

# REDUCTION OF COLOR VARIATION DEFECTS IN POLYESTER DYEING PROCESS

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**Abstract**— This research presents a methodology to reduce color variation defects in the polyester dyeing process. Color variation is the most prevalent defect found in the case study. Failure Mode and Effect Analysis (FMEA) and Fishbone diagram are used to analyze root causes and prioritize the causes. The pretreatment process and the dyeing laboratory are the early steps of dyeing process. The improvement in these stages has significant effects on reducing process variation which leads to color variation defects. The result shows that the percentage of color variation defects is reduced from 20.61% to 17.32%.

**Index Terms**— Failure Mode and Effect Analysis, Fishbone diagram, Defect reduction, Polyester dyeing process.

## I. INTRODUCTION

A dyeing process is a value-added treatment for textile materials. It is the transference of dyes from the aqueous solution onto a fiber surface, where it then diffuses into the fiber. One of the most commonly occurring dyed fabric defects in the textile dyeing industry is color variation, which causes huge annual losses of profits [1]. Similarly, the highest percentage of defects in the case study presented is color variation. Different factors that may influence this type of defects include fiber kind, yarn or fabric structure, dyes, chemical auxiliaries, technology, and process conditions during the pretreatment and dyeing process. In addition, before starting bulk production, dyeing is performed in a dyeing laboratory, and this plays a major role in controlling the quality of raw materials, shade matching, and detaching the characteristics of the dyes and chemicals used in the large scale of production. The pretreatment process and the dyeing laboratory are the upstream stages of dyeing process, which means that the downstream stages depend on effectiveness and efficiency of these stages. This research focuses on the improvement of upstream stages for reducing causes which lead to the color variation defects.

In today's highly competitive global market, quality of products, quick response, and low price are crucial issues in customer satisfaction in products and services. Many companies have adopted quality improvement methods in order to eliminate defects and process variation, resulting in more certainty, less reworking, better quality, and lower costs. FMEA is one of the most popular methods used to identify, prioritize, and eliminate potential failure modes in products and processes.

Failure Mode and Effect Analysis (FMEA) is a proactive analysis tool, which is used to identify, prioritize and eliminate possible failures in processes. FMEA is also an inductive approach to support risk

assessment studies. The principle of FMEA is to identify potential hazard along with focused system and to prioritize the required corrective actions or strategies [2]. FMEA is initiated by the United States Army in 1949 and is firstly introduced into the aerospace industry in 1960s. FMEA is then improved by automotive industries for designing and developing products and processes. The proper usage of FMEA provides several benefits to the users. The benefits of FMEA are as follows [3];

- Improves reliability and quality of process and product
- Increases customer satisfaction
- Early identification and elimination of potential failure modes of product and process
- Prioritizes deficiencies of product and process
- Captures the collective knowledge of a team
- Emphasizes on problem prevention
- Documents and tracks risk reduction activities
- Focuses on improved testing and development
- Fewer late changes and associated costs
- Catalysts for teamwork and idea exchange between functions

FMEA is used to determine the effects of failure modes and identify possible actions which will prevent any potential failure modes. Each potential failure mode is assessed relative to three criterion scales: severity, occurrence, and detection. The three scales for each potential failure are multiplied together to produce the combined rating known as the risk priority number (RPN). The highest value indicates that it is a serious situation and needs immediate actions [4]. Today, FMEA is widely applied to many industries such as waste management [5], food [6], health care [7], and fiber manufacturing [8]. Moreover, some researches have integrated different analysis tools with FMEA to support more effective analysis especially fishbone diagram. For example, application of a fishbone diagram to group a list of potential problems of spindle collect damage places them into categories and then using FMEA to prioritize and select the causes with the highest RPN

[4] or application in spindle motor assembly process to reduce hub flange height defects which are not within specifications [9].

The applicability and effectiveness of FMEA and fishbone diagram have been proven by researches. Thus, this study aims to reduce the percentage of color variation defects, the major defect found in the case study, by using a fishbone diagram and FMEA to solve the problems in the upstream stages of dyeing process.

