ROOT CAUSE ANALYSIS OF DEFECTS IN SFS COMB PRODUCTS USING FMEA AND FTA METHODS IN INJECTION MOLDING

Final Project

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I, the undersigned, certify that the contents of part or all of my Final Project entitled: "State the Title of Your Final Project" is my own work, completed without the use of materials that are not permitted , and is not the work of other parties which I acknowledge as my own work. All references cited or referred to have been written in full in the bibliography. If it turns out that my statement is not true, I am willing to accept sanctions in accordance with applicable regulations.

Batam, 24.06.2026

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Approval sheet

The Final Project is structured to fulfill one of the requirements for obtaining a degree
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ROOT CAUSE ANALYSIS OF DEFECTS IN SFS COMB PRODUCTS USING FMEA AND FTA METHODS IN INJECTION MOLDING

Abstract

Injection molding is a critical process for producing high-precision components, yet it remains vulnerable to quality variations. The production of the SFS Comb using the Sumitomo SG series machine and PC Makrolon resin faces challenges with inconsistent defect rates. This study aims to analyze and minimize these issues by applying an integrated Failure Mode and Effect Analysis (FMEA) and Fault Tree Analysis (FTA) approach. To ensure a focused and in-depth investigation, this research is limited to analyzing the top three (4) dominant defects identified during the observation period. FMEA is utilized to prioritize these failure modes based on the Risk Priority Number (RPN), while FTA is employed to perform a deductive, top-down analysis that maps the logical relationships between machine parameters, material properties, and environmental factors. The integration of these methods allows for a precise identification of root causes, such as unstable injection pressure or improper drying of the PC resin. The results provide technical recommendations for process parameter optimization, aimed at reducing critical defects, enhancing process stability, and supporting more effective quality control on the SFS Comb production line.

Keywords: FMEA, FTA, Injection Molding, SFS Comb, Sumitomo SG, PC Makrolon.

Foreword

Praise and gratitude are expressed to God Almighty, who has granted strength, health, and guidance, enabling the author to complete this Final Project Proposal entitled "Root Cause Analysis of Dominant Defects on SFS Comb Products Using Failure Mode and Effect Analysis (FMEA) and Fault Tree Analysis (FTA) Methods."

This Final Project is prepared as a requirement to fulfill the Final Project submission in the Electronics Manufacturing Engineering Study Program at Politeknik Negeri Batam. The research focuses on identifying the technical root causes of defects in the injection molding process by applying systematic analytical methods to improve process stability and product quality.

The author would like to express sincere appreciation to all individuals who have provided support and assistance during the preparation of this Project:

- Mr. Lasrin, as the Project Supervisor, for his valuable guidance, technical advice, and encouragement provided throughout the development of this research idea.
- The lecturers and staff of the Electrical Engineering Department for their continuous support and for sharing their knowledge throughout the academic period.
- The management and technical team, for providing the opportunity, technical insights into the Sumitomo SG machine operations, and access to data regarding Moulding processing.

The author realizes that this proposal is still far from perfect. Therefore, constructive feedback, suggestions, and comments from the board of examiners are sincerely welcomed for future improvement. The author hopes that this proposal can contribute to academic development and provide practical insights for quality control optimization in the injection molding industry.

Batam, [June 2026]

[Galvin]

ROOT CAUSE ANALYSIS OF DEFECTS IN SFS COMB PRODUCTS USING FMEA AND FTA METHODS IN INJECTION MOLDING

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Abstract

— Injection molding is crucial for producing high-precision components but remains highly susceptible to quality variations. The current production of SFS Comb using the Sumitomo SG series machine with Polycarbonates Makrolon resin continues to experience inconsistent defect rates. This study employs an integrated Failure Mode and Effect Analysis (FMEA) and Fault Tree Analysis (FTA) approach to investigate and mitigate these issues. Focusing on the three most prevalent defects identified during the observation period, FMEA ranks failure modes based on their Risk Priority Number (RPN), while FTA maps the logical relationships among machine parameters, material properties, and environmental factors. The combined approach enables precise identification of key root causes, including unstable injection pressure and improper resin drying. Technical recommendations are then provided to optimize process parameters, reduce critical defects, enhance process stability, and improve quality control on the SFS Comb production.

Keywords: FMEA, FTA, Injection Molding, SFS Comb, Sumitomo SG, Polycarbonates Makrolon.

1. Introduction

This study *integrates Failure Mode and Effect Analysis (FMEA) with Fault Tree Analysis (FTA)* to systematically identify critical root causes in the production of SFS Comb using the Sumitomo SG series machine and Makrolon (PC) resin. While FMEA prioritizes risks based on Severity,Occurrence, and Detection, FTA models the logical relationships between machine parameters, material properties, and environmental factors. Combining these methods enables precise identification of key issues such as unstable injection pressure and improper resin drying.

Recurring quality problems in industrial practice often lead to material waste, reduced machine efficiency, and increased rework. Traditional defect reduction methods—manual parameter tuning and preventive maintenance—yield inconsistent results unless root causes are thoroughly addressed. Research highlights that proper material preparation, including adequate resin drying, is as crucial as machine settings, yet it is frequently overlooked on the shop floor, causing defect rates to exceed industrial tolerances. FMEA alone often falls short in capturing the complex interplay between defects and their multiple technical origins. Integrating FTA provides a top-down logical mapping that bridges this gap, allowing manufacturers to shift from symptom-based fixes toward data-driven preventive optimization. This investigation focuses on the four most prevalent defects observed during production: silver streaks, bubbles, flash, and high gate vestige. The objectives of this study are threefold:

- To identify which of the four defect categories occurs most dominantly and to evaluate whether the overall defect rate relative to total production exceeds the company's 5% tolerance limit.
- To investigate the compounding effects of machine parameters on these four defects through the machine
- To create a detailed FTA and FMEA to identify and map the root causes of the Four defects in the SFS Comb production.
- To determine specific, data-driven corrective actions required to the most critical defect.

The aim is to evaluate if a defect rate exceed the tolerance limit elucidate the logical relationships between machine parameters and these defects to develop technical recommendations for process optimization. The outcomes are intended to serve as a practical roadmap for enhancing process stability.

2. Method

The research methodology in this study comprises seven key steps: problem identification, literature review, data collection, FMEA processing, FTA mapping, analysis, and formulation of technical recommendations seen on figure 1. Each step is designed to systematically investigate quality variations in the production of SFS Comb using the Sumitomo SG series machine and Makrolon (PC).

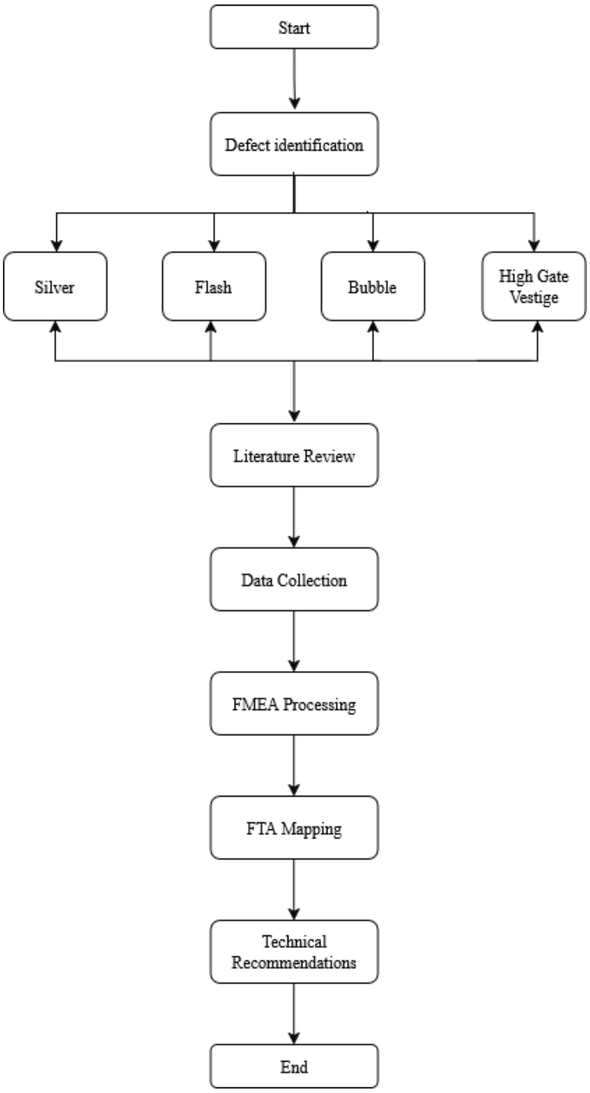


Figure 1. Research methodology flowchart

2.1 Literature Review

Analytical quality tools such as Failure Mode and Effect Analysis (FMEA) and Fault Tree Analysis (FTA) have been widely applied in previous studies to optimize injection molding processes. These methods provide a solid foundation for developing systematic troubleshooting frameworks by enabling risk quantification and logical mapping of defect origins. Through these techniques, researchers can shift from trial-and-error tuning to a data-driven understanding of how machine parameters and material properties interact. While FMEA effectively prioritizes risks, integrating it with FTA is essential to identify the "Top Event" and trace it back to its "Basic Events," such as variations in injection pressure or improper material drying. This combined approach has been successfully applied across various manufacturing sectors to stabilize production lines and maintain high-precision standards.This study extends these proven methodologies to the production of SFS Comb with the Sumitomo SG series machine and Makrolon (PC) resin. The research framework, outlined in Fig. 1, illustrates the Method step-by-step flow of the investigation—from Observe Production to analysis. This structured approach supports the application of FMEA and FTA to systematically identify dominant failure modes and root causes of defects in the injection molding process, ultimately guiding effective process optimization.

