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Appearance Defective Reduction in Nonwoven Process

Worapot Rodraksa and Wipawee Tharmmaphornphilas

Abstract—**The objective of this paper is to reduce defectives due to their appearance in a nonwoven production process. We found that this type of waste normally occurs at a spinning machine. A brainstorming process as well as knowledge from previous works are used to determine root causes, which include 4 parameter settings within a spinning machine - cabin pressure, die temperature, cooling temperature and suction speed. We used 2^{k-1} factorial design to screen parameters and Box-Behnken design to fine-tune the parameters. From the experiments, we found that only 3 parameter settings are the major causes of the problem. Cooling pressure should be set at 2660.60 Pa, die temperature should be set at 219.85 degree Celsius, and cooling temperature should be set at 29.73 degree Celsius. After implementing this solution in manufacturing, it reduces the appearance waste from 1.54% to 0.90%, which equals to 42% improvement.**

Index Terms— **Nonwoven Process, Spinning Machine, Appearance, Parameter Optimization, Box-Behnken Design**

I. Introduction

A nonwoven production process using the spun bonding method has been widely used. One of the most widely used systems is a Reicofil system shown in Fig 1. In this system, a raw material is melted in an extruder and pushed through a spinneret to create a strand. Then, the strand is cooled in a chamber by passing through cold air, which flows into the system. The cooled strand is then formed to be nonwoven fabric on a belt. The nonwoven fabric is entered a bonding process, winded, and then stored at a winder unit.

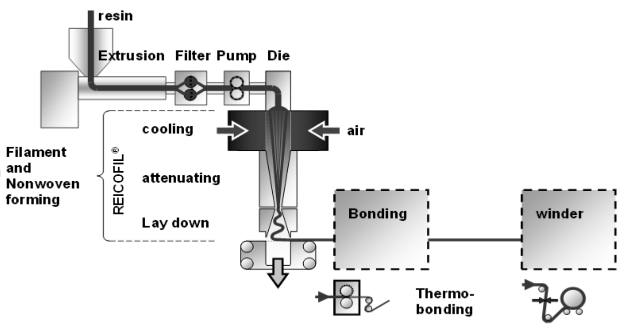

Fig. 1. Reicofil System

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Wipawee Tharmmaphornphilas is with the Department of Industrial Engineering, Faculty of Engineering, Chulalongkorn University, Bangkok, Thailand. E-mail: wipawee.t@eng.chula.th, phone no. 662-218-6829 (Corresponding author)

Worapot Rodraksa is with the Department of Industrial Engineering, Faculty of Engineering, Chulalongkorn University, Bangkok, Thailand. E-mail: potnaa@hotmail.com

II. Defectives in a Nonwoven Process

We collected data from January 2012 to March 2012 and found that defectives in the nonwoven production process can be classified into 2 main groups:

1. Appearance defectives – defectives whose appearance do not fit customer requirements.
2. Nonappearance defectives – defectives whose properties are out of specifications.

The percent defective can be calculated from the ratio between the weight of the defective baby roll and the weight of total baby roll.

Fig. 2 compares the percent defective in case of appearance versus non-appearance types among 4 product groups – 13 grams per square meter (gsm), 15 gsm, 17 gsm, and 19 gsm. The highest percentage of waste is 1.76%, which comes from 15-gsm product, followed by 1.27% from 13-gsm product. We also found that appearance defectives are consistently higher than non-appearance defectives in all product groups.

Fig. 3 shows the production volumes of every product groups. The production amount of 15-gsm product is the highest. Therefore, this paper focuses on the reduction of appearance defectives for the 15-gsm nonwoven fabric. However, the proposed methodology can be applied to other product groups as well. Appearance defectives can be classified into many types. Fig. 4 shows the Pareto chart of appearance defectives in the nonwoven process. Filament break is a major problem, followed by hole, dust, lump, others (other types of defectives) and metal respectively.

