated significantly from its target. The process mean, the process standard deviation, the target, and the specification limits of the tensile strength of Jumbo roll tissue were presented in Table 1. These data were collected from 2,494 Jumbo rolls of tissue papers produced from April to July, 2013.

Table 1 Process mean, Standard deviation, and Specification limits before improvement

Tensile strength	Lower Spec.	Target	Upper Spec.	Mean	SD
Unit [gf/in^2]	1800	1950	2100	1962.13	122.14

Table 1 showed that the process mean of 1962.13 gf/in^{2}deviated from its target of 1950 gf/in^2. In addition, the variation of this process was significant as presented by the standard deviation of 122.14 gf/in^2. The distribution of the tensile strength data was shown in Fig. 1. It can be seen that the variation of the process was significant compared to the specification limits. There were some rolls that were out of specification limits. Thus, there was a need to adjust the process mean to the target and reduce the variation of this process.

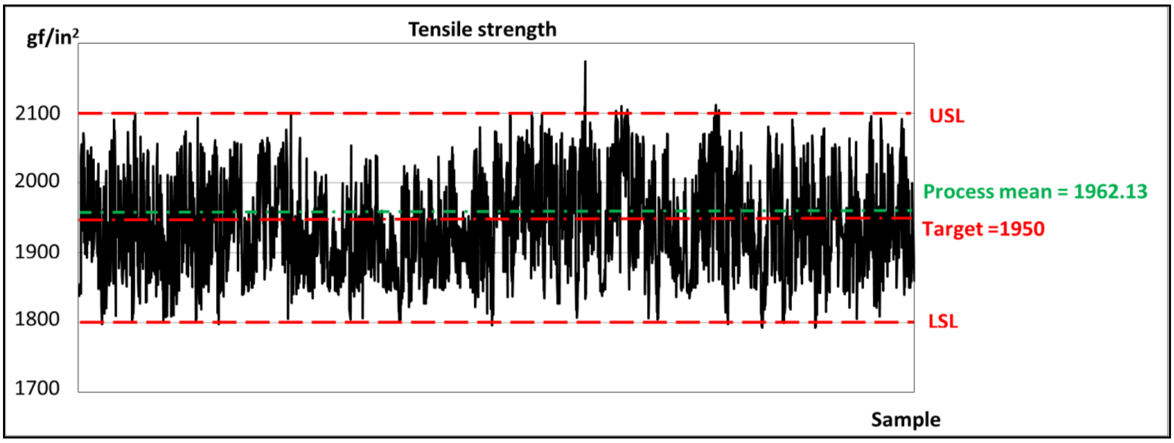

Fig.1 Distribution of tensile strength compared to specification limits

III. METHODOLOGY

An experimental design with the use of the stepwise regression technique is a method that can help find the relationship between the interested response and the factors significantly affecting the response. Then, the optimal setting of those significant factors that yield the response value closest to the target could be obtained by using an optimization technique [5], [6], [7], [8], [9], [10], [11].

In the case study factory, the refiner load and the dry strength chemical addition rate were usually adjusted within the ranges of 29 to 35 ampere and 500 to 2,500 cc/minute, respectively. Once the tensile strength deviated from its target, the operator tried to make an adjustment on these two process factors expecting to get the process back to the target. However, this over-adjustment resulted in the high variation of the tensile strength since the operators did not have enough knowledge on how much to adjust these factors. Thus, it was important to study and obtain the relationship equation between the tensile strength and these two factors. Then, the optimal levels of these two factors can be determined from the equation. It was expected that once the optimal setting was known, the process mean would be close to the target and the variation would be reduced due to the absence of the over-adjustment.

This research proposed the use of the response surface design with the Central Composite Design (CCD) type as the tool to find the quadratic relationship between the response and the factors. The CCD needed a small number of experimental runs as possible [11]. In addition, since there were two factors under the investigation, the use of other response surface design such as the Box-Behnken design was not possible. The CCD consists of three types of experimental runs [11] as follows: 1) 2^kfullfactorial runs, 2) star runs or axial runs, and 3) center point runs. The design matrix of the two factors was shown in Table 2.

Table 2 Design matrix of Central Composite Design for Two factors and Experimental results

Standard order	Run order	Refiner load: X_1 [Ampere]	Dry strength chemical addition rate: X_2 [cc/min]	Coded Unit X_1	Coded Unit X_2	Run type	Tensile strength: Y [gf/in^2]
1	2	29	500	-1	-1	Factorial run	1788
2	10	29	2500	-1	1	Factorial run	1810
3	9	35	2500	1	1	Factorial run	1804
4	3	35	500	1	-1	Factorial run	1820
5	5	28	1500	-1.414	0	Axial run	1720
6	7	36	1500	1.414	0	Axial run	1750
7	1	32	100	0	-1.414	Axial run	1693
8	11	32	2900	0	1.414	Axial run	1807
9	4	32	1500	0	0	Center run	1820
10	6	32	1500	0	0	Center run	2071
11	8	32	1500	0	0	Center run	1830

IV. RESULTS

Table 2 showed the tensile strength result obtained from each experimental run. These results were then analyzed using the Stepwise regression technique to obtain the relationship equation. The relationship between the tensile strength (Y) and the refiner load (X_1) and the dry strength chemical addition rate (X_2) was shown in Eq. 1.

$$Y = 1794 + 102X_1 + 46X_2 + 43X_1^2 \quad (1)$$

Eq. 1 showed that the refiner load had a non-linear relationship to the tensile strength, whereas the dry strength chemical addition rate had a linear relationship to the tensile strength.

