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A Comprehensive Study on Implementing Six Sigma Methodology in the Injection Moulding Process for Quality Enhancement

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Abstract

Introduction: This study aims to address the challenges faced in the injection moulding process, particularly focusing on reducing defects and improving quality. The study utilizes the Six Sigma DMAIC methodology to identify root causes of defects and suggest improvements in the manufacturing process. Quality improvement is imperative in today's competitive market to meet customer expectations and minimize costs associated with poor quality.

Objectives: The main objective is to identify the problems hindering quality in the injection moulding process and propose effective solutions. Specific objectives include ranking defective parts, identifying factors affecting quality, finding root causes of defects, and suggesting improvements.

Methods: The research employs the DMAIC (Define, Measure, Analyze, Improve, Control) approach, involving data collection, analysis, brainstorming sessions, and implementation of corrective measures. Various quality tools such as Pareto charts, Ishikawa diagrams, and root cause validation sheets are utilized to identify and address issues.

Results: Through data collection and analysis, the study identifies critical defects such as short fill, black dots, and scratches in the injection moulding process. Defect-wise Pareto analysis reveals the most significant contributors to defects, aiding in setting improvement targets. The root cause analysis highlights factors like insufficient injection pressure, inadequate cooling, and operator errors. Proposed improvements include adjusting machine parameters, enhancing training programs, and implementing preventive maintenance measures.

Conclusions: Quality improvement in injection moulding is essential for meeting customer expectations and maintaining competitiveness. The Six Sigma DMAIC methodology provides a structured approach to identify, analyze, and address quality issues effectively. By prioritizing defects, understanding root causes, and implementing targeted improvements, organizations can achieve significant enhancements in product quality and operational efficiency.

Keywords: Injection Moulding, Quality Improvement, Six Sigma, DMAIC Methodology, and Defect Reduction.

1. Introduction

Quality is an indispensable aspect of manufacturing processes, particularly in sectors like automotive, where precision and reliability are paramount [1]. In the realm of plastic component production, injection moulding stands out as a fundamental method, offering versatility and efficiency in creating intricate shapes with high repeatability [2]. Despite its widespread use and effectiveness, injection moulding is not immune to imperfections, which can manifest as defects in the final products. These defects not only lead to the rejection of parts but also escalate production costs and undermine customer satisfaction [3]. Therefore, there is a compelling need for continuous improvement initiatives to bolster quality and streamline operations in injection moulding.

Recent literature underscores the multifaceted impact of defects on manufacturing operations and the broader supply chain [4]. For instance, Rathi and Salunke [5] emphasize the influence of injection moulding parameters on defect occurrence, such as short shots, which occur when insufficient material fills the mould cavity. Similarly, Raos and Stojsic [6] delve into the effects of processing parameters like injection velocity and pressure on the tensile strength of plastic moulded parts. They demonstrate how variations in these parameters can significantly influence product quality. Furthermore, Lin et al. [7] highlight the intricate interplay between injection speed, pressure, and melt temperature in determining the mechanical properties of plastic components, underscoring the complexity of injection moulding processes.

In addressing quality challenges, Six Sigma has emerged as a prominent methodology, offering a systematic approach for defect reduction and process optimization [8]. Gurjeet Singh and Ajay Verma [9] conducted a comparative analysis of different models and experimental data, revealing persistent challenges like warpage and shrinkage in injection moulding. Their study underscores the efficacy of Six Sigma in addressing these challenges and driving continuous improvement. Similarly, Kaushik and Khanduja [10] advocate for the adoption of Six Sigma philosophy in thermal power plants, citing its effectiveness in water reduction initiatives. These findings highlight the versatility of Six Sigma across diverse industrial settings and its potential to drive substantive improvements in quality and efficiency.

Moreover, industry reports and case studies provide valuable insights into the practical application of quality improvement strategies in injection moulding [11]. Pal et al. [12] focus on micro-injection moulding processes, demonstrating the influence of parameters like injection pressure and temperature on product quality. Their findings underscore the importance of precise parameter control for achieving desired outcomes. Similarly, Bharti and Khan [13] provide a comprehensive overview of optimization methods in plastic injection moulding, stressing the need for proactive defect mitigation strategies. The evolving landscape of manufacturing technologies further underscores the need for continuous adaptation and innovation in quality improvement efforts [14]. Studies by Islam et al. [15] and Singh et al. [16] explore the impact of emerging technologies on quality enhancement in metal injection moulding and small-scale industries, respectively. These insights underscore the dynamic nature of quality improvement initiatives and the need for holistic approaches to address evolving challenges.

Despite the wealth of research in this field, there still exist notable gaps that warrant further investigation. One such gap is the lack of comprehensive studies that integrate various factors influencing defect occurrence in injection moulding processes. While existing literature has examined individual aspects such as processing parameters and defect types, there is a need for holistic research that considers the interplay between these factors. Additionally, while Six Sigma has shown promise in improving quality and efficiency in various industries, its application and effectiveness in the context of injection moulding processes require further exploration. By addressing these gaps, the present research aims to contribute to a deeper understanding of quality improvement strategies in injection moulding and provide actionable insights for practitioners in the field.