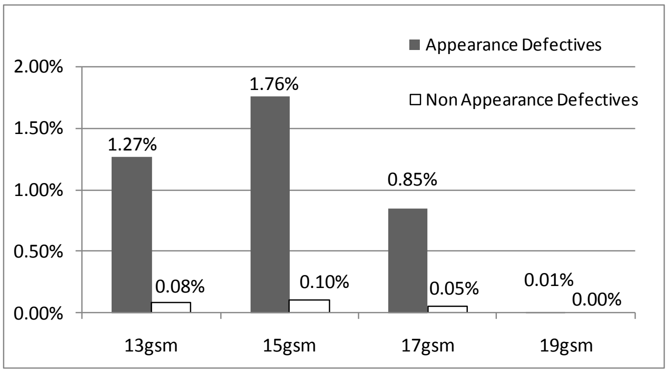

Fig. 2. Appearance versus Non-appearance defectives

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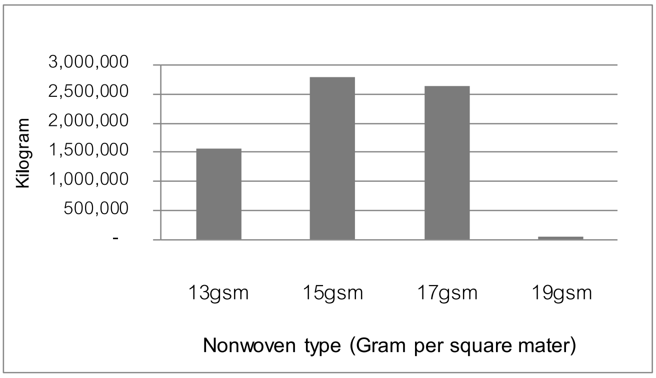

Fig. 3. Production volumes

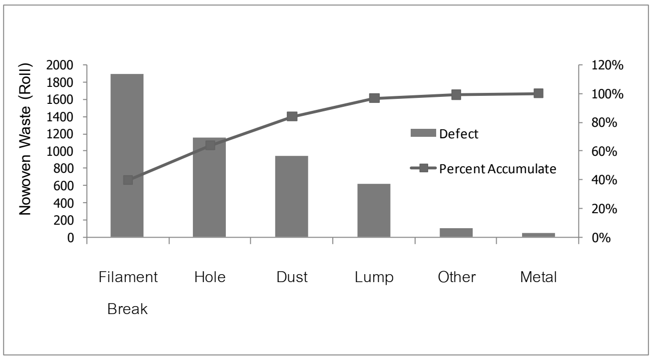

Fig. 4. Types of appearance defectives.

III. Root Cause Determination

To determine root causes of the problems, we start by brainstorming based upon 4M analyses: man, machine, material and method to develop fishbone diagrams. The brainstorming process is performed among experienced operators in the nonwoven production process to determine possible causes of filament break, hole, dust, and lump.

We found that filament break, hole and lump have common root causes. Moreover, these types of defectives usually occur due to spinning conditions. From the historical data, these problems can be solved by adjusting the same parameter condition. Therefore, we combine these three defectives as a group.

Fig. 5 shows that more than 80% of defectives come from filament break, hole and lump. Therefore, we focus on reducing this group of waste. Root causes of these problems and the numbers of occurrences of each problem are shown in Table I. The highest three causes are cabin pressure, die temperature and cooling air temperature, which are not in good settings.

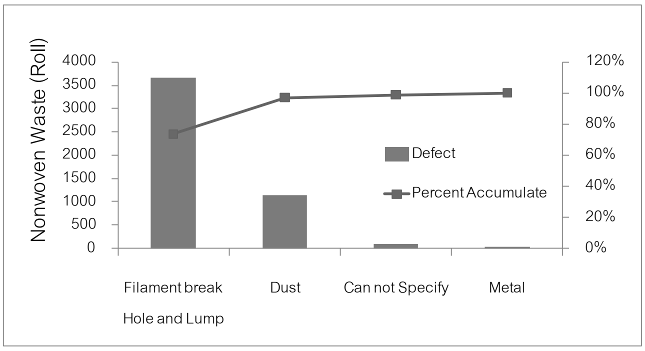

Fig. 5. Groups of appearance defectives

Table I. Root causes and frequency of defectives

	Root Cause	Filament Break	Hole	Lump
Man	Wrong adjust parameter	0	0	0
	Wrong load material	1	0	0
	No Cleaning before start up	0	0	0
	Action out of procedure	0	0	0
	Low skill of new operator	0	0	0
Machine	Die dirty	2	1	1
	Die plug or die screen dirty	5	3	0
	Chamber leak	2	0	0
	Hani comb dirty	3	1	0
	Air flow meter broken	0		
	Air pressure meter broken	0		
	Temperature out of range	2	2	3
	Spin belt dirty		5	
Material	MFI property out of specification	0	0	0
	Contamination	0	0	0
Method	Cabin pressure not suitable	43	11	8
	Die temperature not suitable	28	8	7
	Cooling temperature not suitable	37	18	16
	Cleaning point is not suitable	2	0	0
	Other	9	5	2

From previous works, Nanjundappa and Bhat [1] studied process variables on the structure and property of filament. It was found that the structure of polymer changed during the course of bonding. Also, the final structure was the result of the spinning and bonding conditions.