## II. METHODOLOGY

This study focuses on applying FMEA and fishbone diagram to analyze the root causes of color variation defects and conducts by 7 steps as follows:

### A. Process study

The process is studied through observation, conversation with experienced workforce and by studying handbooks and previous research. The current polyester dyeing process in the case study is shown in a detailed process map in Fig. 1. The polyester dyeing process starts with preparation process. The next stage is scouring process which is the process to remove all types of impurities. Subsequently, the fabric is set with heat and then inspected for width and density. The weight of the fabric meeting the standard is reduced for a soft hand feel and sent a sample to the dyeing laboratory in order to test it for confirming recipe of bulk production. Next is the dyeing production which is operated by jet dye machine. After that, water is removed from the fabric and then opened. The next stage is finishing process which is the process to improve the appearance, properties and quality of fabric. Before being packed and sent it to the customers, the product quality is checked by quality control employees.

As a result of the process study, it is found that the textile factory case study has many defects that occurred in the polyester dyeing process, causing a huge annual loss. The defect data in the process are gathered by observing the process for a period of one year to determine the magnitude of the types of defects. A Pareto chart of the prioritized defect types is developed as displayed in Fig. 2. This study calculated the percentage of defects by using (1). Fig. 2 illustrates the color variation with the highest percentage of defects. Thus, this study selects this defect for improvement.

$$\% \text{Defect} = \frac{\text{Number of Defects (batches)}}{\text{Number of production orders (batches)}} \quad (1)$$

The upstream stages which include the preparation process, the pretreatment process and the dyeing laboratory significantly influence the quality of products and the performance of downstream stages.

Thus, the research emphasize on improvement in upstream stages in order to find the causes that lead to color variation defects.

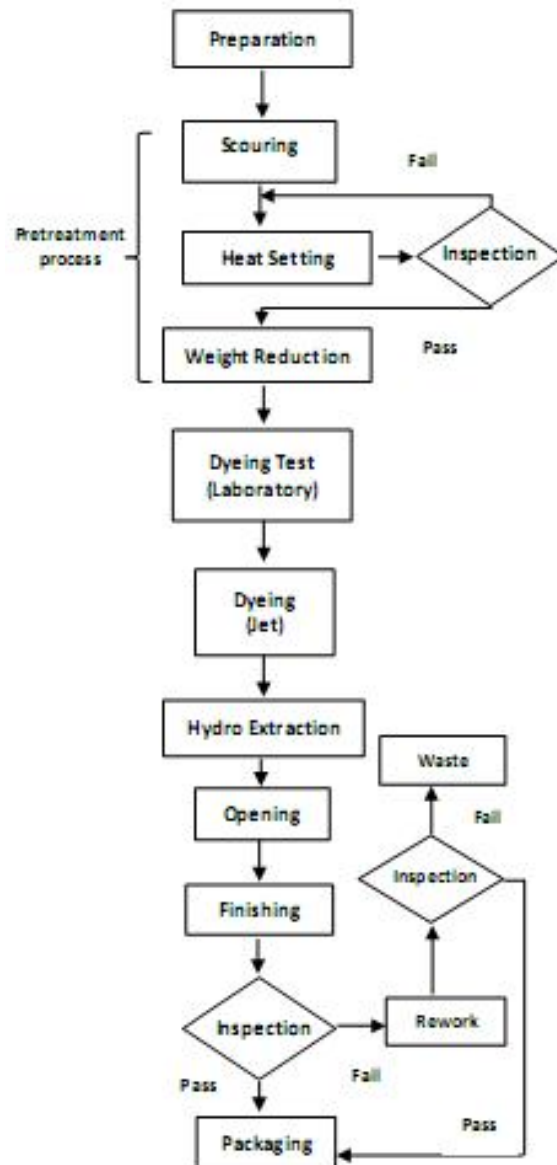


Fig. 1 polyester dyeing process flow in the case study

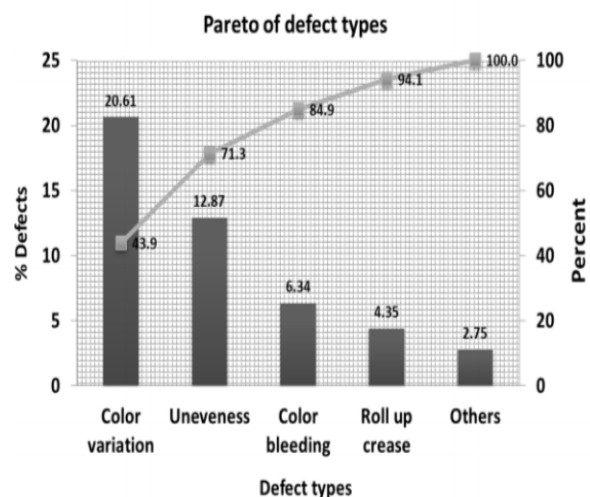


Fig. 2 Pareto chart of defect types

### B. Setting up a team

The team approach consists of multidisciplinary people who have experience or knowledge about the process and the product. The team includes a production manager, a production assistant manager, a laboratory supervisor, a pretreatment process supervisor, and a dyeing process supervisor.