Fig. 2 showed the contour plot of the tensile strength to present the effects of the refiner load and the dry strength chemical addition rate on the tensile strength. The contour plot showed that as the refiner load (X_1) and the dry strength chemical addition rate (X_2) increased, the tensile strength also increased. The combination of high levels of X_1 and X_2 provided higher tensile strength.

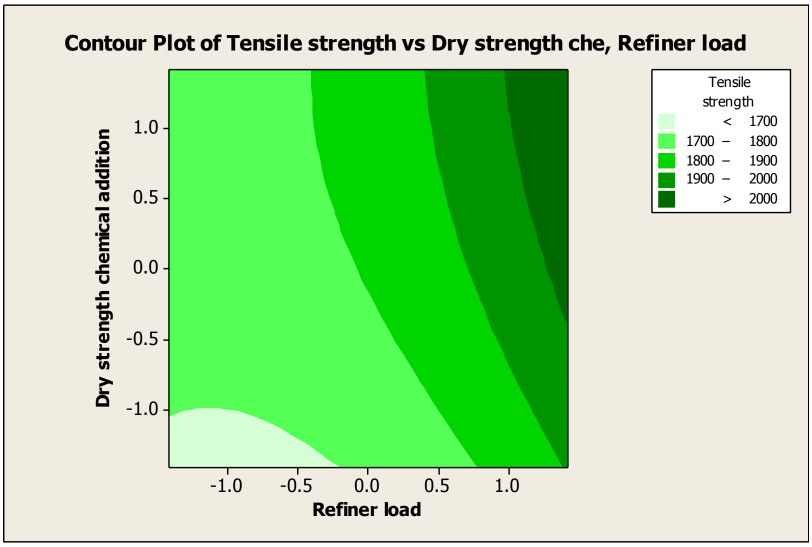

Fig.2 Contour plot of tensile strength vs. refiner load and dry strength chemical addition rate

Next, an optimization technique was conducted to determine the optimal setting of the refiner load and the dry strength chemical addition rate, which provided the tensile strength of 1950 gf/in^2. The optimization result predicted that the tensile strength of 1950 gf/in^2 could be obtained by setting the refiner load at 0.7065 in coded unit or equivalent to 34.12 ampere, and the dry strength chemical addition rate at 1.4140 in coded unit or equivalent to 2900 cc/minute.

The solution obtained from the optimization was implemented on the shop floor and 122 Jumbo rolls were sampled. Table 3 showed that based on the sampled data, the process mean of 1953.59 gf/in^2 and the standard deviation of 35.41 gf/in^2 were obtained after improvement.

Table 3 Comparison of Process mean and Standard deviation before and after improvement

Tensile strength	Lower Spec.	Target	Upper Spec.	Before		After	
				Mean	SD	Mean	SD
Unit[gf/in^2]	1800	1950	2100	1962.13	122.14	1953.59	35.41

Table 3 and Fig.3 showed that the new process mean of 1953.59 gf/in^2 was much closer to the target of 1950 gf/in^2 than before the improvement (1962.13 gf/in^2). Moreover, the variation of the tensile strength after improvement was significantly reduced from 122.14 gf/in^2 to 35.41 gf/in^2. The distribution of the tensile strength in Fig. 3 showed that after improvement, there was no roll out of the specification limits.

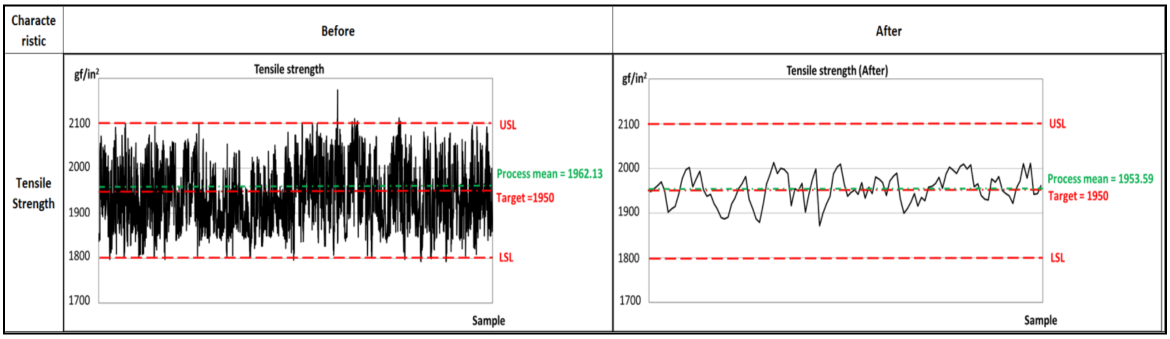

Fig. 3 Comparison of Tensile Strength Distributions between Before and After Improvement

V. CONCLUSION

The purpose of this research is to find the optimal levels of the refiner load and the dry strength chemical addition rate that provide the targeted tensile strength of tissue paper. The experimental design using the Central Composite Design (CCD) type with the Stepwise regression method was applied to find the relationship between the tensile strength, the refiner load and the dry strength chemical addition rate. Based on the relationship equation, an optimization technique was then applied for the optimal setting. It was found that the refiner load should be set at 34.12 ampere and the dry strength chemical addition rate should be set at 2900 cc/minute. Once the operators knew the optimal setting, the over adjustment was reduced, leading to a significantly lower variation and the tensile strength mean closer to the target.

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