Jia [2] discussed two types of physical mechanisms of filament break during a spinning process - cohesive failure and capillary filament break. The capillary web break was related to surface tension and occurred less than 1%. The major cause of filament break was a cohesive failure, which occurred when the tensile stress exceeded the fiber tensile strength. Cabin pressure was a parameter that specified an amount of airflow, which affected tensile stress. An improper level of cabin pressure resulted in filament break.

Hietel [3] developed mathematical models of fiber dynamic in the spinning and laydown region. He found that fiber was stretched and changed its diameter due to viscous and rubbery conditions. He also explained that the fiber flow interaction was based on air flow, momentum and heat exchange.

Bhat and Malkan [4] explained that the filament break and spot formation on a spin belt were due to high temperature of polymer. If polymer temperature was too high at a spinning process, it would lead to filament break problem. Also, the fiber tensile strength would increase when the air suction speed increased, which leaded to lower filament break.

From the root causes analysis and previous papers, we can conclude the causes of filament break, hole, and lump as in Table II.

Table II. Summary of causes of the problem

Fishbone	Jia [2]	Hietel [3]	Bhat et al. [4]	Root causes
Cabin Pressure	Air Flow	Air Flow		Cabin Pressure
Die Temp			Melt Temp	Die Temp
Cooling Air Temp	Polymer Strength	Heat Exchange		Cooling Air Temp
			Air Suction	Suction Speed

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Fig. 6 illustrates the relationship of parameter conditions in a spinning region:

- The cabin pressure is a parameter which affects air flow. We can increase air flow in a spinning region by increasing cabin pressure.
- The die temperature is used to heat up polymer before sending to a spinning zone. In our manufacturing, an extruder temperature is fixed to prevent coke and improve the extruder lifetime. Therefore, we use die temperature to adjust melt temperature. However, it might cause polymer degradation if the temperature is set too high.
- The cooling air temperature is a used to transform melted polymer to solid polymer. The heat exchange between melted polymer and cooling air affects polymer strength.
- The suction speed is used to balance air-to-polymer during spinning process.

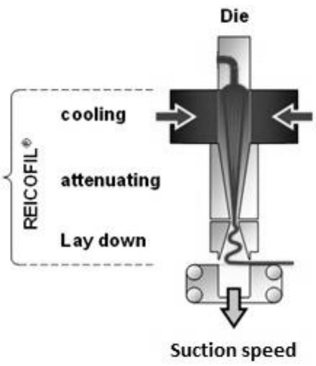

Fig. 6. A spinning region

IV. Parameter Condition Determination

From the previous section, four parameter settings are found to be major causes of the problem. To determine proper levels of each parameter, 2^{k-1} factorial design is used in a screening process [5]. Then, Box-Behnken design is used to fine-tune parameter levels. Details are discussed in the following sections.

A. 2^{k-1} Factorial Design

A single replicate 2^{k-1} factorial design including 8 experiments is applied to screen the factors. These data are analyzed in Minitab. We set the factors and factor levels as shown in Table III. There are 4 factors, which are cooling pressure (A), die temperature (B), cooling temperature (C), and suction speed (D). The total waste due to filament break, hole, and lump is used as a model response.

Table III. Factors and factor levels of 2^{k-1} Factorial Design

Factor	Unit	Level (-1)	Level (+1)
Cabin Pressure	Pa.	2400	3000
Die Temperature	Degree Celsious	215	225
Cooling Temperature	Degree Celsious	27	33
Suction Speed	rpm	1500	2100

The model adequacy checking is done before analyzing the data. The normal probability plots in Fig. 7 show that the residuals are normally distributed with p-value equals to 0.959. Since the plots of residuals against fitted values show no pattern, we conclude that the residuals are independent. The plot of residuals versus the observation order also appears random, which implies a constant residual variance. Thus, the model meets all assumptions and the analysis process can be continued [5]. The normal plot of the effects in Fig. 8 shows that only three factors, including cabin pressure (A), die temperature (B) and cooling temperature (C), are significant with a significance level of 0.05. Therefore, we eliminate the suction speed (D) in the next experimental design.