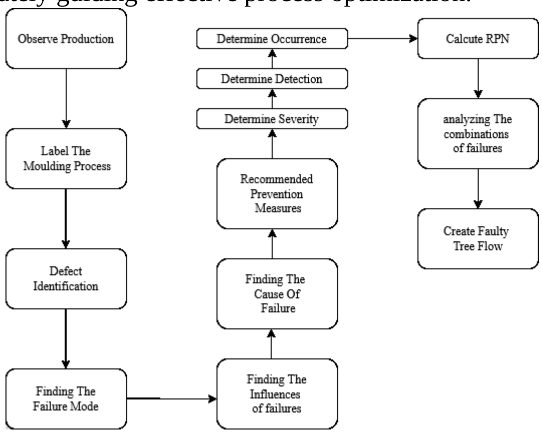


Figure 2. Research flowchart for FMEA and FTA

2.2 Data Collection

The dataset collected in this study on machine parameters and material conditions was collected from direct, real time observations on the SFS Comb production line. Operational data of the Sumitomo SG series injection molding machine were obtained directly from the control panel over First shifts. The process consisted of recording critical variables during the plasticizing, injection and clamping phases, namely barrel zone temperatures, injection velocity profiles (mm/s), peak injection pressures (MPa) and residual melt cushion size (mm) to capture the actual thermal and mechanical dynamics of the machine. Concomitantly, systematic documentation of the material pre-conditioning data for the PC Makrolon resin was undertaken in the hopper dryer area. Polycarbonate (PC) is a highly hygroscopic polymer. The drying temperatures (°C) and total drying time (hours) were recorded to ensure the resin met the required processing standards. The percentage of residual moisture after drying and the ratio of virgin to regrind material were also recorded for each monitored batch. This method gives a concrete empirical basis for the following analysis of FMEA and FTA to track root causes.

2.2.1 Materials and equipments

An injection molding grade of Makrolon Polycarbonate (PC) resin was chosen for the fabrication of the SFS Comb. This grade of PC has a specific gravity of 1.20 g/cm³, a melt volume-flow rate (MVR) of approximately 19 cm³/10 min (at 300°C and 1.2 kg of load), Molding trials were carried out on a Sumitomo SG S180M all-electric injection molding machine with a clamping capacity of 1800 kN (180 tons) and employing precise servo-drive control for high-reproducibility cycles. The tests were performed on a two-plate mold with 4 cavities. Beyond evaluating the investigation was extended to assess critical thermal and process parameters. This included tracking the temperature of the hopper and the hot runner tips, alongside a detailed analysis of cooling time, mold opening speed, and injection rate to determine their combined influence on quality variations across the cavities The machine specifications used are the Sumitomo SGM 180M type, as shown in the table below.

Table 1.0 Specification Sumitomo SGM 180M

Specification	Value	Unit
Max. Mold clamping force	180	TF
Screw diameter	36	mm
Max. Injection pressure	2,800	Kgf/cm²
Max. Injection speed	300	mm/s
No of temperature control zones	4	pc
Heater capacity	8.9	kW
Nozzle pressing force	4670	kgf
Hopper capacity	30	L

2.2.2 Mould Sheet Condition

Molding Condition Sheet (also commonly known as a Process Setup Sheet or Run Sheet) is a critical manufacturing document used in injection molding, SMC, and casting processes.It acts as the "recipe book" for a specific mold, recording the exact machine parameters required to produce a defect-free part consistently every single time.the Molding Condition Sheet serves as our baseline benchmark to analyze parameters and troubleshoot potential molding defects.

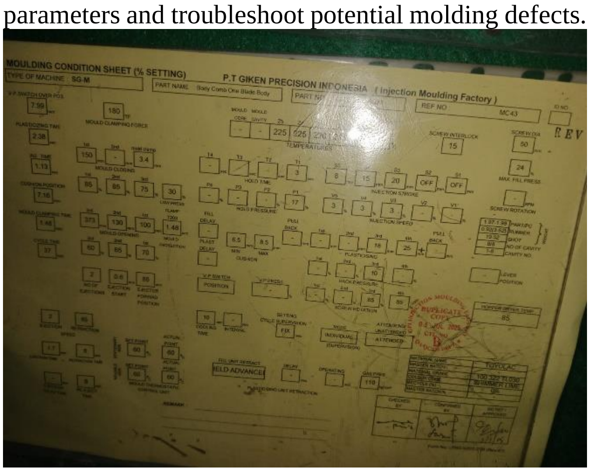


Figure 4. Mould Sheet Condition

2.2.3 Tooling Dimension

the kinematic profiles of both mold closing and mold opening on the Sumitomo SG180M machine are evaluated. Based on the technical specifications of the tool seen on figure 11, the mold dimensions are 496 mm (L) × 346 mm (W) × 402 mm (H) with a significant tooling weight of 430 kg. Operating a 430 kg mold on a 180-ton machine requires precise speed and position tuning.

Figure 4. Tooling Dimension

2.3 Defect Identification

A Two Weeks period of monitoring was done with direct observations on the SFS Comb manufacturing floor to isolate the specific quality variations that impact the production line. Production data was reviewed on a scheduled 8 hour operational shift (t_{shift}) basis per day. To ensure that the baseline dataset reflects real factory outputs, the calculation of production volume included directly non-productive operational downtime $(t_{downtime})$– such as hopper refills, nozzle purging and technical adjustments – and a dedicated manual handling buffer. The hourly control panel logs indicated a stable mean cycle time for the automated injection molding process (T_c). An empirical manual handling time $(t_{handling})$ was also incorporated into the denominator to account for the average handling timeestimated around 6 second required by the operator to remove the molded SFS Comb from the cavities and start the next clamping sequence following. The structural equation below was used to calculate the actual daily output (Q_{Daily}) given that the system is based on the multi-cavity mold configuration (N):

$$Q_{Daily} = \left(\frac{t_{shift} - t_{downtime}}{T_c + t_{handling}} \right) x\ N$$

Four major Defeect were also observed to be predominant threats to product quality within this Two weeks tracking window: silver streaks, internal bubbles, flashing along the parting line and high gate vestiges.further explained in the results section. Ultimately, these four specific defect categories form the empirical baseline needed for the next stages of risk prioritization and root-cause mapping, as follows:

2.3.1 Silver Streaks

These appeared as whitish, moisture-like streaks or splash marks running along the melt flow direction on the surface of the SFS Comb. For example, as illustrated in the visual sample in Fig. 5, they look like silvery, fan-shaped streaks radiating from the gate or long metallic-looking lines etched onto the smooth surface of the comb.

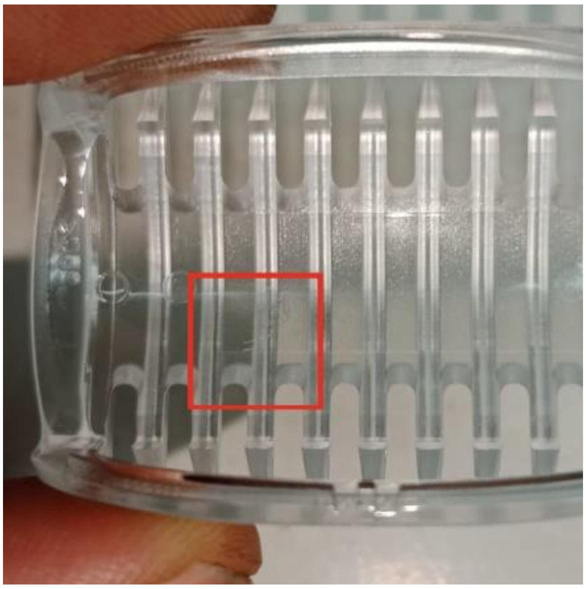


Figure 5.Silver

2.3.2 Flash

This defect manifested as excess plastic material escaping the cavity and forming thin webs along the mold parting line. For example, as shown in Fig. 4, it appears as a sharp, paper-thin plastic skin protruding outward from the edges or teeth of the comb where the two halves of the mold meet.

Figure 6. Flash Defect

2.3.3 Bubbles

Internal voids or gas pockets trapped inside the thicker sections of the SFS Comb geometry. For example, as presented in the cross-section image in Fig. 5, they are visible as small, clear, spherical pockets of trapped air or vacuum blisters embedded deep inside the thickest frame or handle area of the comb.

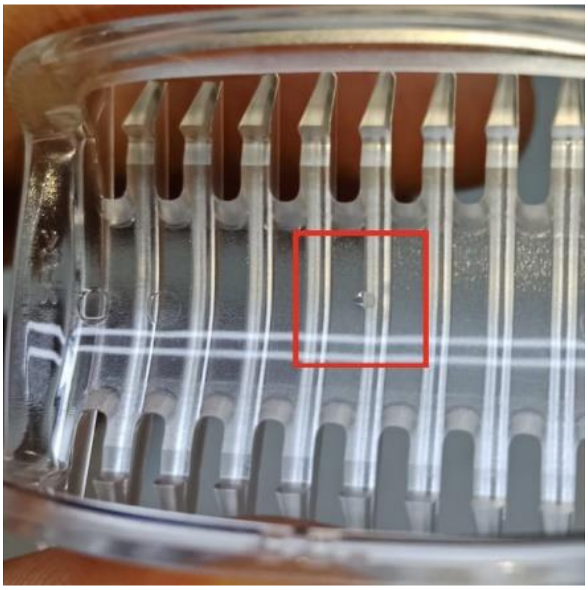


Figure 7.Bubbles Defect

2.3.4 High Gate Vestige

This appeared as a prominent protrusion or excess material remaining at the gate injection point after part ejection. For example, as depicted in the macro photograph in Fig. 6, instead of a smooth, flush surface where the plastic entered the cavity, it leaves a sharp, jagged plastic nub or an un-melted stub sticking out that requires manual trimming.

