# CHAPTER III
# RESEARCH METHODOLOGY

## 3.1 Introduction

The purpose of this study is to eliminate or reduce breakage problem in the PP-band line of the case company. To achieve the objective of this thesis, FMEA technique is employed. This chapter discusses our understanding of the methods and constraints that will yield clear, interpretable results with regards to breakage problems in the case company. Data regarding PP-band breakage was collected in the case company during study period and only one type of PP bands with highest production and breakage was selected for the study.

FMEA is the method used for identifying the causes of breakage in the case company. FMEA methodology, FMEA boundaries, PP-band process flow chart and causes & effect diagram are utilized to systematically analyze the breakage problem in the process FMEA form. Furthermore, DOE (Design of Experiment) are used to analyze the problem statistically to determine significant effects on breakage failure in the case company.

## 3.2 Failure Mode and Effects Analysis in PP-Band Production

### 3.2.1 Data Collection

#### 3.2.1.1 Data Source

The data required for using FMEA technique to solve PP-band production problem in the case company includes data of breakage failure in PP-band production line during the study period of 12 months from January to December 2004. During this study period breakages of each type of PP bands were observed both in breakage times and breakage loss as shown on table 3.1:

**Table 3.1: Data of Breakage Failure in the Study Line**

| | Year 2004 | | |
|---|---|---|---|
| PP-band Type | Rolls | Breakage (Times) | Breakage Loss (Kg.) |
| A15-18W | 6031 | 145 | 1324.57 |
| AU15-20W | 5531 | 104 | 1086.87 |
| AU15-18B | 3323 | 73 | 813.08 |
| A15-18B | 2546 | 59 | 699.58 |
| A15-18Y | 1885 | 45 | 430.01 |
| AU15-18C | 1624 | 35 | 350.77 |
| AU15-25W | 1371 | 31 | 295.72 |
| AU15-16W | 1237 | 37 | 345.43 |
| A15-18G | 940 | 22 | 226.82 |
| AU15-18Y | 812 | 19 | 191.59 |
| **Total** | **25,300** | **570** | **5,764.44** |

#### 3.2.1.2 Sample Selection

Data set employed in the research included the breakages of all PP-band type in the case company (See table 3.1). To be retained in the sample of PP-band breakage employed in this study, only one type of PP bands which has highest production and highest breakage in the study line during the study period will be selected. As a result, PP-band type: A15-18W (A grade, 15mm. of bandwidth, and length in 1,800 m. per roll in white color) is obtained as a sample for the experiment.

### 3.2.2 FMEA Methodology

**<u>FMEA Procedure</u>**

The process of conducting a Failure Mode and Effects Analysis (FMEA) is systematic. There are ten steps to follow:

- Step 1: Define the FMEA boundaries and scope of FMEA, including a description of the process under review.

- Step 2: Assemble the FMEA team consisting of a multidisciplinary group of people. Team members should include a subject matter expert, a leader, and a facilitator who understand the FMEA process.

- Step 3: Review the process by using a detailed flowchart of the process or cause and effect diagram. This flowchart will be used for the life of the FMEA.

- Step 4: Brainstorm to determine failure modes for each process step, including a review related to categories such as people, methods, equipment, materials, and the environment of the process.

- Step 5: Identify the potential causes of each failure mode at the point provides some insight into probability.

- Step 6: Identify the potential effects of each of the failures mode in terms of its impact on the performance of the product or process.

- Step 7: Assess each of the failure modes in terms of the combined severity, occurrence and ability to detect the failure.

- Step 8: Develop and prioritize strategies and action to reduce risk associated with the most significant failure modes.

- Step 9: Assign responsibility for implementing corrective actions and determine project completion date.

- Step 10: Monitor to evaluate if the risk reduction strategies have reduced risk.

### 3.2.3 The FMEA Boundaries

FMEA boundaries or scope of the FMEA will need to be clearly defined to all the team members. FMEA boundaries include a description of the process under review. The scope of FMEA in this study will concentrate on the process from mixing process through stretching process as explained in detail below:

1. Put PP (Polypropylene) no. 1102 H, Calcium and Color Master Batch (depends on product color) in the Mixer as shown in figure 3.1 below and mix its for 20 minutes.

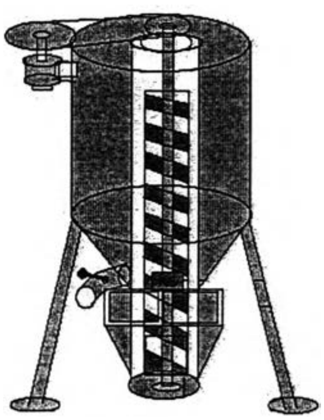


**Figure 3.1: Mixer**

2. After mixing, Hopper sucks the mixed materials out from the Mixer to Extruder as shown in figure 3.2.

3. Extruder melts the mixed materials and extrudes them through nozzle by 49, 50 and 51 rpm (for 12mm, 15mm bandwidth and heavy type respectively) into chilled water (temperature at 11 C°) in quenching bath which is used for bands setting.

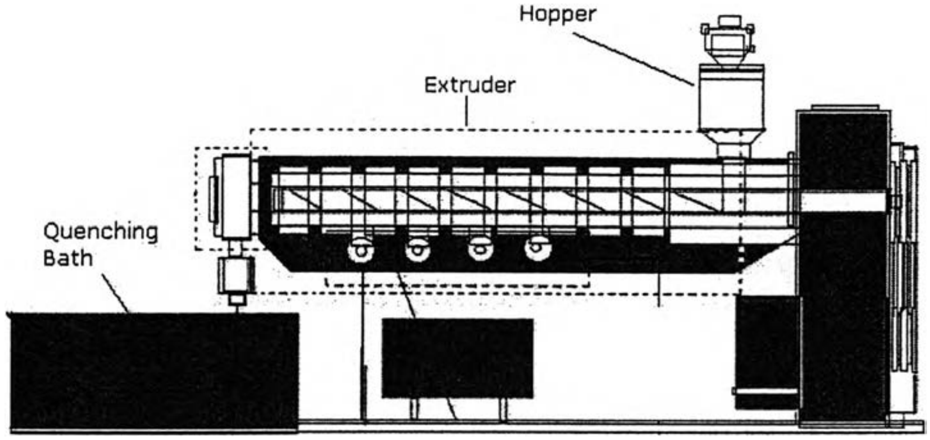



**Figure 3.2: Hopper, Extruder and Quenching Bath**

4. 1st Roller Stand (as depicted in figure 3.3) pulls PP bands out from Quenching Bath, applying for suitable speed (17 rpm) for controlling bandwidth.