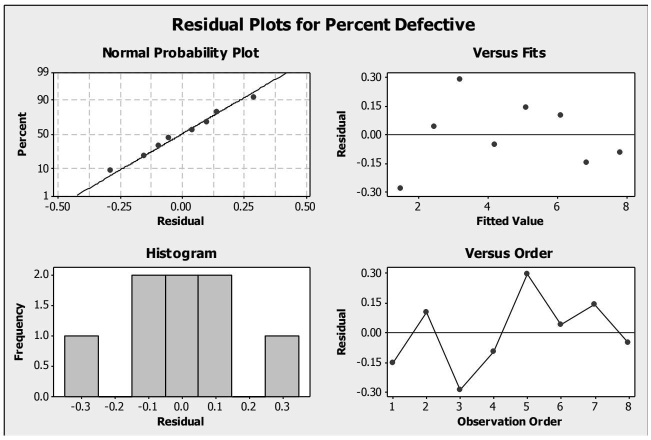

Fig. 7. Residual plots for percent defective (2^{k-1} design)

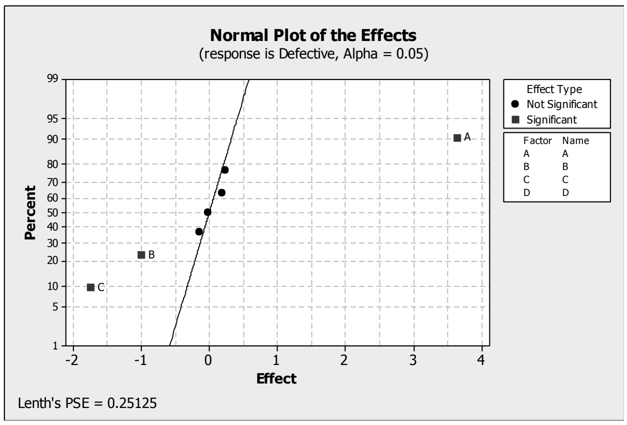

Fig. 8. Normal plot of the effects

B. Box-Behnken Design

The response surface methodology is very useful in solving the engineering issues. The Box-Behnken design is often used in the processes which are difficult or costly to run at corner points.

Aslan [6] studied a methodology for modeling of Turkish coal grinding circuits by applying the Box-Behnken design. This study proved that the Box-Behnken design and the response surface methodology could efficiently be applied to model Turkish coals grinding circuits. It was an economical way of obtaining the maximum amount of information in a short period of time and with the fewest number of experiments.

Ferreira et al. [7] described fundamental, advantages and limitations of the Box-Behnken design for the optimization of analytical methods. He concluded that the Box-Behnken was a good design for response surface methodology because it permitted: (1) estimation of the parameters of the quadratic model; (2) building of sequential designs; (3) detection of lack of fit of the model; and (4) use of blocks.

Zhu and Liu [8] optimized the extraction process of crude polysaccharides from pomegranate peel with water by applying the Box-Behnken design. He concluded that the response surface method proved to be useful for optimization of technology PPP extraction.

From the benefits of the Box-Behnken design as discussed, we applied this method to find the proper factor levels. Three factors from the screening process are considered in the experiments, including cooling pressure (A), die temperature (B) and cooling temperature (C). Fifteen experiments are performed as in Table IV, with factors and their levels shown in Table V.

Table IV. The Box-Behnken design

StdOrder	RunOrder	PtType	Blocks	A	B	C
10	1	2	1	0	1	-1
6	2	2	1	1	0	-1
14	3	0	1	0	0	0
15	4	0	1	0	0	0
9	5	2	1	0	-1	-1
13	6	0	1	0	0	0
2	7	2	1	1	-1	0
3	8	2	1	-1	1	0
1	9	2	1	-1	-1	0
11	10	2	1	0	-1	1
7	11	2	1	-1	0	1
5	12	2	1	-1	0	-1
8	13	2	1	1	0	1
4	14	2	1	1	1	0
12	15	2	1	0	1	1

Table V. Factors and factor levels for the Box-Behnken design

Factor	**Unit**	**Level 1 (-1)**	**Level 2 (0)**	**Level 3 (1)**
Cabin Pressure	Pa.	2400	2700	3000
Die Temperature	Degree Celsious	215	220	225
Cooling Temperature	Degree Celsious	27	30	33

Similar to the previous section, the model adequacy checking is performed before analyzing further results. In Fig. 9, the normal probability plot shows that the residuals are normally distributed with p-value of 0.195. From the plots of residuals against fitted values and observation order, we conclude that residuals are independent with constant variance.