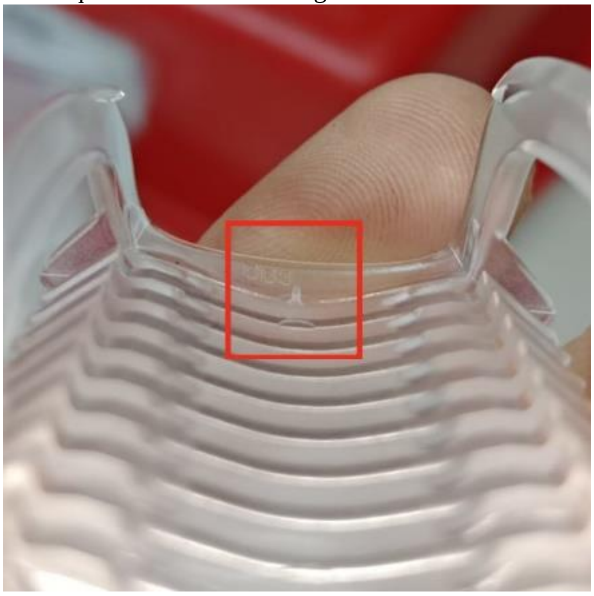


Figure 8. High Gate Vestige Defect

2.4 Failure Mode and Effect Analysis

The four main defect categories identified in the production monitoring stage were systematically analyzed using Failure Mode and Effect Analysis (FMEA). The primary aim of the process was to rank the manufacturing risks by their potential impact on product quality and operational efficiency. A cross-functional assessment was conducted to assign quantitative and qualitative scores for each identified failure mode using three standard risk parameters: Severity (S), Occurrence (O) and Detection (D).

2.4.1 Process Function and Requirements

This component refers directly to the manufacturing process under consideration. The operational objectives should be expressed as fully and clearly as possible. Injection molding of the SFS Comb consists of a series of operations such as plasticization of material, high pressure injection, holding pressure, cooling and automatic part ejection. Each operation is separated and documented with functional descriptions.

2.4.2 Potential Failure Mode

This defines the specific way in which a process step could potentially fail to achieve its intended requirements. The immediate physical failure within the current operation, the potential failure mode cascading into subsequent assembly or finishing operations, and the operational impacts linked to potential errors inherited from previous stages are the three different dimensions of failure examined in this Process FMEA.

2.4.3 Potential Effect of Failure

This outlines the downstream effects of a particular failure mode, with a particular emphasis on the final effect felt by the end user. The descriptions clearly describe what the consumer would encounter, such as the comb's structural weakening or visual deterioration. Additionally, this evaluation rigorously assesses whether the failure mode violates applicable product regulatory and industry compliance standards individual safety.

2.4.4 Severity

This component refers directly to the manufacturing process under consideration. The operational objectives should be expressed as fully and clearly as possible. Injection molding of the SFS Comb consists of a series of operations such as plasticization of material, high pressure injection, holding pressure, cooling and automatic part ejection. Each operation is separated and documented with functional descriptions.

Table 1.1 Severity Rating

Rating	Effect	Severity Criteria
10	Hazardous without warning	Failure compromises personal safety or violates government regulations without any prior warning.
9	Hazardous with warning	Failure compromises personal safety or violates government regulations, but gives a prior warning before failure occurs.
8	Very High	The SFS Comb is completely inoperable, loses its primary function, and leads to high customer dissatisfaction.
7	High	The product is still operable, but its performance is severely degraded. Customer is highly dissatisfied.
6	Moderate	The product is operable, but comfort/convenience functions are inoperable. Customer experiences discomfort or annoyance.
5	Low	The product is operable, but performance is slightly reduced. The customer will notice the defect
4	Very Low	Minor defect noticed by most customers
3	Minor	Minor defect that will only be noticed by discriminating/critical customers
2	Very Minor	Very minor surface defect that does not affect function at all. Average customer will not notice it.
1	None	No noticeable effect on product performance or aesthetics. No operational impact.

2.4.5 Potential Cause of Failure

This pinpoints the precise underlying mechanical, thermal, or operational factors that can lead to a failure mode. It is explained in terms of factors like varying barrel temperatures, worn mold venting, or inadequate clamping force that can be physically adjusted, modified, or regulated. Every potential reason for every failure mode is described in the most thorough and lucid manner possible.

2.4.6 Occurrence

The frequency or probability that a certain cause of failure would occur throughout the production process is estimated using a numerical rating scale with a range of 1 to 10. Each possible cause is given a ranking; the higher the likelihood that the cause will materialize under typical operating conditions, the higher the occurrence score.

Table 1.2 Occurrence Rating

Rating	Probability of Occurrence	Failure Rate
10	Very High	Failure is almost inevitable ≥ 1 in 2 (≥ 50.0%)
9	Very High	High frequency of failure 1 in 3 (~33.3%)
8	High	Repeated failures 1 in 8 (12.5%)
7	High	Frequent failures 1 in 20 (5.0%)
6	Moderate	Occasional failures 1 in 80 (1.25%)
5	Moderate	Infrequent failures 1 in 400 (0.25%)
4	Moderate	Low frequency of failures 1 in 2,000 (0.05%)
3	Low	Relatively few failures 1 in 15,000 (~0.007%)
2	Low	Very few failures 1 in 150,000 (~0.0007%)

1	Remote	Failure is unlikely < 1 in 1,500,000

2.4.7 Detection

The effectiveness of the current process controls and inspection techniques to identify a possible failure mode or its cause prior to the defective SFS Comb leaving the manufacturing workstation is evaluated using a numerical rating system that ranges from 1 to 10. When a fault cannot be found with existing techniques, a high grade (such as 10) indicates complete doubt. On the other hand, a low grade (e.g., 1) indicates that the defect will almost certainly be detected or prevented by the inspection system.

Table 1.3 Detection Rating

Rating	Detection Opportunity	Detection Criteria
10	Absolute Uncertainty	Current process controls cannot detect the failure mode or its cause, or no inspection is performed.
9	Very Remote	Defect can only be detected via destructive testing, or random, un-standardized manual checks.
8	Remote	Defect is visually inspected post-processing away from the station via periodic visual sampling.
7	Very Low	Defect is checked visually on a 100% manual basis after the parts leave the active workstation.
6	Low	Defect is detected at the station via manual gauging or 100% visual inspection by the operator.
5	Moderate	Defect is controlled via statistical process control (SPC) and verified after part cooling intervals.
4	Moderately High	Defect is detected at the station via automated post-molding sensors or optical vision sorters.
3	High	Defect is prevented or detected during plasticization/injection via automated machine alarms and control parameters.
2	Very High	Defect is easily detected by specialized attribute fixtures or automated error-proofing inline gauges.
1	Almost Certain	Defect is completely prevented by robust mold architecture and process design

2.4.8 Prevention Measures

These represent the proactive engineering and operational practices established to eliminate or minimize the likelihood that a failure cause will occur. Unlike detection controls which catch defects after they are generated, prevention measures act directly on the process input variables—such as implementing automated resin pre-drying protocols for PC Makrolon, conducting preventive mold maintenance to clear venting, or locking standard injection parameters on the Sumitomo SG S180M machine.

2.4.9 Risk Priority Number (RPN)

The cumulative risk level of a particular failure mode is translated and quantified using the Risk Priority Number (RPN), a structured mathematical scoring method. It incorporates three crucial operational dimensions: the severity of the failure's impact (Severity), the probability that the underlying cause will materialize (Occurrence), and the efficiency of the current inspection methodology in identifying the defect before it reaches the final consumer (Detection). The following equation defines the RPN, which is computed by multiplying these three independent ranking metrics:

$$RPN = S \times O \times D$$

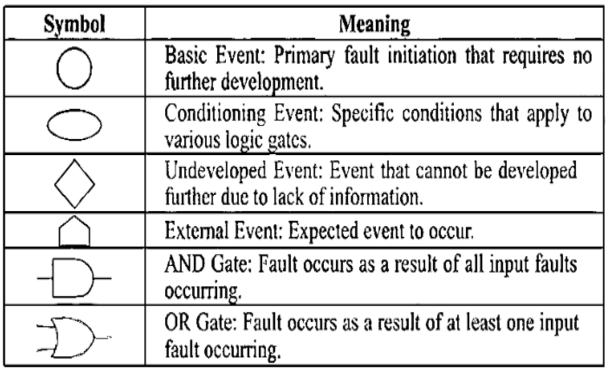
A minimum score of 1 and a maximum possible score of 1,000 make up the resulting RPN value. A lower score in this framework indicates a manufacturing risk that is minimal or under control. Higher numerical values, on the other hand, provide an objective reference for identifying the most significant process irregularities. Defects that produce the highest RPN indicators are designated as top-priority failures, indicating a pressing need for deeper root-cause analysis, process stability, or quick corrective action.

2.4.10 Fault Tree Analysis

The FTA (Fault Tree Analysis) analysis method is used to find and solve problems by analyzing the affected areas. FTA is a graphical model that represents the effect of parallel and mixed faults on the occurrence of the identified problems. An FTA method is used to identify the factors that influence failure. The top-down approach starts with the assumption of failure at the top event, then find the root cause of failure by detailing the causes that cause the top event until the root cause is attained. A fault tree represents the state of the components of the system (basic events) and the relation between the basic events and the top events through logic gates.

2.4.11 FTA Steps

- The kind of system failure that happens at this stage is identified to identify potential errors. The system is explained by analyzing all the data and system scope.
- A Fault Tree Diagram is constructed to show how failures at the top level event can occur in the network.
- Clear data about the system is collected through Fault Tree Analysis and the deficiencies detected are solved.Fault Tree Analysis has special symbols in construction. The symbols and their meanings are shown in Table 1. 4 Symbols in Fault Tree Analysis below:



Symbol	Meaning
	Basic Event: Primary fault initiation that requires no further development.
	Conditioning Event: Specific conditions that apply to various logic gates.
	Undeveloped Event: Event that cannot be developed further due to lack of information.
	External Event: Expected event to occur.
	AND Gate: Fault occurs as a result of all input faults occurring.
	OR Gate: Fault occurs as a result of at least one input fault occurring.