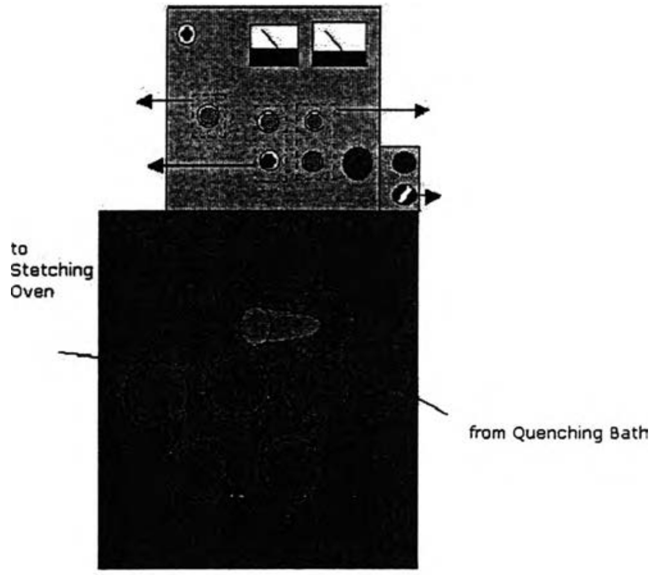



**Figure 3.3: 1st Roller Stand**

5. Stretching Oven stretches PP bands from 1st Roller Stand and using different speed of roller R1 (17.5 rpm) and roller R2 (135 rpm) in oven for stretching bands as in figure 3.4 and 3.5.

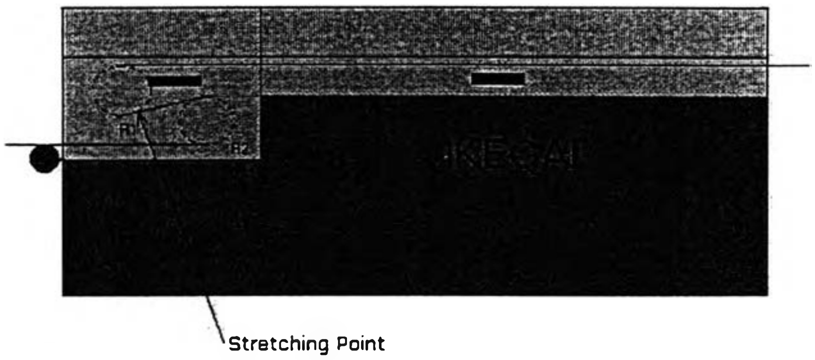



**Figure 3.4: Stretching Oven**

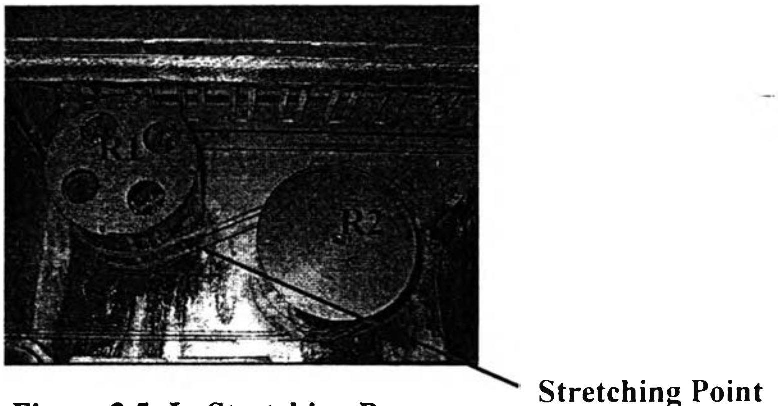



**Figure 3.5: In Stretching Process**

A clear view of FMEA boundaries can be shown in figure 3.6 below.

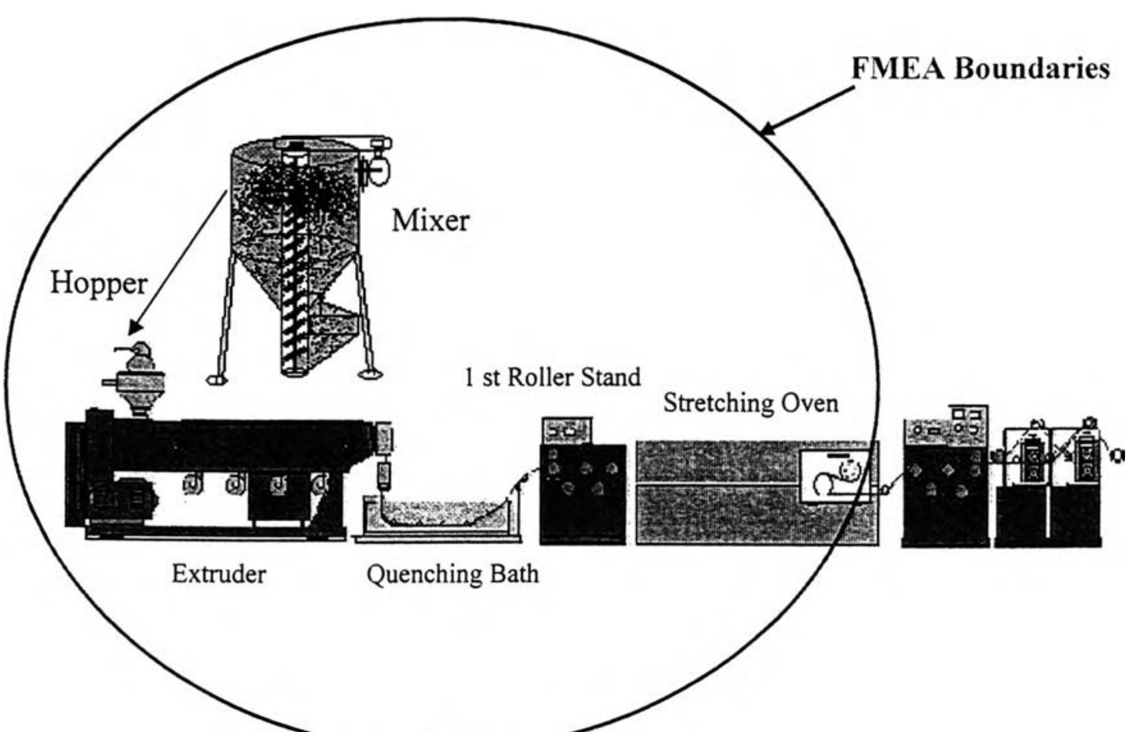



**Figure 3.6: FMEA Boundaries**

### 3.2.4 Applying FMEA

To apply FMEA technique to address the breakage problem in the research point of stretching process of PP-band line in the case company, FMEA team is formed to analyze the potential cause (s) of breakage. The researcher is a production engineer who is in charge for the production in PP-band line and he is accountable for forming a FMEA team as the team leader. The leader sets up a FMEA team from related departments such as process, maintenance and production to solve PP-band breakage problem at the stretching process. As such, FMEA team of the case company consists of the production manager, production engineer, production supervisors and line operators. Moreover, it is expected that the leader should direct, coordinate, and motivate the FMEA team members for the exchange of ideas, experience and knowledge between each function.