### C. Build criteria of severity, occurrence and detection to calculate risk priority number (RPN)

The FMEA criteria of AIAG are commonly used in automotive and electronics industries [8], but there are no FMEA criteria particularly developed for the textile industry. Some current FMEA criteria are not appropriate for processes and products of this case study of the textile company. Accordingly, the team has modified the rating scales to be properly used in this case study, as shown in Table I-III.

### D. Brainstorm and list potential failure modes and causes

Next, a fishbone diagram is integrated with FMEA to analyze the causes of failure in order to illustrate the relationship between a given outcomes and factors influencing it. The team brainstorms all the potential causes of failure in the case study. The team members bring a list of ideas to the meeting. These ideas are grouped into categories by using the fishbone diagram. The causes are divided into four categories: man, machine, material, and method as shown in Fig. 3 and then the failure modes and the causes from the fishbone diagram are tabulated in Table IV. Table IV shows that there are nine potential failure modes and ten causes which lead to color variation defects.

### E. Rate the severity, occurrence and detection

This step assigned effects by the team for severity (S), the causes of occurrence (O), and current controls for detection

(D) in Table IV based on the rating scales as shown in Table I-III.

### F. Calculate the risk priority numbers (RPN) and prioritize

The risk priority numbers (RPN) are calculated for each cause by multiplication of the severity rating, the occurrence rating and the detection rating and then prioritized the values which are the results of multiplication. The potential failure modes with the higher RPN values which are considered serious situations and needed immediate actions toward them thus, they will be selected to solve.

### G. Identify and implement the corrective actions

In this study, all of the causes are presented in Table IV but only those with the highest RPN values are identified and appropriate corrective actions are taken. After the implementation is completed, the team concludes the FMEA process by reassigning S, O, and D and recalculating the RPN values.

Table I  
Severity rating scale for effects to failure

Scale	Description	Criteria
5	Very high	Failure results in major effects on product quality. Products cannot rework or process of rework products spend more than 6 hours
4	High	Failure results in major effects on product quality. Process of rework products spend 1-6 hours
3	Moderate	Failure results in minor effects on product quality. Process of rework products spend less than 1 hour
2	Low	Failure results in slight effects on product quality. Products do not rework.
1	None	No effects on product quality

Table II  
Occurrence rating scale for causes of failure

Scale	Description	Criteria
5	Very high	Very high probability of occurrence (> 50% of production orders)
4	High	High probability of occurrence (31-50 % of production orders)
3	Moderate	An occasional probability of occurrence (11-30% of production orders)
2	Remote	A remote probability of occurrence (1-10% of production orders)
1	Unlikely	An unlikely probability of occurrence (<1% of production orders)

Table III  
Detection rating scale for current controls

Scale	Description	Criteria
5	Very low	Very low (or zero) probability that inspection will detect a potential cause and failure mode
4	Low	Low probability that inspection will detect a potential cause and failure mode
3	Moderate	Moderate probability that inspection will detect a potential cause and failure mode
2	High	High probability that inspection will detect a potential cause and failure mode
1	Very high	Very high probability (or almost certain) that inspection will detect a potential cause and failure mode