Figure 9. Symbols in Fault Tree Analysis

In FTA (Fault Tree Analysis) creation, there are two gates. The "AND" gate and the "OR" gate. The OR gate is used to show that one or more input events will cause one or more events to happen. Input events to the OR gate. Figure 6. Two input events for the OR gate. Input events A and B, and generates output Q. Input if Output Q is. A occurs, B occurs, or both occur.

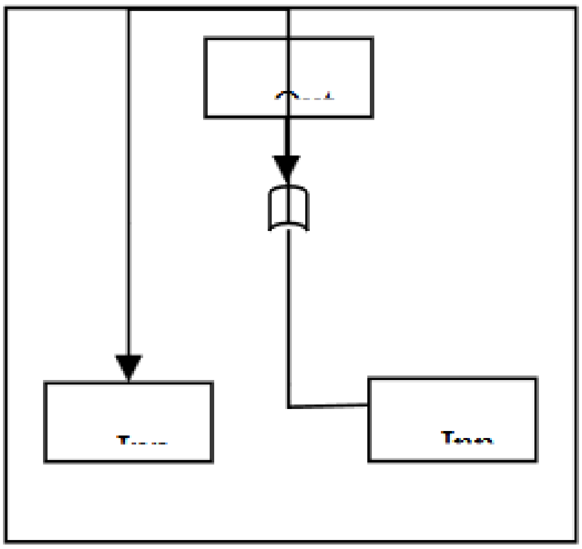


Figure 10. OR Gates

An AND gate means that an output will only happen when all inputs are met. An AND gate may have more than one input.

3. Results and Discussion

Data collection was carried out to obtain the information required to achieve the objectives of this study. The collected data were generally into main categories, namely the operational data to be analyzed in this research.

3.1 Production Output Data and Total Defect Data

Production data and defect data used in this study consist of SFS Comb production data and product defect data obtained from the injection molding process using the Sumitomo SG series machine with PC Makrolon material. The data were collected through direct observation on the production line as well as documentation from the production and quality control departments during the observation period.The following data were collected, including production data and defect data of SFS Comb products, as presented below:

Table 1.4 Total production data and defect data for SFS Comb

Day	Total Production	Total defect	Average Cycle time (s) + Handling time	Down Time (m)
1	2865	136	38.95 (s)	15(m)
2	2743	123	40.69 (s)	15(m)
3	2929	142	37.69 (s)	20(m)
4	2915	156	38.29 (s)	15(m)
5	2916	127	37.87 (s)	20(m)
6	1462	71	39.39(s)	240(m)
7	1957	98	44.14(s)	120(m)
8	3263	167	34.2(s)	15(m)
9	2943	105	36.7(s)	30(m)
10	2921	111	37.8(s)	20(m)
11	2693	104	40.1(s)	30(m)
12	2825	124	39.5(s)	15(m)
13	2952	188	37.8(s)	15(m)
14	1009	115	42.8(s)	300(m)

Source : Internal Company

Tabel 1.5 Data defect sfs comb

Day	Type Defect				Total
	Silver	Flash	Bubble	High Vestige	
1	61	32	25	18	136
2	18	78	7	21	123
3	21	90	3	28	142
4	15	112	5	24	156
5	11	94	4	18	127
6	8	47	2	14	71
7	21	53	5	19	98
8	26	105	8	28	167
9	19	71	4	11	105
10	16	69	5	21	111
11	13	59	9	23	104
12	15	86	6	17	124
13	28	124	16	20	188
14	16	75	6	18	115

Source : Data Processing

3.1.1 Comparison of Total Production Data and Defect Data SFS Comb

The information needed to achieve the research objectives was obtained by processing data already collected by the researcher. The total production and defect data for SFS Comb can be seen in Figure 11.

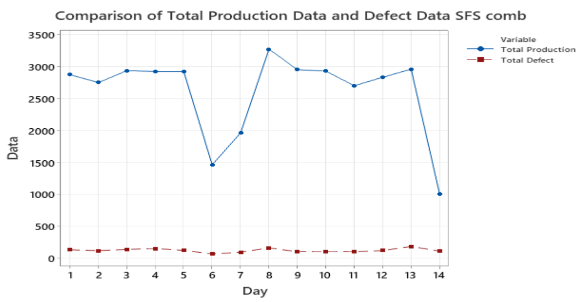


Figure 11. Comparison graph of total production data and SFS Comb defect data

3.1.2 Proportion of Total Production Data and SFS Comb Defect Data

The proportion of total production and total defects, then the author compares the percentages during a certain period which is displayed in the form of a pie chart, namely as follows:

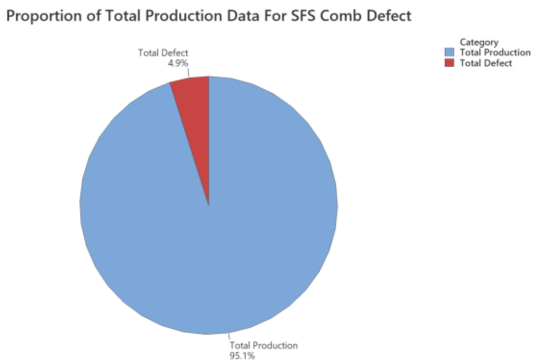


Figure 12. Proportion of Total Production Data For SFS Comb Defect Data

Based on the pie chart, it can be seen that the total defect data for SFS Comb for the 2 weeks period reached 4.9% of total production.

Tabel 1.6 Defect type data on SFS Comb

Defect Type	Number of defects	Percent (%)	Accumulation (%)
Silver	306	16,94%	16,94%
Flashes	1.115	61,74%	78,68%
Bubble	105	5,81%	84.49%
High Gate Vestige	280	15,50%	100%
Tota Defect	1806	-	-

Source : Data Processing

The data was then processed using a Pareto Diagram with the aim of determining the highest defects in the SFS Comb for the2 weeks period, as follows:

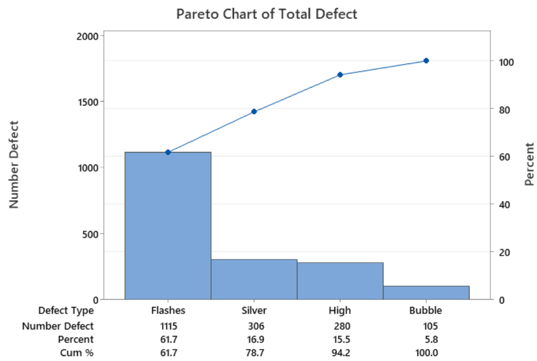


Figure 13. Pareto Chart of SFS Comb defect data

From the Pareto Diagram above, it can be seen that there are several types of defects in SFS Comb that occurred during the 2 weeks period, namely as follows:

a. 61.74% of the total weight is Flashes Defects
b. Silver Defects have a weight of 16.94%
c. High Gate Vestige Defects have a weight of 15.50%
d. Bubble Defects have a weight of 5.81%

Based on the Pareto Chart principle, known as the 80/20 principle, which means that 80% of the consequences are caused by 20% of the triggers. Therefore, of the 4 defects, namely Flashes defects with a weight of 61.74%, Silver defects with a weight of 16.94%, High Gate Vestige defects with a weight of 15.50%.and Bubble Defects have a weight of 5.81% Therefore, the main revision is focused on these four types of defects.

3.2 The effect of injection molding parameters

next step is to analysis the effect of injection molding parameters,such as cooling time, mold opening and closing time,injection rate, and total injection time (Filling + Holding), For Investigate the cause of defect.

3.2.1 Analysis of cooling time

What cooling time is : the phase in the injection molding cycle where molten plastic inside the cavity is held to solidify before ejection, driven by heat transfer from the melt to the (cooler) mold wall.

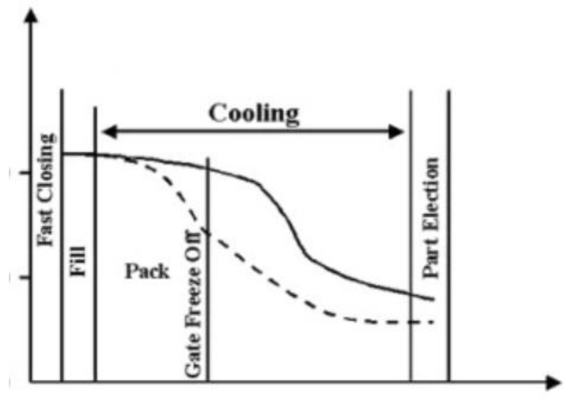


Figure 14. Cooling Phase

Here are illustrated in Figure 14, the cooling phase begins after the pack stage and continues until part ejection. During this phase, two distinct freezing fronts occur at different rates: the gate, being a thin cross-section, solidifies first (Gate Freeze Off), while the core (inside the part) continues to cool and shrink for a longer duration before reaching a temperature safe for ejection. The gap between gate freeze-off and core solidification drives cooling time's effect on defects. Once the gate freezes, the flow path is sealed, so no more material can compensate for the core's ongoing shrinkage. Too short a cooling duration risks ejecting the part before the core (and parting-line skin) fully solidifies, causing flash. A longer duration reduces flash but lets the outer skin freeze rigidly while the core keeps shrinking with nowhere to go, forming a bubble/void — and keeps the mold surface cold longer, raising the risk of moisture condensation and silver streak**.** Gate vestige is shaped mainly by conditions at the Gate Freeze Off point itself, which is why it barely changes across cooling time levels.

Specimens were injection molded with cooling times of 10 seconds according to the mold sheet condition as the baseline setting. To investigate the effect of cooling time on defect occurrence, additional trials were conducted at cooling times of 1, 5, 10, 15, 20, 25, and 30 seconds. 10 specimens per cooling time level (1, 5, 10, 15, 20, 25, 30s).