To solve the breakage problem in the existing manufacturing process of PP bands, the process FMEA is applied in this case in order to minimize or eliminate all possible causes and mechanisms that have impact to the breakage of PP bands in the stretching process. Standard Process FMEA form (See Appendix D) shall be used for documentation. For tracking and identification purpose, a number is assigned in the header of process FMEA form.

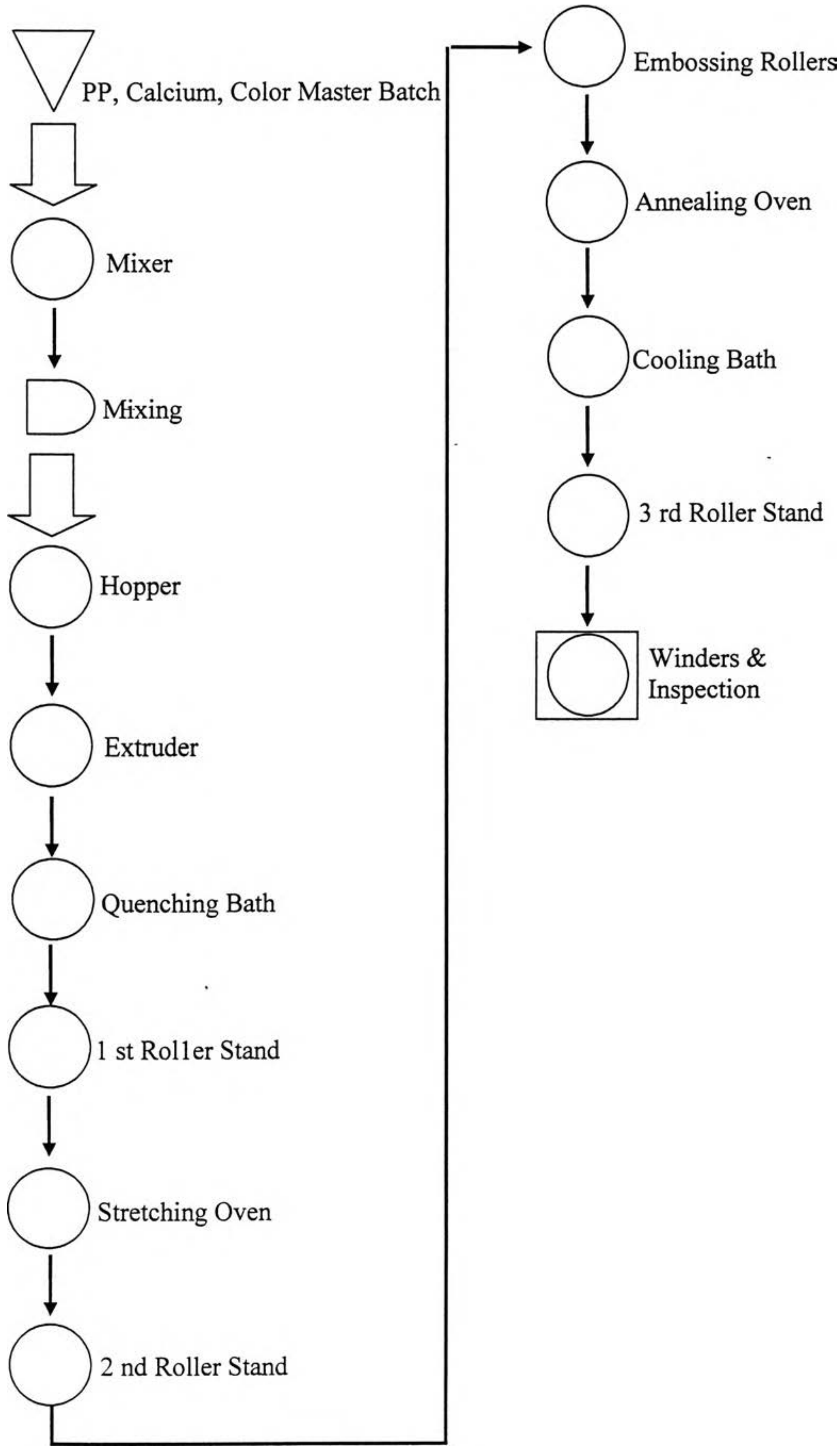
The FMEA team members will have various responsibilities. The FMEA team brainstorms to determine all potential causes of failure for each process step of stretching process that could potentially lead to PP-band breakage problem. To organize brainstorm ideas, fishbone diagram (cause and effect diagram) will be employed. Current process control and recommended corrective action for each scenario need to be filled in process FMEA form. It is important to make and assignment of responsibility and project the completion date to the appropriate member.

In addition, FMEA team is expected to assign ranking severity, occurrence and detection (See Appendix A, B and C) for evaluation criteria and ranking for Severity, Occurrence and Detection. The Risk Priority Number (RPN) which is the degree of risk of each failure is represented by the product of these 3 ranked indices. RPN value should be used to rank the concerns in the process. Special attention should be given for higher

RPN because this means the team needs to find corrective action to reduce this higher risk.

The leader of FMEA team implements corrective action to reduce the high risk failure modes according to its priority from the RPN. FMEA is a living document and never ends because new potential causes and corrective actions are updated on new FMEA revisions as the research goes on. Once the actions have been implemented, it is required for the team to continue documenting the FMEA actions for an evaluation of effectiveness as part of the FMEA documentation. Severity, Occurrence and Detection are re-assessed after these FMEA actions have been taken and revised RPN is reviewed to determined whether further actions is required. Once the team has a consensus that the FMEA does not require any changes then the FMEA file will be kept in a folder for documentation and history tracking purposes. It is important to update the FMEA as the design or process changes so that the assessment changes or new information becomes known.