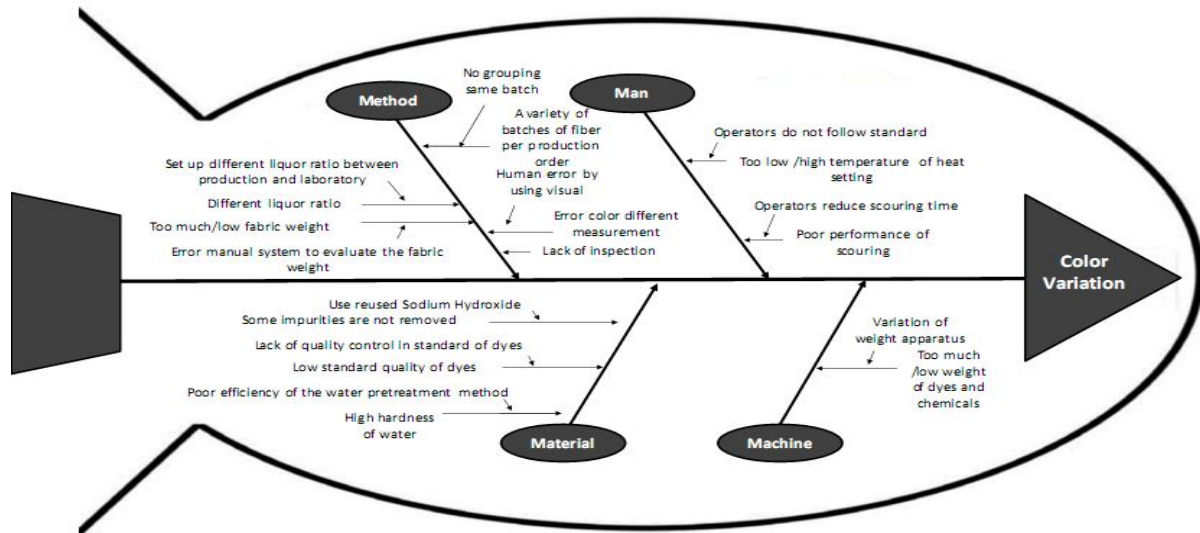


Fig. 3 Fishbone diagram of color variation defect

### III. RESULTS AND DISCUSSION

The team brainstorms to list out all potential failure modes, failure causes, and detection methods according to each process, the RPN values are marked in Table IV. Table IV shows the RPN values of nine failure modes which have ten failure causes in the preparation process, the pretreatment process, and the dyeing laboratory. There are five causes with the highest RPN that are selected to improve for reducing color variation defects. After the corrective actions are completed, the team reassigns S, O, and D and then recalculates the RPN values. The RPN values are reduced as shown in Table IV and the percentage of color variation defects is reduced from 20.61% to 17.32%.

The corrective actions are implemented in the scouring process and the dyeing laboratory as follows:

#### A. In pretreatment process

From the FMEA, the first cause, selected to improve is color difference measurement. Color measurement of this company using visual of dyeing laboratory employees has many variations, since each individual has the ability to interpret colors at a different level. On the other hand, the spectrophotometer, which is a device to measure color and express it in a numerical data forms, is the instrument used by many companies to measure color. Thus, the solution is to apply the spectrophotometer to measure the color of sample to confirm the recipe of bulk dyeing production. Using the spectrophotometer spends more time than visual of employees, but it performs the inspection task with higher accuracy.

The second improved cause is poor performance of scouring; impurities are still found in the fiber after process. The impurities have a variety of sources;

polyvinyl alcohol (PVA), polyacrylic acid, lubricants, and other impurities. These will impede the diffusion of reagents and dyes into the fiber. In the case study, the efficiency of the chemicals is one of the reasons for all impurities not being removed. The major cause of failure is sodium hydroxide (NaOH) which is one of the chemicals used in this process.

Sodium hydroxide which is used in the case study is reused solution from the weight reduction process as shown in Fig. 4. Reused sodium hydroxide has many fluffs and particles which will decrease efficiency of impurities elimination. If dyeing companies do not have sodium hydroxide recovery process as in the case study, pure sodium hydroxide will be used to reduce the occurrence of failure.

In addition, the team finds that a lack of inspection procedures after this process which causes the fabric with the impurities to not be intermediately repaired. If it is sent to the heat setting process, it is difficult to remove the impurities from the fiber after this process. The impurities contaminated the fiber will impede diffusion of reagents and dyes into the fiber, causing color variation defects. Consequently, the team decides to add two tests for PVA and polyacrylic acid after scouring process has already finished for reducing the occurrence of the poor scouring performance. These tests are not complex and expensive.

The third improved cause is the operators of the scouring process whom do not follow the standard time for scouring leaving the impurities in the fiber. To solve this problem, the supervisors should be monitoring workers and conducting a random check in the operation machine.



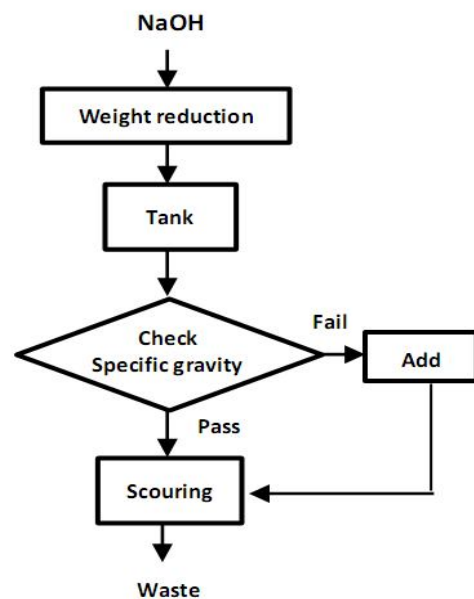
**Table IV**  
Failure Mode and Effect Analysis