Tabel 1.7 Data Defect for Cooling Time Testing

Cooling Time	Flash	Silver Streak	Bubble	Gate Vestige
1	5	0	7	2
5	4	0	6	2
10	3	1	2	1
15	4	0	3	1
20	7	1	2	1
25	5	0	3	1
30	6	1	2	1

Based on the experimental investigation, the existing cooling time setting of 10 seconds (as specified in the mold sheet) was found to be near-optimal, resulting in the lowest overall defect occurrence across all four defect types compared to both shorter and longer cooling durations. Therefore, the proposed corrective action is to maintain the current cooling time setting of 10 seconds as the standard operating parameter, rather than adjusting it. It is recommended that operators strictly follow this mold sheet specification during production, since deviation toward shorter cooling times (1–5 seconds) increases the risk of bubble and flash defects, while extending cooling time beyond 10 seconds (up to 30 seconds) does not proportionally reduce defects and instead increases flash occurrence at 20 seconds and silver streak risk at longer durations.

3.2.2 Analysis of mold closing Parameter

The mold closing stage in the injection molding process is not a single continuous movement, but is instead divided into several phases, each controlled by a specific parameter: Velocity 1st, Velocity 2nd, Velocity Mold Clamp, Low Press Clamp Position, and Low Press Clamp Pressure. These parameters regulate how fast and how far the mold travels at each stage of closing, from fully open to fully closed. Because each phase plays a different role — some prioritizing speed, others prioritizing safety and protection — an improperly set parameter can lead to various product defects. For example, closing too fast may cause impact or incomplete mold seating, resulting in flash, while closing too slowly may trap air or gas between the mold surfaces, leading to defects such as bubble or silver streak.

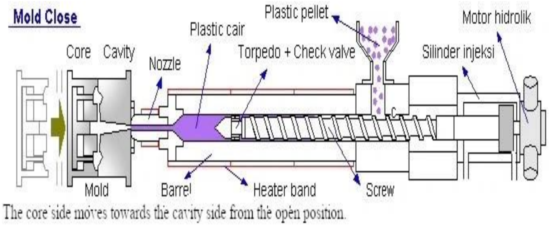


Figure 14. Cooling Phase

In this section, the current parameter settings of the Sumitomo SG180M machine for close were Evaluated.The parameters analyzed in this section are extracted from the machine data. Here a result :

Tabel 1.8 Description Mold Close Parameter

Parameter	Value	Description
Position 1st	70mm	The point/position where the mold switches from Velocity 1st to the next, slower speed phase
Position 2nd	35mm	The point where the mold switches to an even slower speed (the mold clamp phase), usually when the mold is very close to fully closed, to prevent collision or damage.
Position Mold Clamp	3.8mm	The final position at which the mold is considered fully closed, right before the machine begins building up clamping force.
Velocity 1st	50%	The speed at which mold closing begins; usually the fastest phase, since the mold is still far from closed and there is no collision risk yet.
Velocity 2nd	50%	The speed after the transition at Position 1st; slower than the first phase, as the mold is now getting closer to closing
Velocity Mold Clamp	45%	The slowest speed in the final closing stage, used right before the mold is fully shut, so that closing is smooth and does not damage the mold surfaces.

Low Press Clamp Position	10.00 mm	The position at which the machine enters "mold protection" mode; before full clamp force is applied, the machine attempts to close with low pressure first to detect any foreign object or leftover product blocking the mold.
Low Press Clamp Pressure	25%	The low-pressure setting used during that phase. If the actual pressure exceeds this setting — indicating an obstruction or the mold not being fully seated — the machine will alarm or stop to prevent mold damage.

The mold closing time is determined by the cumulative duration of each closing segment, since the stroke is divided into multiple speed phases: a fast close from full-open to 70 mm at 50% velocity, a medium close from 70 mm to 35 mm at 50% velocity, a slow/protective close from 35 mm to 10 mm at 45% velocity, a low-pressure check from 10 mm to 3.8 mm capped at 25% pressure to detect obstructions, and a final lock from 3.8 mm to fully closed where the clamp mechanism engages and builds up to full tonnage.

To identify the relationship between mold closing parameters and product defects, an experiment was designed by adjusting one parameter at a time from its baseline (origin) setting and keep other parameter same as origin at the same time, which produced a closing time of ±1.77 seconds. The tested parameters and their variation levels were: Velocity 1st (100% and 0%), Velocity 2nd (100% and 0%), Velocity Mold Clamp (100% and 0%), Low Press Clamp Pressure (50% and 0%), and Low Press Clamp Position (20 mm and 10 mm). Each variation was tested using 10 products per parameter level to observe its effect on the closing time as well as its influence on four defect categories — silver streak, flash, high gate vestige, and bubble — in order to determine which parameter(s) contribute most significantly to defect occurrence.

Tabel 1.9 Data Defect for Mold Closing Testing

No	Parameter	Value	Silver	Flash	Bubble	HGV
1	Velocity 1st	0%	2	6	1	6
2	Velocity 1st	100 %	2	7	2	5
3	Velocity 2nd	0%	4	4	3	4
4	Velocity 2nd	100 %	3	8	4	6
5	Velocity Mold Clamp	0%	3	7	0	5
6	Velocity Mold Clamp	100 %	2	6	1	4
7	Low Press Clamp Pressure	0%	3	4	0	6
8	Low Press Clamp Pressure	50%	2	5	2	6
9	Low Press Clamp Position	0 mm	3	8	1	4
10	Low Press Clamp Position	30 mm	4	5	0	4

Based on the observation data presented in the table above, it can be seen that Velocity 2nd and Low Press Clamp Position show a significant and drastic change in flash defect count compared to the other tested parameters. At Velocity 2nd = 100%, the flash count increased to 8 (compared to 4 at 0%), and at Low Press Clamp Position = 0 mm, the flash count also reached 8 (compared to 5 at 20 mm). This indicates that these two parameters have a strong influence on flash occurrence. Therefore, further testing will be focused specifically on Velocity 2nd and Low Press Clamp Position to identify the optimal parameter settings that can minimize flash defects.

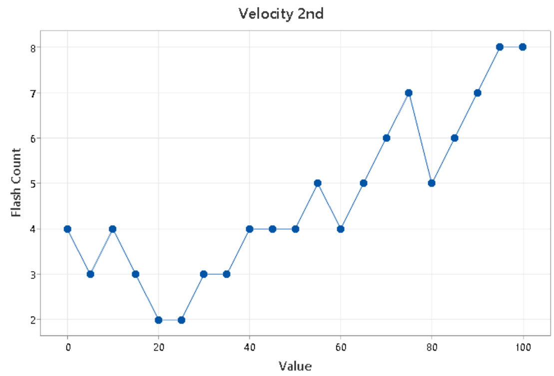


Figure 15. Analysis Velocity 2nd Graph

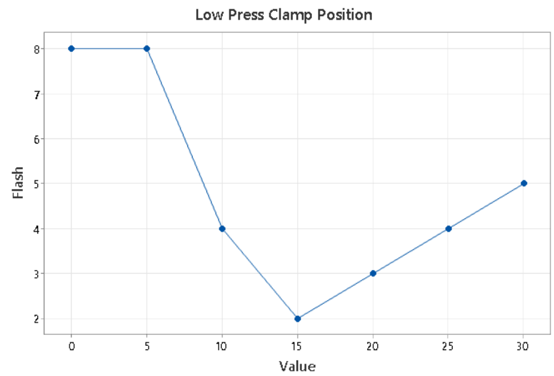


Figure 16. Analysis Low Press Clamp Position Graph

From the further testing results shown above, we can see that: Velocity 2nd shows a similar pattern, where flash count is lowest (2) at the 20–25% range, then generally increases as the value moves higher, reaching its peak (8) at 95–100%. This suggests that running Velocity 2nd too slow or too fast both increase flash risk, with the optimal range sitting around 20–25%. Based on these findings, the proposed corrective action is to set Low Press Clamp Position at 15 mm and Velocity 2nd at approximately 20–25%, as these settings correspond to the lowest observed flash defect counts and represent the optimal operating parameters for reducing flash occurrence in the SFS Comb molding process.

3.2.3 Analysis of total injection time (Filling + Holding)

The injection molding process consists of two key stages: Fill and Hold. During the Fill stage, the injection cylinder drives the screw forward, acting like a torpedo that pushes the molten (liquid) material through the barrel and into the mold cavity, with the check valve closed to prevent material from flowing backward over the screw flights, ensuring all material moves forward into the cavity — this forward motion is powered by hydraulic pressure, referred to as Fill Pressure**,** which controls how fast the cavity fills with molten plastic. Once the cavity is fully filled, the process transitions into the Hold stage, where the check valve remains closed and the screw applies a lower, sustained pressure — the Holding Pressure — to pack additional material into the cavity, compensating for material shrinkage as the plastic cools and solidifies while also pushing out trapped air/gas (back pressure), ensuring the part is fully formed, dense, and dimensionally accurate before the gate freezes off.

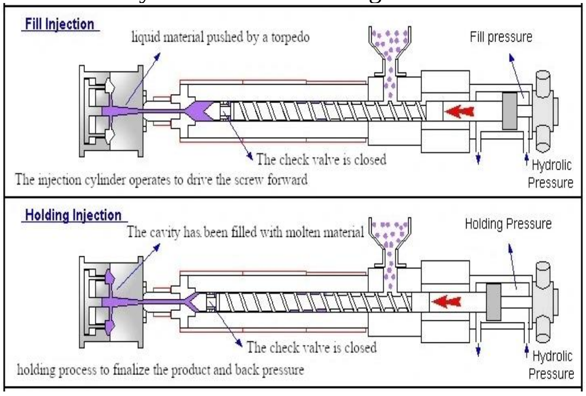


Figure 17. Fill and Hold Process

The effect of Filling and Holding total time, on Monitor was also analyzed. For More detailed origin were seen for injection Parameter.seen on Below.