### 3.2.5 PP-Band Process Flow Chart



### 3.2.6 Cause & Effect Analysis

A brainstorming session was conducted among FMEA team members to identify possible causes of PP-band breakage by applying a cause and effect diagram as illustrated in figure 3.7. Team members brainstormed to identify possible causes of breakage failures for each PP-band process step which can be categorized as follows:

Manpower: The operators may not follow Work Instruction for machine operation.

Machines: There are many potential causes that can lead to breakage including broken heaters in stretching oven, broken inverter at 1st roller stand and 2nd roller stand, inadequate air pressure at pushing bands roller. Besides, broken thermostats and magnetic at Extruder, dirty filter at Extruder before use, and dirty water in quenching bath from water tank are suspected to be the cause of breakage. Water wave in quenching bath from bad water flow system and bubbles from water pipe linkage or broken chillers may also be cause of PP-bands breakage.

Methods: The potential breakage causes from methods of operation are that operators do not follow Work Instruction in setting up temperature in stretching oven and in extruder. In addition, operator may not properly setup quenching bath, band speed in stretching oven and warm-up treatment. Oven temperature and band speed in stretching oven are another factors that can be the causes of breakage failure because the company has changed supplier for source of material to reduce material cost since the beginning of 2004. It is suspected that oven temperature and band speed should be adjusted to new value to prevent breakage problem because the current source of material is not from supplier suggested by machine vendors.

Material: Material was considered as a cause of breakage failure. PP-MI (Melted Flow Index) value and colour master batch may be out of specification.

Environment of the process: Humidity of material may be caused of breakage if storage area was set outside closed area.

Therefore, after brainstorming through the use of cause and effect diagram to determine all potential causes of breakage failure, the next task of the team is to find the factors that are mostly to be the real causes of breakage. To accomplish this, the team assigns ranking severity, occurrence and detection and calculate the Risk Priority Number (RPN) for each potential causes. Current process control and recommended corrective action for each scenario need to be filled in process FMEA form.

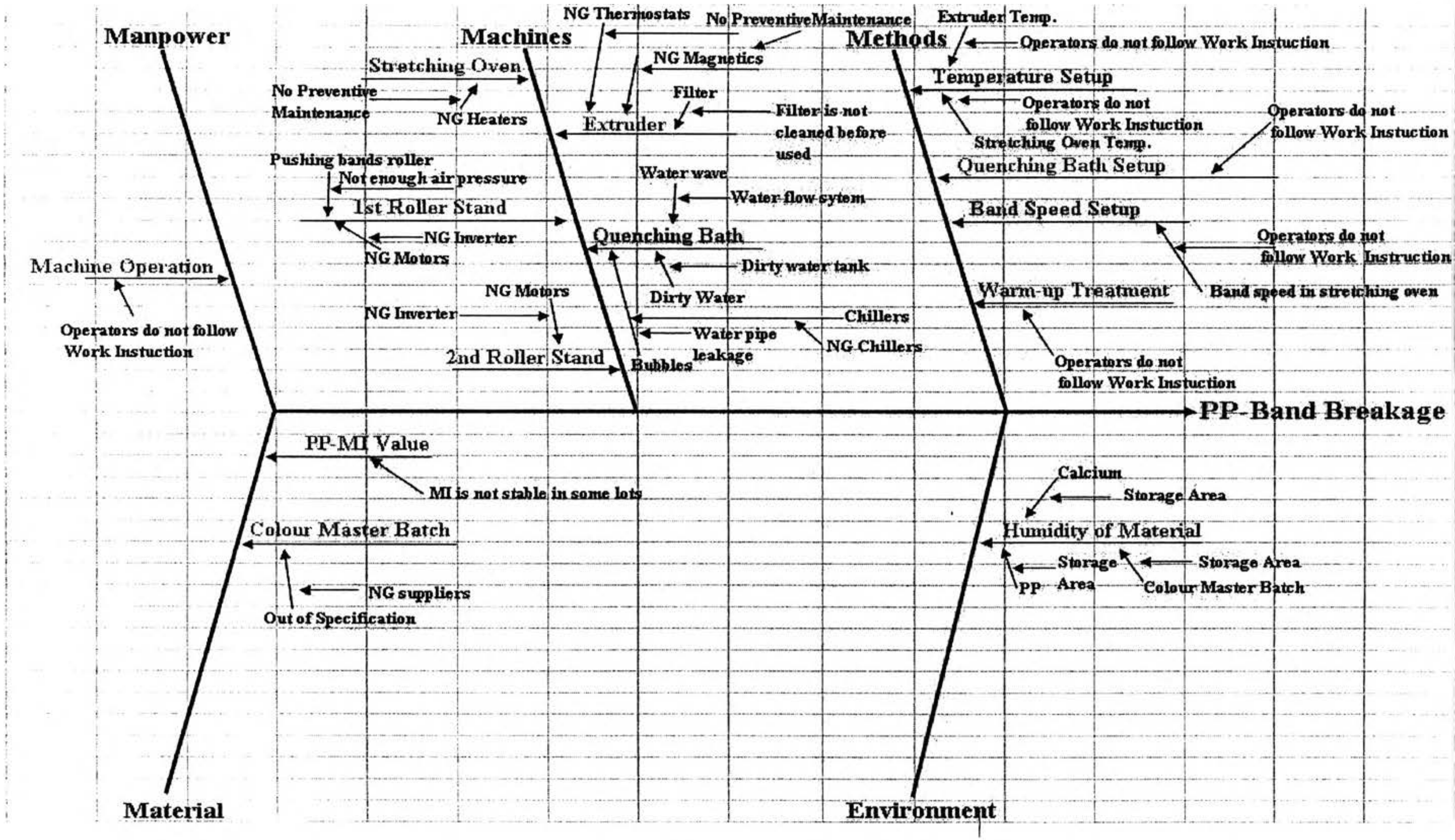



**Figure 3.7: Cause & Effect Diagram**

### 3.2.7 Process FMEA at Stretching Process

From table 3.2 (process FMEA form), process functional requirement is stretching process and the breakage that the company found is at stretching oven. Potential failure mode is breakage. PP-band breakage is the main failure of this study. Potential effects of failure are intermittent operation and scrap because the breakage failure of PP bands results in inconsistency operation and create a lot of scrap. Potential causes of failure were in the table but the high RPN belongs to bubbles in chilled water of quenching bath, oven temperature in stretching oven, and band speed in stretching oven. The team will consider only these three factors. Prevention of current process is none for these factors because the company still has no idea to prevent breakage problem.