Process	Potential Failure Modes	Potential Failure Effects	S	Potential Causes	O	Current Controls	D	RPN	Recommended Corrective Actions	After Implementation			
										S	O	D	RPN
Preparation	A variety of batches of fiber per production order	Dyed diffusion is variant	3	No grouping same batch	3	None	3	27	-	-	-	-	
Scouring (Pretreatment)	Poor performance of scouring	Sizes, lubricants and other impurities still are found after process. They will impede diffusion of reagent and dyes into the fiber	5	Using reused NaOH	4	Check the specific gravity	4	80	1.Using pure NaOH 2.Inspection Impurities after scouring	5	1	2	10
				Operators reduce scouring time	3	None	4	60	1.Monitoring of workers by supervisors 2.Conducting random check the operation of the machine program 3.Training the operators	5	2	3	30
	High hardness of water	The metals in water will change the shade of disperse dyes.	5	Poor efficiency of the water pretreatment method	2	Check the water hardness every day	2	20	-	-	-	-	
Heat setting (Pretreatment)	Too low /high temperature of heat setting	Inadequate the properties of yarn that affect dye ability of fiber	5	Operators do not follow standard	2	Monitoring by supervisor	3	30	-	-	-	-	
Weight reduction (Pretreatment)	Too much/low fabric weight	Dyeing recipe is variant	4	Error of manual system to evaluate the fabric weight	3	Random checking by supervisor	3	36	-	-	-	-	
Dyeing test (Laboratory)	Error of color different measurement	Dyeing recipe is variant	4	Error of measurement by visual of employees	5	Measure by experienced employees	4	80	1.Measurement by the spectrophotometer	4	1	2	8
	Too much /low weight of dyes and chemicals	Dyeing recipe is variant	4	Variation of weight apparatus	3	None	4	48	1. Calibrate weight apparatus every month 2.Training the supervisors for calibrating	4	2	2	16
	Different liquor ratio between laboratory and production	The variations of liquor ratios lead to the change in the concentration of chemicals	4	Set up different liquor ratio between laboratory and production	4	None	4	64	1.Set up same liquor ratio	4	1	1	4
	Low standard quality of dyes	Penetration of reagent and dyes into the fabrics is not good	5	Lack of quality control in standard of dyes	3	Irregularly inspect color of dyes	3	45	-	-	-	-	

*B. In dyeing laboratory*

The forth improved cause is the liquor ratio. It is the ratio of weight of the dry material being dyed to the water weight of dye bath. The variations of liquor ratios lead to change the concentration of chemicals used in exhaust dyeing process and affect shade repeatability. As a consequence, it is necessary to maintain the same liquor ratio in the dyeing laboratory to production to reduce variation. Therefore, the team sets up the same liquor ratio between dyeing laboratory and production for reducing process variation leading to color variation defects.

The last improved cause is variation of the weight apparatuses, which changes the recipe of dyeing and leads to color variation defects. Hence, the team concludes that the weight apparatuses are required to verify by internal calibration every month to improve the equipment reliability.



**Fig. 4 Sodium hydroxide flow before implementation**

**CONCLUSION**

Color variation is one of the most common defects found in the case study presented of a textile dyeing company, causing huge annual losses profits. This research presents methodology to reduce color variation defects in the polyester dyeing process. Color variation is a complex problem, since it involves many factors and processes. From a through process study, the downstream stages of dyeing process depend on the efficiency and the effectiveness of the upstream stages. This research emphasizes on improvement in upstream stages, which includes the pretreatment process and the dyeing laboratory, in order to find the causes that lead to color variation. The integration of fishbone diagram and Failure Mode and Effects Analysis (FMEA) are the adequate tools in order to prevent defects. Fishbone diagram focuses on every aspect that helps provide the causes of failure and produces a graphically visualized relationship between failure modes and causes. FMEA helps analyze and prioritize the important failure causes in order to drive further improvement. This research selected the five highest RPN values improved. After the corrective actions are completely implemented, the RPN values are reduced and the percentage of color variation defects is reduced from 20.61 % to 17.32%.

The downstream stages; the dyeing process and the finishing process in dyeing process of the case study, will be analyzed by using fishbone diagram and FMEA in future research.

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