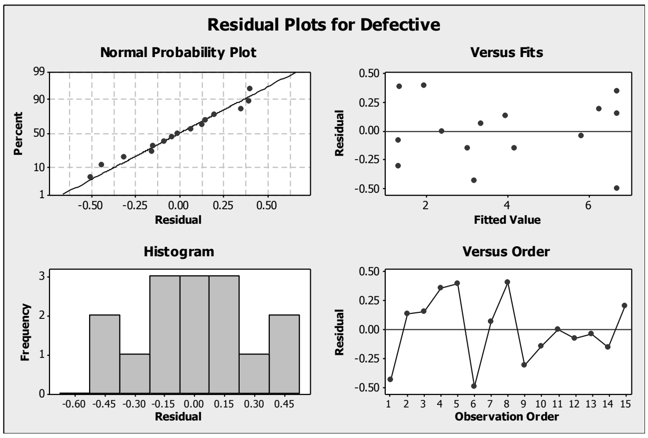

Fig. 9. Residual plots for percent defective (Box-Behnken)

The fitted response surface equation is shown in (1). The model fits with r^2(adj) equals to 0.9485.

$$Y = 5886.5967 - 0.2373 X_A - 44.3558 X_B - 46.7817 X_C + 0.0916 X_B^2 + 0.2851 X_C^2 - 0.0002 X_A X_B + 0.0011 X_A X_C + 0.1219 X_B X_C \quad (1)$$

The response surface optimization in Fig. 10 shows the most appropriate parameter levels. Cabin pressure (A) should be set at 2,660.60 Pa, die temperature (B) should be set at 219.85 degree Celsius, and cooling temperature (C) should be set at 29.73 degree Celsius. Due to the machine resolution, we set cabin pressure at 2,661 Pa., die temperature at 220 degree Celsius and cooling temperature at 30 degree Celsius. For the suction speed, it is set at 1,500 revolutions per minute.

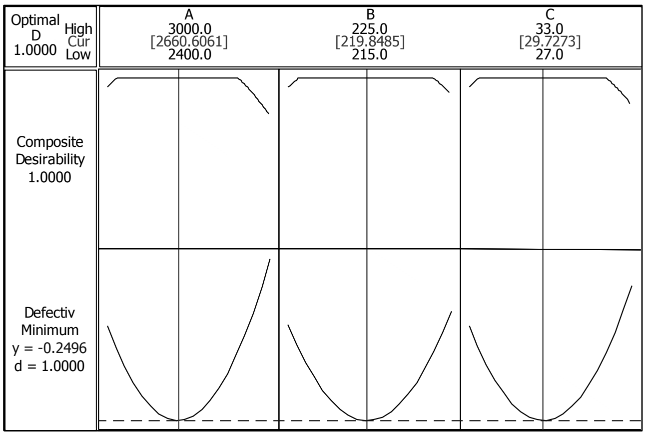

Fig.10. An optimal plot from the response surface.

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We set the most appropriate parameter levels in the nonwoven process and collected the percent defective during November to December 2012. Fig. 11 illustrates the defect rate after improvement for 15-gsm fabric. The percent defective of filament break is reduced from 2.14% to 1.26%, corresponding to 41% improvement. The percent defective of hole is reduced from 2.11% to 1.18%, corresponding to 44% improvement. The percent defective of lump is reduced from 0.38% to 0.24%, corresponding to 37% improvement. The average percent defective before implementing the solution is 1.54% and after implementing the solution is 0.90%, which equals to 42% improvement.

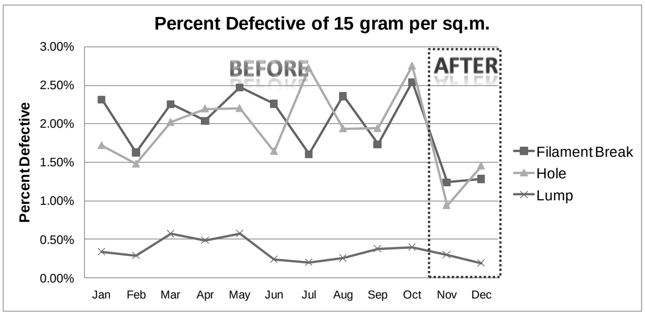

Fig.11. The percent defective of 15-gsm fabric before and after improvement.