Table 3.2 also shows that severity of effect for bubbles, oven temperature, and band speed is equal to 8 (See Appendix A). Occurrence ranking is equal to 10 (See Appendix B) and Detection ranking is equal to 8 (See Appendix C). Risk Priority Number (RPN) (8*10*8) is equal to 640. Other factors in table 3.2 the team brainstormed that they may be cause of breakage failure have low RPN. As a result, they were not considered for recommended corrective action.

Recommended corrective action is design of experiment on oven temperature in stretching oven, band speed in stretching oven and bubbles in chilled water of quenching bath to determine the effect of stretching oven temperature, band speed in stretching oven and bubbles in quenching bath on PP-band breakage. Experiment will be further conducted to determine whether there are any significant differences among temperature, speed and bubbles.

**Table 3.2: Process FMEA at Stretching Process**

**The Case Company**

Item : PP bands

Process Responsibility : Production Line

Prepared by : Sunya S.(Production Engineer)

Key Date : 07-Jan-05

Core team : PM(Production Manager),PE(Production Engineer), PS(Production Supervisors),LO(Line Operators)

**Failure Mode and Effects Analysis**

Design FMEA

Process FMEA

Service FMEA

FMEA No.PP-001

Original Date 7-1-05

Revised Date

Page 1 of 1

| Process Functional Requirement | Potential Failure Mode | Potential Effect(s) of Failure | SEV | Potential Cause(s) of Failure | OCC | Current Process Controls Prevention | Current Process Controls Detection | DET | RPN | Recommended Corrective Action(s) | Person Responsible and Target Completion Date | Action Results: Action Taken | SEV | OCC | DET | RPN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Stretching Process | Breakage | Intermittent operation and scrap | 8 | Bubbles in chilled water of quenching bath ,band speed and temperature in stretching oven | 10 | None | Surface of bands after quenching process | 8 | 640 | Use Design of Experiments (DOE) on bubbles vs. band speed vs. oven temperature | PM,PE,PS and LO/15-3-05 | | | | | |

**Table 3.2: Process FMEA at Stretching Process (continued)**

| Process Functional Requirement | Potential Failure Mode | Potential Effect(s) of Failure | SEV | Potential Cause(s) of Failure | OCC | Current Process Controls Prevention | Current Process Controls Detection | DET | RPN | Recommended Corrective Action(s) | Person Responsible and Target Completion Date | Action Results: Action Taken | SEV | OCC | DET | RPN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Stretching Process | Breakage | Intermittent operation and scrap | 8 | Machine operation | 2 | Follow Work Instruction | Bandwidth Spec. | 8 | 128 | None | | | | | | |
| | | | 8 | NG heaters in stretching oven | 1 | Regular monitor heaters | Bandwidth Spec. | 8 | 64 | None | | | | | | |
| | | | 8 | NG thermostats in extruder | 1 | Regular monitor thermostats | Bandwidth Spec. | 8 | 64 | None | | | | | | |
| | | | 8 | NG magnetic in extruder | 1 | Regular monitor magnetics | Bandwidth Spec. | 8 | 64 | None | | | | | | |
| | | | 8 | Pushing bands roller at 1st roller stand is not enough pressure | 2 | Regular monitor air pressure | Bandwidth Spec. | 8 | 128 | None | | | | | | |

**Table 3.2: Process FMEA at Stretching Process (continued)**

| Process Functional Requirement | Potential Failure Mode | Potential Effect(s) of Failure | SEV | Potential Cause(s) of Failure | OCC | Current Process Controls Prevention | Current Process Controls Detection | DET | RPN | Recommended Corrective Action(s) | Person Responsible and Target Completion Date | Action Results: Action Taken | SEV | OCC | DET | RPN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Stretching Process | Breakage | Intermittent operation and scrap | 8 | NG inverter at 1st roller stand | 1 | Regular monitor inverter | Bandwidth Spec. | 8 | 64 | None | | | | | | |
| | | | 8 | NG inverter at 2nd roller stand | 1 | Regular monitor inverter | Bandwidth Spec. | 8 | 64 | None | | | | | | |
| | | | 8 | Water wave in quenching bath | 2 | Control water flow system | Bandwidth Spec. | 8 | 128 | None | | | | | | |
| | | | 8 | Dirty water in quenching bath | 2 | Regular clean water tank | Surface of bands after queching bath | 8 | 128 | None | | | | | | |
| | | | 8 | Temperature set up in extruder | 2 | Follow Work Instruction | Bandwidth Spec. | 8 | 128 | None | | | | | | |

**Table 3.2: Process FMEA at Stretching Process (continued)**

| Process Functional Requirement | Potential Failure Mode | Potential Effect(s) of Failure | SEV | Potential Cause(s) of Failure | OCC | Current Process Controls Prevention | Current Process Controls Detection | DET | RPN | Recommended Corrective Action(s) | Person Responsible and Target Completion Date | Action Results: Action Taken | SEV | OCC | DET | RPN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Stretching Process | Breakage | Intermittent operation and scrap | 8 | Quenching bath set up | 1 | Follow Work Instruction | Bandwidth Spec. | 8 | 64 | None | | | | | | |
| | | | 8 | Warm up treatment | 1 | Follow Work Instruction | Surface of bands | 8 | 64 | None | | | | | | |
| | | | 8 | PP-MI value is out of spec. | 1 | Check PP-MI value in every lot | Bandwidth Spec. | 8 | 64 | None | | | | | | |
| | | | 8 | Colour master batch is out of spec. | 1 | Check colour master batch in every lot | Colour of bands | 8 | 64 | None | | | | | | |
| | | | 8 | Humidity of material | 1 | Storage in closed area | Surface of bands after quenching process | 8 | 64 | None | | | | | | |

## 3.3 Experiments for Determining Causes of Breakage

### 3.3.1 Design of Experiment

A design of experiment was conducted to collect information for a statistical analysis of the impact on stretching oven temperature, band speed in stretching oven and bubbles in chilled water of quenching bath. The analysis involved application of a full factorial design in order to investigate the impact of critical factors and their responses as shown in table 3.3. The desirable responses were to have maximum productivity or to have no breakage in the production process.

**Product**

PP-band type: A15-18W (A grade, 15mm. of bandwidth, and length in 1,800 m. per roll in white color) is selected as a sample for this experiment.

**Objective**

The objective of statistical analysis is as follow:

- To determine the best settings for three factors in the stretching process that will maximize productivity (no breakage) consistently.