Tabel 2.0 Description Fill and Hold Parameter

No	Parameter	Value	Description
1	Hold Time 1st	2.8 sec	Duration holding pressure stage 1 is applied
2	Hold Time 2nd	Off	Duration holding pressure stage 2 is applied
3	Hold Time 3rd	Off	Duration holding pressure stage 3 is applied
4	Hold Time 4th	Off	Duration holding pressure stage 4 is applied
5	Hold Press 1st	17%	Pressure level applied during Hold Time 1st
6	Hold Press 2nd	0	Pressure level applied during Hold Time 2nd
7	Hold Press 3rd	0	Pressure level applied during Hold Time 3rd
8	Hold Press 4th	0	Pressure level applied during Hold Time 4th
9	Fill Position 1st	Off	Screw position where speed switches to Fill Velocity 1st
10	Fill Position 2nd	20 mm	Screw position where speed switches to Fill Velocity 2nd
11	Fill Position 3rd	18 mm	Screw position where speed switches to Fill Velocity 3rd
12	Fill Position 4th	15 mm	Screw position where speed switches to Fill Velocity 4th
13	Fill Position 5th	10 mm	Screw position where speed switches to Fill Velocity 5th
14	Fill Velocity 1st	0%	Screw speed at the start of the fill stage
15	Fill Velocity 2nd	12%	Screw speed from position 2nd during fill
16	Fill Velocity 3th	Off	Screw speed from position 3th during fill
17	Fill Velocity 4nd	Off	Screw speed from position 4nd during fill
18	Fill Velocity 5th	Off	Screw speed from position 5th during fill

To determine the effect of each injection parameter on defects in the SFS Comb product, an experiment was conducted by testing 7 parameters at two extreme levels — a low level (0%/0 seconds) and a high level — as follows: Hold Press 1st — tested at 0% and 100%, Hold Time 1st — tested at 0 seconds and 10 seconds, Fill Velocity 1st — tested at 0% and 100%, Fill Velocity 2nd — tested at 0% and 100%,Hold Press 2nd — tested at 0% and 100%, Hold Press 3rd — tested at 0% and 100%, Hold Press 4th — tested at 0% and 100% Testing at these two levels aims to observe the extent to which changes in these parameter values affect the occurrence of defects (silver streak, flash, gate vestige, bubble) on the product. Meanwhile, the parameters Fill Position 1st–5th, Fill Velocity 3rd–5th, and Hold Time 2nd–4th were not included in the testing, as they were set to Off (inactive) in the standard production process, making them irrelevant to test.

Fill Position 2nd–5th, although active with defined values (20 mm, 18 mm, 15 mm, and 10 mm respectively), were kept constant at their standard production settings and were not varied as part of this experiment

Tabel 2.1 Data Defect for Hold and Fill Testing

No	Parameter	Value	Silver	Flash	Bubble	HGV
1	Hold Press 1st	0%	2	6	8	7
2	Hold Press 1st	100 %	2	5	5	4
3	Hold Time 1st	0s	4	4	5	3
4	Hold Time 1st	10s	3	5	1	3
5	Fill Velocity 1st	0%	3	6	3	4
6	Fill Velocity 1st	100 %	7	5	2	3
7	Fill Velocity 2nd	0%	4	7	3	3

8	Fill Velocity 2nd	100 %	2	6	2	3
9	Hold Press 2nd	0 %	2	5	4	2
10	Hold Press 2nd	100 %	3	4	3	4

Based on the observation data presented in the table above, it can be seen that Hold Press 1st shows a significant and drastic change in both Bubble and HGV defect counts compared to the other tested parameters. At Hold Press 1st = 0%, the Bubble count reached 8 and HGV reached 7, while at 100% these dropped to 5 and 4 respectively. This indicates that Hold Press 1st has a strong influence on reducing both Bubble and HGV occurrence. In addition, Hold Time 1st also shows a notable change in Bubble defect count, decreasing sharply from 5 at 0 seconds to 1 at 10 seconds, indicating that longer hold time significantly reduces Bubble occurrence. Meanwhile, Fill Velocity 1st shows a significant change in Silver defect count, increasing drastically from 3 at 0% to 7 at 100%, indicating that higher fill velocity strongly contributes to Silver streak occurrence. Therefore, further testing will be focused specifically on Hold Press 1st, Hold Time 1st, and Fill Velocity 1st to identify the optimal parameter settings that can minimize Bubble, HGV, and Silver defects respectively.

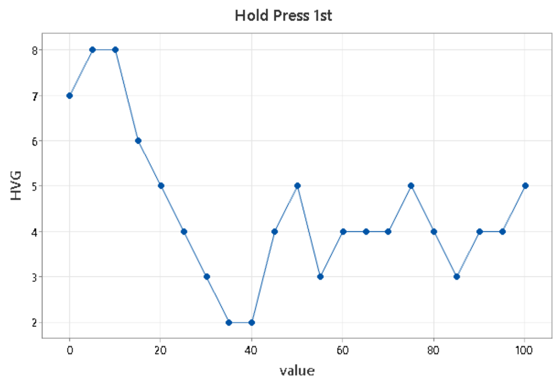


Figure 18. Analysis Hold Press 1st Graph

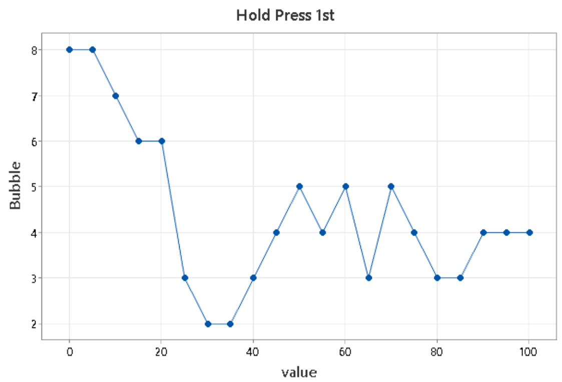


Figure 19. Analysis Hold Press 1st Graph

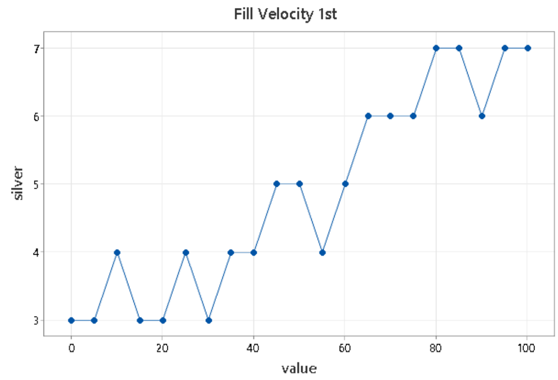


Figure 20. Analysis Fill Velocity 1st Graph

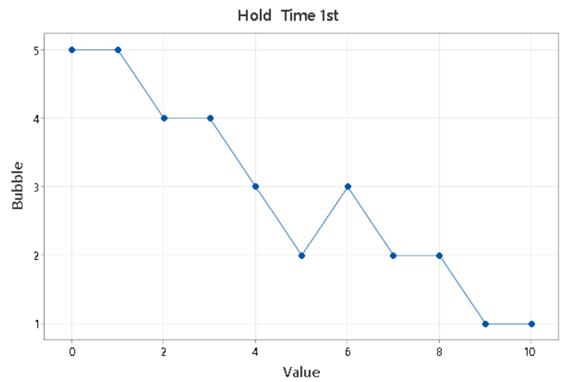


Figure 21. Analysis Hold Time 1st Graph

Further testing across the full parameter range confirmed optimal settings for each defect type: Fill Velocity 1st (Silver defect): Count stayed low and stable (3) within 0–20%, then rose progressively to a peak of 7 at 80–100%. The initial setting (0%) remains optimal, as increasing Fill Velocity only worsens Silver streaks. Hold Press 1st (Bubble & HGV defects): Bubble defects dropped sharply from 8 (0–5%) to a minimum of 2 at 30–35%, then fluctuated upward beyond 40%. HGV defects followed a similar pattern, bottoming out at 2 within 35–40%. Since both minima overlap closely, ~35% is the optimal Hold Press setting, minimizing both defects simultaneously rather than favoring one. Hold Time 1st (Bubble defect): Count decreased steadily from 5 (0–1s) to a low of 1 at 9–10s, with a minor fluctuation (rising to 3) at 6s before continuing to decline. Longer Hold Time is effective, with ~9–10s as the optimal setting. Based on the additional testing conducted across the full range of values, the optimal parameter settings for minimizing each defect type were identified as follows: Fill Velocity 1st should remain at its initial setting (0%), as increasing this parameter only increases Silver defect occurrence. Hold Press 1st should be set at approximately 35%, as this value simultaneously minimizes both Bubble and HGV defects. Hold Time 1st should be set at approximately 9–10 seconds, as longer hold times consistently reduce Bubble defect occurrence. These findings indicate that defect reduction can be achieved not by adjusting each parameter to favor a single defect type, but by selecting settings that provide the best overall balance across multiple defect categories.

3.2.4 Analysis of Injection Rate

The effect of injection rate (screw/ram speed) on the four defects was also analyzed. The origin value according to the mould condition sheet was approximately 25 cm³/s. For this test, injection rates of 5 and 50 cm³/s were set as the low and high extremes. Decreasing the injection rate to 5 cm³/s was found to significantly worsen the defect rate. The slower fill increases melt viscosity, producing silver streaks where cooled flow fronts meet, and triggers internal bubbles as the rapidly freezing outer skin traps vacuum gaps while the inner core continues to shrink. Flash, however, decreases slightly due to the lower pressure spike at the V/P (velocity-to-pressure) switchover point. Conversely, increasing the injection rate to 50 cm³/s produced a different set of problems. The high-speed melt front exceeds the critical velocity threshold at the gate, causing air entrapment as it enters the cavity, which results in silver streaks, and also increases flash risk at the parting line due to the higher pressure spike generated at the switchover point. These results indicate that both extremes (5 and 50 cm³/s) worsen defect occurrence compared to the origin condition. Therefore, the original injection rate setting of approximately 25 cm³/s remains the optimal value, as it provides a balanced melt flow that minimizes silver streaks, bubbles, and flash without introducing the defects caused by either excessively low or high injection speed.