V. Standard Work Procedure Development

The nonwoven production process operates 24 hours, 7 days. Four shifts of workforce are scheduled to cover the whole period of operating time. Currently, there is no standard work procedure to deal with the appearance defective problem. Workers solve problems based on their experience, resulting in different corrective actions among shifts.

After the proper parameter levels are determined by using our methodology, an effective corrective process is developed to standardize the work procedure. We conduct meetings among experienced workers to share and discuss alternative ways to solve the problems. Finally, we come up with the method shown in Fig. 12.

Basically, what the operators need to do in case of having hole defectives is increasing the web suction until the problems are solved. Otherwise, the operators will need to inform supervisor if the tensile strength, the elongation, or the basis weight go out of specification.

In case of filament break or lump problems, the cabin pressure must be reduced, the cooling temperature must be increased if filament break occurs and the cooling temperature must be decreased if lump occurs, or the die temperature must be increased until the problems are solved while the tensile strength, elongation, or basis weight must be maintained within their specifications. For example, for a 15-gsm fiber, the tensile strength must be kept within 10-20 N/25mm, the elongation must be between 25-75 %, and the basis weight must be between 13.5 – 16.5 g/m^2.

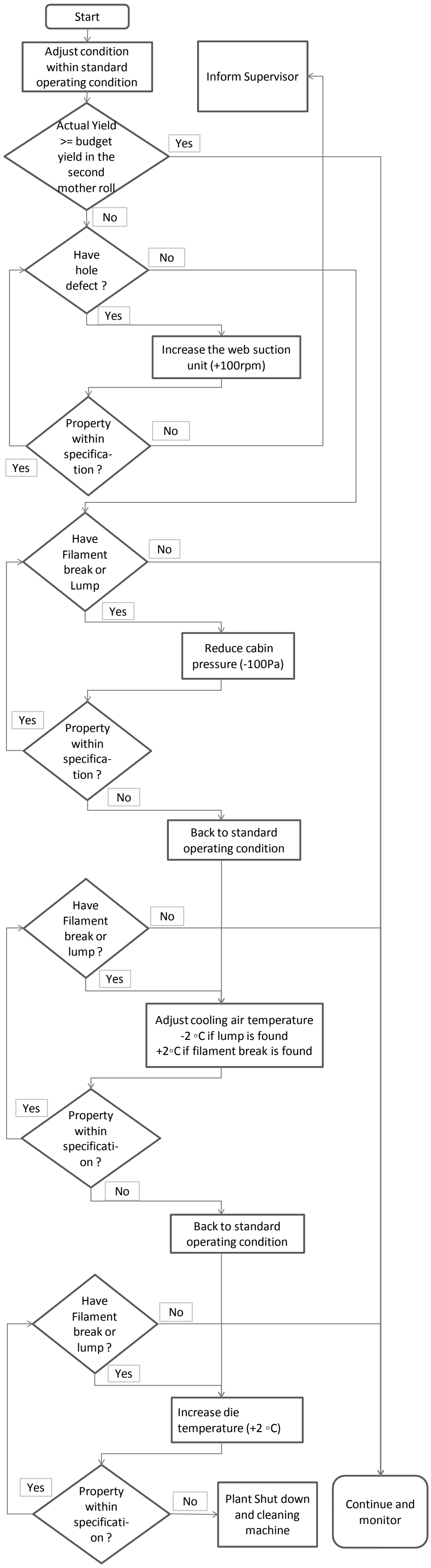

Fig.12. Standard Work Procedure

VI. Conclusion

The waste occurring the most in the nonwoven production process comes from appearance defectives, which is around 95.4% of the total waste. It was found that filament break, hole and lump are the major appearance problems. Brainstorming techniques as well as knowledge from previous literatures are used to define root causes of the problem. A 2^{k-1} experimental design is used to screen factors, and it was found that the cabin pressure, the die temperature, and the cooling temperature, are the significant factors. Then, the response surface techniques are developed to determine the optimum levels of these parameters – the cabin pressure is 2660.60 Pa, die temperature is 219.85 degree Celsius, and cooling temperature is 29.73 degree Celsius. Moreover, the standard work procedure for correction process is developed based upon the operators' experience to deal with the appearance defective problem.

After implementing the solution, the average percent defective is reduced from 1.54% to 0.90%, which equals to 42% improvement on average.

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