**Factors and Levels**

An investigation begins with the identification of a broad set of candidate factors from cause & effect diagram as in figure 3.7 identified by production manager, production engineer, production supervisors and line operators through discussions and brainstorming sessions. Experimental factors and levels selected for two-level, three-factor experimental designs are shown in table 3.3. The two-level, three-factor experimental design is shown in table 3.4.

Four replicates at each factor and level setting were used to provide a good sample of PP-band breakage. The four replicates per run were taken in random order to allow estimating the experimental error and taking the variation of bubbles in quenching bath. For this experiment there were a total of eight runs (k). The greater the numbers of replicates per run make it easier to see variations in the mean. A total of 32 trials (N) run in random order. Eight (8) runs * 4 replicates per run equals 32 trials. Making the runs in random order made it possible to minimize the effects of bubbles variation, as well as other random events. A random number table was used to assign the order of each replicate run. Table 3.5 shows the replicate test order, the corresponding run and times of breakage per lot (30 rolls).

The experiments were set at the extreme low and high temperatures and speeds usable for the process. Stretching oven temperature was normally set at 230 °C for low level setting for practical economic reason. At temperature oven 290 °C will cause breakage due to overheating. Minimum and maximum band speeds in the stretching oven were 17 m/min and 19 m/min, respectively. Higher band speed was not possible because other parts of the machine cannot function properly.

Experiments were also set with and without bubbles in chilled water in the quenching bath. No bubbles would occur in the first day after the weekly start up. They would start to form after then.

**Table 3.3: Experimental Factors and Levels: Two-Level, Three-Factor Experimental Design**

| Factors | Name | Level 1(-) | Level 2(+) |
|---|---|---|---|
| A | Oven Temperature | 230 °C | 290 °C |
| B | Band Speed in Stretching Oven | 17m/min | 19m/min |
| C | Bubbles in Quenching Bath | No | Yes |

**Table 3.4: Two-Level, Three-Factor Design for the Experiment**

<table>
<tr><th colspan="2" rowspan="4">PP-band type:<br>A 15-18W</th><th colspan="4">A: Oven Temperature</th></tr>
<tr><th colspan="2">(-) 230 °C</th><th colspan="2">(+) 290 °C</th></tr>
<tr><th colspan="2">C: Bubbles</th><th colspan="2">C: Bubbles</th></tr>
<tr><th>(-) No</th><th>(+) Yes</th><th>(-) No</th><th>(+) Yes</th></tr>
<tr><td rowspan="2">B: Band Speed</td><td>(-)17m/min</td><td>Run 1 (---)</td><td>Run 5 (--+)</td><td>Run 2 (+--)</td><td>Run 6 (+-+)</td></tr>
<tr><td>(+)19m/min</td><td>Run 3 (-+-)</td><td>Run 7 (-++)</td><td>Run 4 (++-)</td><td>Run 8 (+++)</td></tr>
</table>

**Table 3.5: Replicate Testing Order**

<table>
<tr><th colspan="3">PP-band type: A 15-18W</th><th colspan="3">Factor Level Settings</th></tr>
<tr><th>Trial # (N)</th><th>Run (k)</th><th>Times of breakage per lot (30 rolls)</th><th>Oven Temperature</th><th>Band Speed</th><th>Bubbles</th></tr>
<tr><td>1</td><td>5</td><td>10</td><td>-</td><td>-</td><td>+</td></tr>
<tr><td>2</td><td>8</td><td>13</td><td>+</td><td>+</td><td>+</td></tr>
<tr><td>3</td><td>7</td><td>13</td><td>-</td><td>+</td><td>+</td></tr>
<tr><td>4</td><td>5</td><td>12</td><td>-</td><td>-</td><td>+</td></tr>
<tr><td>5</td><td>1</td><td>1</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>6</td><td>6</td><td>11</td><td>+</td><td>-</td><td>+</td></tr>
<tr><td>7</td><td>4</td><td>0</td><td>+</td><td>+</td><td>-</td></tr>
<tr><td>8</td><td>2</td><td>0</td><td>+</td><td>-</td><td>-</td></tr>
</table>

| PP-band type A 15-18W | | | Factor Level Settings | | |
|---|---|---|---|---|---|
| Trial # (N) | Run (k) | Times of breakage per lot (30 rolls) | Oven Temperature | Band Speed | Bubbles |
| 9 | 1 | 0 | - | - | - |
| 10 | 3 | 1 | - | + | - |
| 11 | 6 | 14 | + | - | + |
| 12 | 6 | 10 | + | - | + |
| 13 | 7 | 11 | - | + | + |
| 14 | 2 | 0 | + | - | - |
| 15 | 6 | 12 | + | - | + |
| 16 | 5 | 11 | - | - | + |
| 17 | 8 | 9 | + | + | + |
| 18 | 4 | 0 | + | + | - |
| 19 | 4 | 0 | + | + | - |
| 20 | 2 | 0 | + | - | - |
| 21 | 7 | 14 | - | + | + |
| 22 | 4 | 0 | + | + | - |
| 23 | 7 | 10 | - | + | + |
| 24 | 8 | 12 | + | + | + |
| 25 | 3 | 0 | - | + | - |
| 26 | 3 | 0 | - | + | - |
| 27 | 8 | 11 | + | + | + |
| 28 | 1 | 0 | - | - | - |
| 29 | 5 | 13 | - | - | + |
| 30 | 3 | 0 | - | + | - |
| 31 | 1 | 0 | - | - | - |
| 32 | 2 | 0 | + | - | - |

### 3.3.2 Experimental Results and Analysis

The experiment was carried out according to the design and the results are shown in table 3.6. The average and variance for each run were calculated and are shown in table 3.6. The results were then analyzed as shown in the following.

**Table 3.6: Results of Experimental Run**

| Run | Y1 | Y2 | Y3 | Y4 | Average | Variance |
|---|---|---|---|---|---|---|
| 1 | 1 | 0 | 0 | 0 | 0.25 | 0.25 |
| 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 1 | 0 | 0 | 0 | 0.25 | 0.25 |
| 4 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 10 | 12 | 11 | 13 | 11.5 | 1.67 |
| 6 | 11 | 14 | 10 | 12 | 11.75 | 2.92 |
| 7 | 13 | 11 | 14 | 10 | 12 | 3.33 |
| 8 | 13 | 9 | 12 | 11 | 11.25 | 2.92 |

**1) <u>Calculation of the Effects</u>**

The effects for each factor and factor combination are equal to the difference between the average high and average low-level measurement.