3.2.5 Analysis of Barrel Temperature

The barrel temperature profile was configured in a descending gradient from front to rear: 300°C / 290°C / 290°C / 280°C. This profile falls within the manufacturer-recommended processing window for Polycarbonate (PC) Makrolon (280–320°C), with consistent 10°C decrements ensuring stable, gradual plasticization without risking thermal degradation.

However, the rear feed zone (T4), set at 280°C, sits precisely at the lower boundary of this window. Operating this close to the threshold introduces a minor risk of pellet bridging — where pellets trap air that gets forced forward into the melt instead of escaping through the hopper. As this air-entrained plastic is injected into the cavity, trapped, manifesting as Silver streaks. Since Barrel Temperature primarily affects the Silver defect, further testing focused on this relationship — varying the temperature of front zone individually across the full 280–320°C range while holding the other zones at baseline, to isolate front zone's specific effect on Silver defect occurrence.

Tabel 2.2 Data Defect for Barrel Temperature Testing

Temperature Front	Silver	Flash	Bubble	High Gate Vestige
280	4	5	3	3
285	3	6	2	2
290	3	7	2	4
295	4	6	3	3
300	5	5	1	2
305	4	6	2	4
310	5	7	3	2
315	5	5	2	3
320	6	6	1	2

The Silver defect count started at 4 (280°C), decreased to its minimum value of 3 within the 285–290°C range, then increased progressively as temperature rose further, reaching 5 at 300–310°C and peaking at 6 at 320°C — confirming a clear and significant upward trend beyond ~290°C, consistent with thermal degradation theory in which excessive Front zone temperature promotes resin decomposition and volatile gas release, manifesting as Silver streaks. In contrast, the remaining defect types showed no clear or consistent trend across the tested range: Flash fluctuated between 5–7, Bubble fluctuated narrowly between 1–3, and High Gate Vestige (HGV) fluctuated between 2–4, none showing a significant directional change. This confirms that Barrel Temperature at the Front zone primarily impacts the Silver defect, while Flash, Bubble, and HGV are more strongly influenced by other parameters rather than Front zone temperature, and indicates that the optimal Front zone setting for minimizing Silver defect is approximately 285–290**°C**.

3.2.6 Analysis of Hot tip Parameter

In our current 4-cavity mold configuration, we are observing an uneven temperature distribution across the hot runner system and individual cavities The parameters analyzed in this section are extracted from the machine data shown in Figure Below:

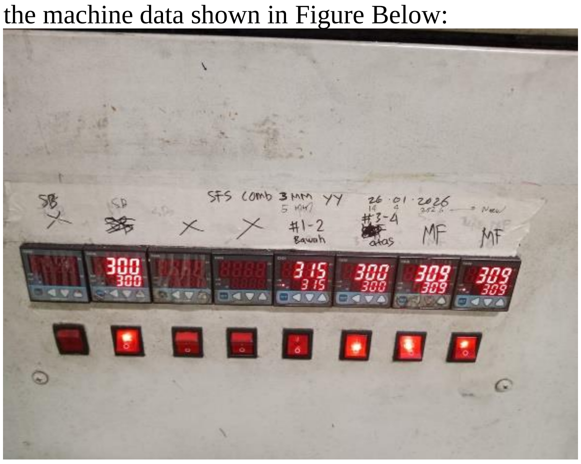


Figure 22. Hottips Parameters

In the current 4-cavity mold configuration, an uneven temperature distribution is observed across the hot runner system (Figure 14): Sprue Bush at 300°C, Cavities 1 & 2 at 315°C, Cavities 3 & 4 at 300°C, and both Manifolds at 300°C. Except for Cavities 1 & 2, the hot tips are running slightly low — they should be set 5–10°C above barrel T1 to compensate for heat loss to the cold mold steel, which acts as a heat sink. At 300°C, the effective gate temperature in practice is likely closer to 285–292°C, causing two issues: fill resistance increases as PC becomes more viscous below 290°C, and the cold hot tip causes premature gate freeze-off, preventing holding pressure from packing additional material to compensate for shrinkage — resulting in internal vacuum bubbles in the core. Following further testing across all cavities, manifolds, and the sprue bush, it was found that setting the temperature within the 305–310°C range resulted in a noticeable reduction in HGV, Silver, and Bubble defect counts. This finding aligns with the earlier analysis, where the hot tip temperature at 300°C (equal to barrel Nozzle) was found to be insufficient to compensate for heat loss to the cold mold steel, resulting in an effective gate temperature of only 285–292°C. Raising the hot runner temperature to 305–310°C helps ensure the gate remains sufficiently hot during the holding phase, preventing premature freeze-off and allowing holding pressure to properly pack the cavity — thereby reducing internal vacuum bubbles (Bubble), gas entrapment near the gate (HGV), and improving melt flow to minimize Silver streaks. Based on these results, 305–310°C is identified as the optimal temperature setting for the hot runner system (Sprue Bush, Manifolds, and all cavities) to simultaneously minimize the three defect types.

3.2.7 Analysis of Hopper Dryer Conditions

The current standard setting for the hopper dryer is 120°C for 3 hours. However, since Polycarbonate requires a minimum of 4 continuous hours at 120°C to reach the critical moisture threshold of ≤0.02%, this raises a concern that the existing 3-hour drying duration may be insufficient to fully remove residual moisture from the resin. To evaluate this, an experiment was conducted holding the hopper dryer temperature constant at 120°C while varying the drying duration across 1, 2, 3, and 4 hours, in order to compare the current setting (3 hours) against the recommended minimum (4 hours) and confirm whether extending the drying time reduces Silver streak defect occurrence.*3.3*

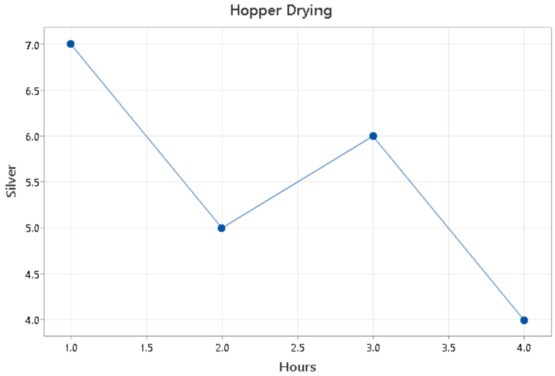


Figure 23. Analysis Hopper Drying Graph

Silver defect count started at 7 (1 hour), decreased to 5 (2 hours), rose to 6 at the current 3-hour setting, then dropped to its lowest value of 4 at 4 hours. This confirms that extending drying time to 4 hours at 120°C — as recommended by the material manufacturer — is more effective at reducing Silver defects than the current 3-hour setting, likely due to insufficient moisture removal at 3 hours. It is therefore proposed to extend the hopper drying duration from 3 to 4 hours at 120°C, update this in the SOP, and communicate the change to operators and supervisors. Operators should also avoid refilling the hopper mid-run to prevent under-dried material reaching the feed zone.

3.3 FMEA Processing

Based on the quality evaluation results of the production process using injection molding machines, several dominant product defects were identified that significantly affect the yield and the quality of the final product. To identify the root causes of these process failures, an in-depth analysis was conducted using the Failure Mode and Effect Analysis (FMEA) method, focusing on four primary types of defects: silver, bubble, flash, and high gate vestige.The application of FMEA aims to identify, assess, and map risks related to potential failures, both in machine parameter settings and mold conditions.. In this study, failure modes encompass all forms of process parameter deviations as well as mechanical conditions that fall outside specified limits.The impacts or effects of each failure during the injection process stages were identified, the flash defect was highlighted as one of the most significant failures because it not only degrades product aesthetics but also carries a high risk of damaging critical mold components if it occurs continuously. Therefore, the determination of Severity (S), Occurrence (O), and Detection (D) ratings for the four types of defects, ensuring the accuracy of the resulting risk analysis and improvement priorities. The scale used as a reference can be seen in the table. Based on the FMEA analysis results, the highest Risk Priority Number (RPN) reached a score of 192 (Flash),. Conversely, the lowest risk priority was recorded for " reached 54 (Bubble).