The equations for each effect are shown below:

$$E\ (A) = \text{AVG Sum}_{A+} - \text{AVG Sum}_{A-}$$

$$E\ (B) = \text{AVG Sum}_{B+} - \text{AVG Sum}_{B-}$$

$$E(C) = \text{AVG Sum}_{C+} - \text{AVG Sum}_{C-}$$

$$E\ (AB) = \text{AVG Sum}_{AB+} - \text{AVG Sum}_{AB-}$$

E (AC) = AVG Sum $_{AC+}$ - AVG Sum $_{AC-}$

E (BC) = AVG Sum $_{BC+}$ - AVG Sum $_{BC-}$

E (ABC) = AVG Sum $_{ABC+}$ - AVG Sum $_{ABC-}$

Using a spreadsheet makes it easier to perform the effect calculations (see table 3.7). The factor effects are shown under the corresponding factor column in the spreadsheet.

**Table 3.7: Spreadsheet Calculations for Factor Effects**

| Run | A | B | C | AB | AC | BC | ABC | Y1 | Y2 | Y3 | Y4 | Average | $S^2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | -1 | -1 | -1 | 1 | 1 | 1 | -1 | 1 | 0 | 0 | 0 | 0.25 | 0.25 |
| 2 | 1 | -1 | -1 | -1 | -1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | -1 | 1 | -1 | -1 | 1 | -1 | 1 | 1 | 0 | 0 | 0 | 0.25 | 0.25 |
| 4 | 1 | 1 | -1 | 1 | -1 | -1 | -1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | -1 | -1 | 1 | 1 | -1 | -1 | 1 | 10 | 12 | 11 | 13 | 11.5 | 1.67 |
| 6 | 1 | -1 | 1 | -1 | 1 | -1 | -1 | 11 | 14 | 10 | 12 | 11.75 | 2.92 |
| 7 | -1 | 1 | 1 | -1 | -1 | 1 | -1 | 13 | 11 | 14 | 10 | 12 | 3.33 |
| 8 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 13 | 9 | 12 | 11 | 11.25 | 2.92 |
| | | | | | | | | | | | | | |
| Calculate Main Effects | | | | | | | | | | | | | |
| Sum(+) | 23 | 23.5 | 46.5 | 23 | 23.5 | 23.5 | 23 | | | | | | |
| Sum(-) | 24 | 23.5 | 0.5 | 24 | 23.5 | 23.5 | 24 | | | | | | |
| AVG Sum(+) | 5.75 | 5.88 | 11.63 | 5.75 | 5.88 | 5.88 | 5.75 | | | | | | |
| AVG Sum(-) | 6 | 5.88 | 0.13 | 6 | 5.88 | 5.88 | 6 | | | | | | |
| Effect=AVG Sum(+)- AVG Sum(-) | -0.25 | 0 | 11.5 | -0.25 | 0 | 0 | -0.25 | | | | | | |

**2) Making a Pareto Chart of the Effects**

Making a Pareto chart of the effects calculated indicates the relative importance of the factors in the experiment (see figure 3.10).

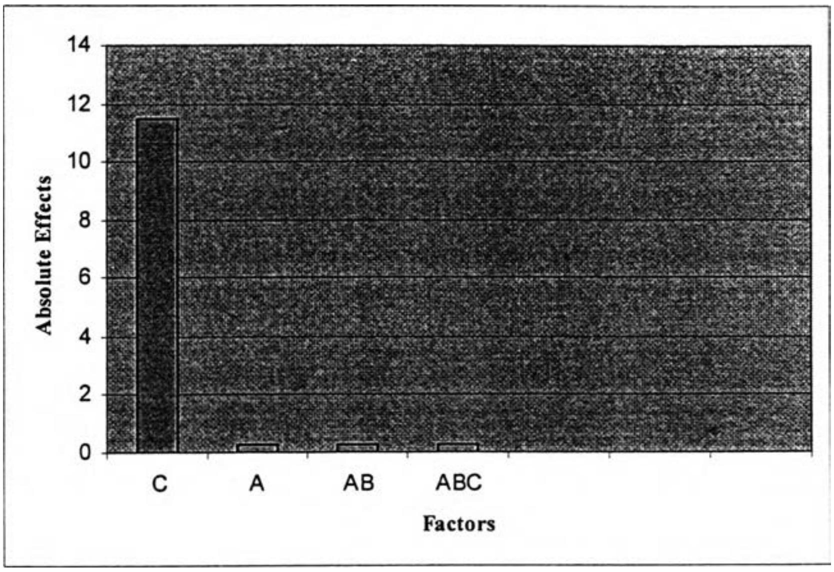



**Figure 3.8: Pareto Chart of Calculated Effects**

An examination of the Pareto chart for this experiment indicates that factor C, bubbles in chilled water of quenching bath rather than no bubbles in chilled water of quenching bath, is the dominant factor followed by Factor A and joint factors AB and ABC.

The next step is to calculate the t-statistic and the decision limits to determine whether any of the factors is significant.

**3) Calculation of the Standard Deviation of the Experiment, $S_e$**

$$S_e = \sqrt{(\text{Sum } S_i^2/k)}$$

Given: k = # of runs = 8

$S_e = \sqrt{11.34/8} = 1.19$

**4) Calculation of the Standard Deviation of the Effects, $S_{eff}$**

$$S_{eff} = S_e * \sqrt{(4/N)}$$

Given: N = # of trials = (# of run) * (# of replicates per run) = (8)*(4) = 32

$$S_{eff} = 1.19 * \sqrt{(4/32)} = 0.42$$

**5) Determination of the t-Statistic**

d.f. = (# of replicates per run-1)*(# of runs) = (4-1)*(8) = 24

For 95 percent confidence or a 5 percent alpha risk and df = 24 the t-value from a t-statistic table (see Appendix E) is, t = 2.06. The t-statistic is used below to calculate the upper and lower decision limits that provide and indication of whether the factor effects are significant.

**6) Calculation of the Decision Limits and Determine the Significant Effects**

$$DL = +/- (t) * (S_{eff})$$
$$= +/- (2.06) * (0.42) = +/- 0.87$$

Graphing the factor effects against the upper and lower decision limits, UDL and LDL respectively, confirms that only factor E(C), bubbles in chilled water of quenching bath, is significant. All the other factors and interactions fall within the upper and lower decision limits, see the Normal Probability Distribution graph in figure 3.11.