Tabel 2.3 Calculate Result RPN

No.	***Defect***	***Severity* (S)**	***Occurrence* (O)**	***Detection* (D)**	**RPN**	***Priority***
1	***Silver***	**6**	**5**	**4**	**140**	**2**
2	***Flash***	**8**	**8**	**3**	**192**	**1**
3	***High gate vestige***	**4**	**5**	**5**	**100**	**3**
4	***Bubble***	**3**	**3**	**6**	**54**	**4**

Tabel 2.4 FMEA Defect

Failure Mode	Effect of Failure	Cause of Failure	Prevention Measure
Drying Duration Low	Silver	Insufficient drying time leaves residual moisture in the material,	Set drying duration per material spec
Hottip Temp low,		Low hot tip temperature causes partial solidification and uneven melt flow at the gate,	Set hot tip temperature per setup instruction temperature per material spec
Barrel temp low		Incomplete melting traps air/moisture inside the Barrel	Set barrel temperature per material spec
Incorrect parameter input		Operator inputs machine setup parameters incorrectly during machine setup	Verify parameter input against the setup instruction before production start and require supervisor sign-off
Did not follow setup SOP		Operator does not follow the standard operating procedure during machine setup	Conduct routine SOP audit and refresher training for operators
Moisture content above spec		Raw material is not properly dried before molding, causing moisture content to exceed material spec	Check material moisture content with a moisture analyzer before production and set dryer duration
Poor resin quality		Variation in resin quality between material batches	Verify the Certificate of Analysis for every incoming material batch and inspect material before use
Velocity fill High	Flash	uneven melt pressure at the gate	Specify Velocity 2nd range in the setup instruction than verify parameter input during machine setup
Low Press Clamp Position too low		material escape through the parting line	Low Press Clamp Position in the setup instruction than verify parameter input during machine setup
Incorrect parameter input		Operator inputs machine setup parameters incorrectly during machine setup	Verify parameter input against the setup instruction before production start and require supervisor sign-off
Did not follow setup SOP		Operator does not follow the standard operating procedure during machine setup	Conduct routine SOP audit and refresher training for operators
Moisture content above spec		Raw material is not properly dried before molding, causing moisture content to exceed material spec	Check material moisture content with a moisture analyzer before production and set dryer duration
Poor resin quality		Variation in resin quality between material batches	Verify the Certificate of Analysis for every incoming material batch and inspect material before use
Hold Press is High	Bubble	insufficient to compensate for volumetric shrinkage during cooling, trapping empty spaces inside the part	Specify Hold Press in the setup instruction and verify parameter input during machine setup
Hold Time too short		not enough packing time to compensate for shrinkage, trapping air inside the part	Hold Time in the setup instruction and verify parameter input during machine setup
Incorrect parameter input		Operator inputs machine setup parameters incorrectly during machine setup	Verify parameter input against the setup instruction before production start and require supervisor sign-off
Did not follow setup SOP		Operator does not follow the standard operating procedure during machine setup	Conduct routine SOP audit and refresher training for operators
Moisture content above spec		Raw material is not properly dried before molding, causing moisture content to exceed material spec	Check material moisture content with a moisture analyzer before production and set dryer duration
Poor resin quality		Variation in resin quality between material batches	Verify the Certificate of Analysis for every incoming material batch and inspect material before use
Hold Press is High	High Gate Vestige	overpacking around the gate area, resulting in excessive material buildup at the gate	Specify Hold Press in the setup instruction and verify parameter input during machine setup
Incorrect parameter input		Operator inputs machine setup parameters incorrectly during machine setup	Verify parameter input against the setup instruction before production start and require supervisor sign-off
Did not follow setup SOP		Operator does not follow the standard operating procedure during machine setup	Conduct routine SOP audit and refresher training for operators
Moisture content above spec		Raw material is not properly dried before molding, causing moisture content to exceed material spec	Check material moisture content with a moisture analyzer before production and set dryer duration
Poor resin quality		Variation in resin quality between material batches	Verify the Certificate of Analysis for every incoming material batch and inspect material before use

3.4 FTA Procesing

The Fault Tree Analysis (FTA) method was used to analyze the defects in Flash,silver,bubble, and High Gate Vestige. The aim was to identify the factors causing these Four types of defects. The factors causing the problem of Flash,bubble,silver, and high gate vestige in SFS Comb, caused by human, machine, and material factors, are as follows:

- Human Aspect.The human aspect is a very active aspect because humans play a key role in this process, acting as selectors, operators, and so on. This can be influenced by several factors, including a lack of initiative, such as selectors not reporting to operators, operators dealing with other problems, lack of mastery of defect resolution, and minimal defect resolution training
- Machine Aspect.The machine aspect is a crucial aspect because machines are auxiliary equipment used to carry out production activities. This is influenced by several factors, including uneven heat distribution and lack of a bright cavity
- Material Aspect.The material aspect is a significant aspect because it is the primary raw material used to manufacture a product. This occurs because, during mixing, the material is mixed with other types of plastic pellets

Analysis results indicate that the cause of the problem is due to several factors. Full FTA Will be Provide below:

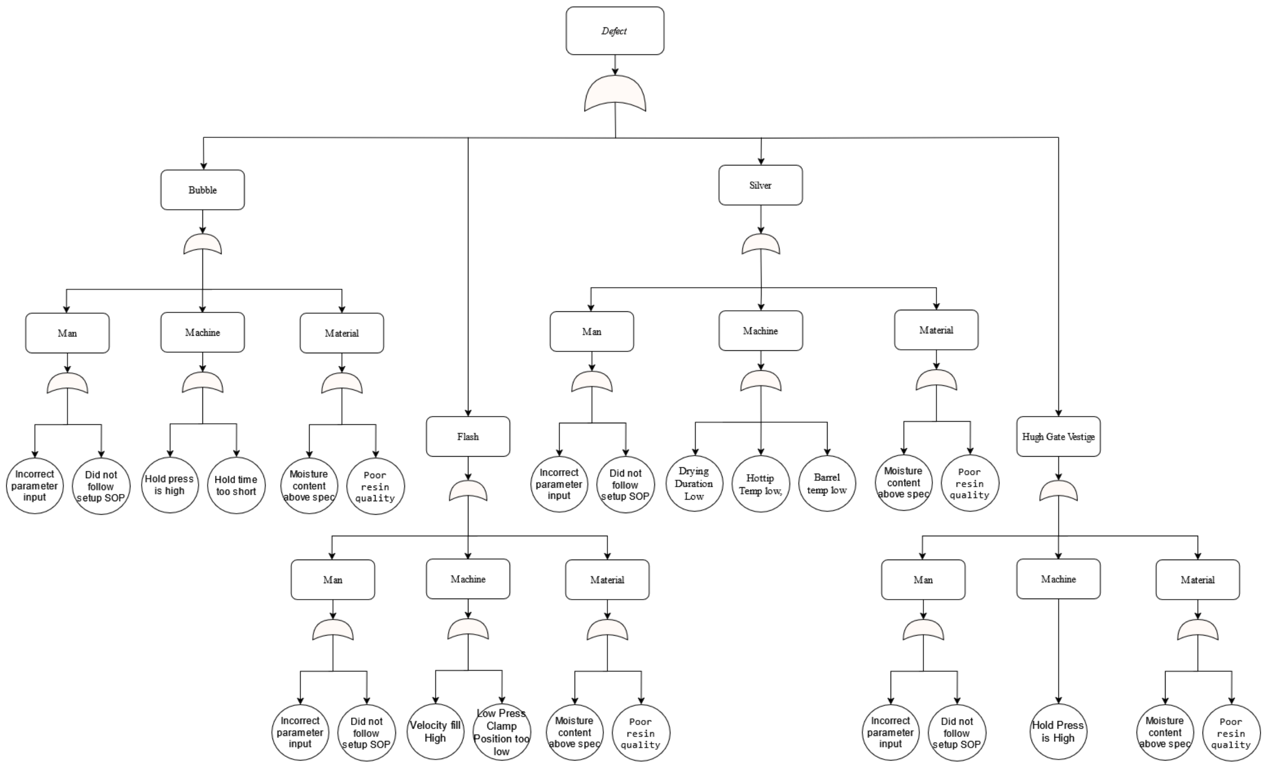


Figure 24. FTA Full Chart

3.5 Proposed Corrective Action

Based on the investigation of cooling time, mould opening and closing time, injection rate, Total injection time, barrel temp, hopper temperature and Hottips Tmeperature, the following corrective actions are proposed to address the four identified defects on the transparent PC Makrolon SFS COMB part

Tabel 1.7 Proposed Corrective Table

Defect Type	Proposed Corrective Action
Flash	• Mold Closing Speed (Velocity 2nd): Reduce setting from 50% to 20%–25% to prevent severe pressure impact upon closing. • Low Pressure Clamp Position: Increase the start position from 10 mm to 15 mm (or 17–20 mm) to ensure effective mold protection and eliminate flash caused by late clamping response. • Clamping & Process Control: Ensure proper mold seating to

	avoid material escaping along the parting line under peak injection.
Silver Streaks	• Pre-Drying Protocol: Extend hopper dryer duration from 3 hours to 4 hours at 120°C to achieve residual moisture content. • Barrel Temperature (Front Zone T1): Lower Front Zone temperature to 285°C–290°C to prevent thermal degradation and volatile gas release. • Fill Speed: Restrict Fill Velocity 1st to 0%–20% to prevent critical shear heating and air entrapment.
Bubbles	• Hold Pressure (Hold Press 1st): Increase holding pressure from 17% to 30%–35% to pack sufficient material into the core and compensate for volumetric shrinkage during solidification. • Hold Time (Hold Time 1st): Extend holding time from 2.8 seconds to 8–10 seconds (9–10 seconds) to maintain packing until gate freeze-off occurs. • Hot Runner Temperature: Increase Sprue Bush, Manifolds, and Cavity Hot Tips to 305°C–310°C to prevent premature gate freeze-off and allow adequate packing.
High Gate Vestige	• Hot Tip Temperature: Maintain Hot Tips at 305°C–310°C (5°C–10°C higher than nozzle temperature) to prevent cold slub formation and ensure a clean shear break at the gate. • Holding Pressure Calibration: Lock Hold Press 1st at 35% to balance complete gate packing with the prevention of local overpacking. • Standardized Trimming: Implement standard operating procedures (SOP) and operator training for post-ejection gate trimming techniques

4. Conclusion

This study successfully diagnosed and resolved four critical injection molding defects—flash, silver streaks, bubbles, and high gate vestige—affecting the production of transparent PC Makrolon SFS Combs. Through systematic parameter optimization and root-cause analysis, the research demonstrated that defect mitigation in transparent polycarbonate relies heavily on precise thermal, pressure, and material regulation. Specifically, enforcing strict pre-drying protocols and lowering the front barrel temperature to 285°C–290°C successfully eliminated moisture and thermal-induced silver streaks. Additionally, elevating holding pressure (30%–35%) and hot runner temperatures (305°C–310°C) eradicated void formation and gate vestige, while reducing mold closing speed mitigated flash. Ultimately, integrating these optimized parameters into a standardized Moulding Condition Sheet provides a robust, data-driven framework that significantly reduces defect rates and ensures consistent optical and structural quality in mass production.

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