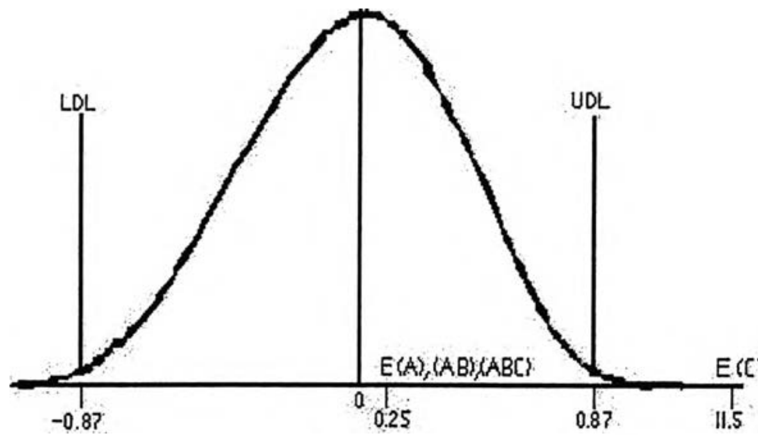



**Figure 3.9: Graph of Factor Effects against Upper and Lower Decision Limits**

**7) <u>Graphing the Significant Effects</u>**

Graphing the significant effects provides an indication of trends for the factor levels. To calculate the high level C average, the average of all runs made with the factor C set to high needs to be calculated. Referring back to the spreadsheet in table 3.7, go to the column for factor C and total the averages where C corresponds to 1 and divide by 4.

High Level for Factor C:

$$(11.5+11.75+12+11.25)/4 = 11.63$$

To calculate the low level C average, refer back to the spreadsheet in table 3.7, and total the averages where C corresponds to a negative 1 and divide by 4.

Low Level for Factor C:

$$(0.25+0+0.25+0)/4 = 0.13$$

The graph of factor C is shown in figure 3.12.

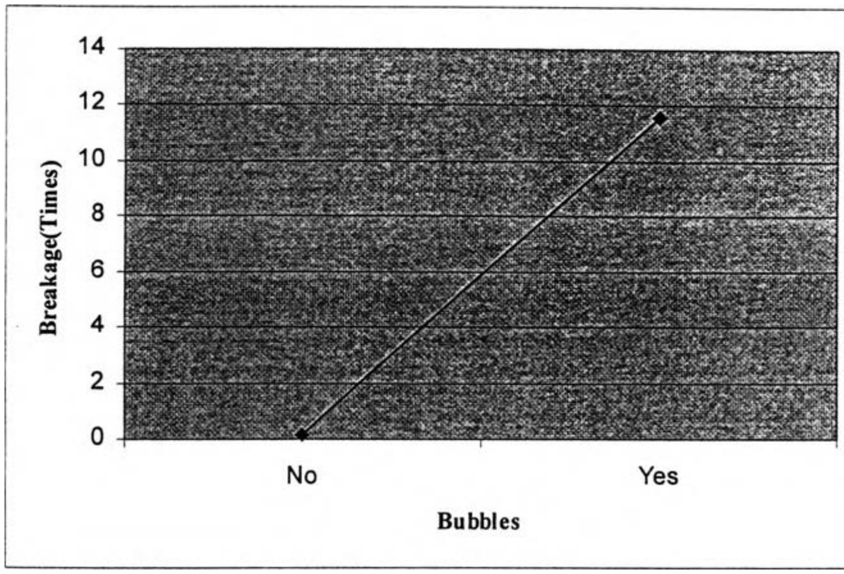



**Figure 3.10: Effect of Bubbles in Quenching Bath on Breakage Times**

The graph indicates that allowing bubbles in chilled water of quenching bath tends to increase times of breakage. Setting no bubbles in chilled water of quenching bath seems to provide better operating performance.

**8) Analysis of Variance (ANOVA)**

The purpose of variation analysis is to determine if any of the factors or factor combinations plays a role in increasing breakage times. Although only factor C was significant the other factors may play a role in increasing or decreasing the variability in the counted breakage times. The variances of each factor as the response for a variation analysis are analyzed.

The procedure for variation analysis follows.

1. Calculate the variances ($S_i^2$) for each run.
2. Calculate the average variance for the high level (AVG $S_+^2$) and low level (AVG $S_-^2$) of each factor and interaction.
3. For each factor and interaction calculate the F-statistic:

   F-Calc = (AVG $S_{+\,larger}^{2}$)/ (AVG $S_{-\,smaller}^{2}$)
4. For a given risk level (10 percent for a two sided test), find the F-table value (see Appendix F) for the critical test value. The F-table is indexed by the level of risk and the degrees of freedom of the numerator and denominator.

**Table 3.8: Spreadsheet Calculation for Factor Variances**

| Run | | A | B | C | AB | AC | BC | ABC | Average | S² |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | -1 | -1 | -1 | 1 | 1 | 1 | -1 | 0.25 | 0.25 |
| 2 | | 1 | -1 | -1 | -1 | -1 | 1 | 1 | 0 | 0 |
| 3 | | -1 | 1 | -1 | -1 | 1 | -1 | 1 | 0.25 | 0.25 |
| 4 | | 1 | 1 | -1 | 1 | -1 | -1 | -1 | 0 | 0 |
| 5 | | -1 | -1 | 1 | 1 | -1 | -1 | 1 | 11.5 | 1.67 |
| 6 | | 1 | -1 | 1 | -1 | 1 | -1 | -1 | 11.75 | 2.92 |
| 7 | | -1 | 1 | 1 | -1 | -1 | 1 | -1 | 12 | 3.33 |
| 8 | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 11.25 | 2.92 |
| | | | | | | | | | | |
| Calculate Variance | | | | | | | | | | |
| (AVG $S^2$+) | | 1.46 | 1.63 | 2.71 | 1.21 | 1.59 | 1.63 | 1.21 | | |
| (AVG $S^2$-) | | 1.38 | 1.21 | 0.125 | 1.63 | 1.25 | 1.21 | 1.63 | | |
| F-Calc | | 1.06 | 1.35 | 21.68 | 1.35 | 1.27 | 1.35 | 1.35 | | |
| F Table | df = 12, 5% risk 10% | 2.69 | 2.69 | 2.69 | 2.69 | 2.69 | 2.69 | 2.69 | | |
| | Significant if > 0 | -1.63 | -1.34 | 18.99 | -1.34 | -1.42 | -1.34 | -1.34 | | |

Using a spreadsheet, step 1 through 4 are calculated (refer to table 3.8). The results indicate that only factor C has a significant influence on the breakage times because the calculated of F value of factor C is equal to 18.99 which is greater than 2.69 which is F value at df = 12.

### 9) Interpretation of Results

Based on the t-statistic and analysis of variance only factor C, Bubbles in chilled water of quenching bath, influenced breakage times of PP bands of the study line.