In the present study, XYZ Company, has been selected, which is renowned for its top-tier automotive solutions, XYZ Company boasts five cutting-edge manufacturing plants strategically located across India. Among its array of offerings, injection moulding takes center stage at XYZ Company's facilities. This injection moulding facility serves as a cornerstone of its operations, manufacturing a diverse range of automotive components essential for various applications.

The injection moulding process at XYZ Company entails several crucial stages, including clamping, injection, hold, and ejection, each meticulously controlled to ensure optimal results. Parameters such as cylinder temperature, mould temperature, injection pressure, and cooling time are carefully monitored to maintain product quality and consistency. At the heart of the injection moulding process lies the intricate interplay of components such as the hopper, barrel, reciprocating screw, and mould system. The hopper, barrel, and reciprocating screw work in tandem to heat and mould the plastic material, while the mould system shapes it into the desired form.

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Meanwhile, the delivery system, cooling channels, hydraulic system, and control system play pivotal roles in ensuring smooth operation and high-quality output. Process Flow Diagram (PFD) as shown in Figure 1 provides a visual representation of the intricate steps involved in the injection moulding process at XYZ Company.

However, despite XYZ Company's meticulous processes, certain defects occasionally arise, necessitating careful identification and remediation. Common defects such as splay, scratch, sink marks, short fill, weld lines, and flash can impact product quality and performance if left unaddressed.

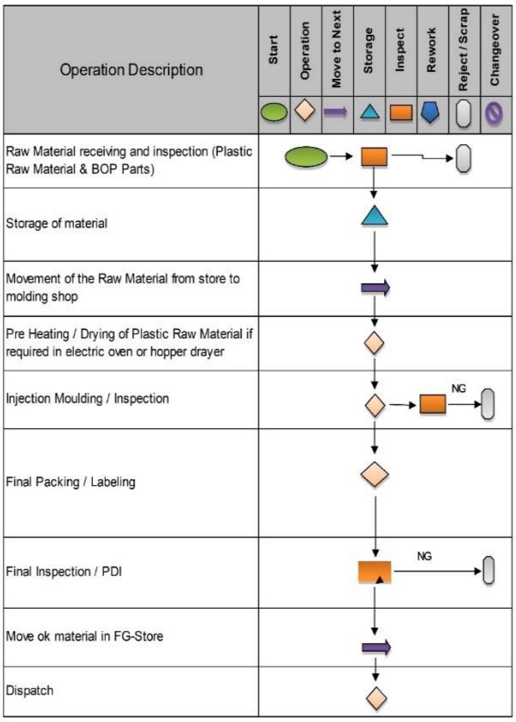

Figure 1. Process Flow Diagram

Figure 2. Common Defects Occurring during the Injection Moulding Operation

2. Objectives

The primary aim of this research is to delve deep into the intricate workings of the injection moulding process with the goal of pinpointing and effectively mitigating the root causes of poor quality. To accomplish this overarching objective, several specific objectives have been outlined.

Firstly, the task involves systematically ranking defective parts to prioritize improvement efforts. By discerning which components are most susceptible to defects or have the most significant impact on product quality, manufacturers can allocate resources more judiciously. This prioritization enables them to focus their attention and resources on areas where improvements will yield the greatest benefits [17].

Moreover, a crucial aspect of the research involves identifying the multitude of factors influencing quality in the injection moulding process. Through a comprehensive literature review and meticulous data analysis, the objective is to synthesize existing knowledge and empirical evidence. By doing so, the study aims to gain profound insights into the various parameters, variables, and external factors that contribute to defects in the production of plastic parts. This comprehensive understanding is pivotal in devising effective strategies to mitigate quality issues and optimize the overall manufacturing process [18].

Furthermore, the research endeavors to uncover the root causes behind the most prevalent and impactful defects observed in the injection moulding process. Through rigorous analysis and thorough investigation, the study seek to delve deep into the underlying reasons for these defects. By identifying and addressing the root causes, manufacturers can implement targeted interventions and corrective measures to rectify the underlying issues effectively. This proactive approach is instrumental in preventing the recurrence of defects and ensuring consistent product quality [19].

Building upon the insights gained from identifying the root causes, this research aims to propose actionable recommendations and improvements to enhance product quality and reduce rejection rates in injection moulding operations. These suggestions are grounded in empirical evidence and best practices, offering practical solutions for mitigating defects and optimizing the manufacturing process. By implementing these recommendations, manufacturers can streamline their operations, enhance product quality, and ultimately bolster customer satisfaction [20].

3. Methods

This study adopts the DMAIC (Define, Measure, Analyze, Improve, Control) approach, a structured problem-solving methodology widely embraced in Six Sigma projects for its systematic and data-driven framework. This methodology serves as a guiding framework to address quality issues in the injection moulding process effectively.

In the initial phase of Define, the research team delineates the scope of the project and establishes clear objectives aligned with enhancing product quality and reducing defects. By defining the problem statement, setting project boundaries, and identifying key stakeholders, the team ensures a focused and purposeful approach to quality improvement. This phase also involves outlining the specific metrics and parameters to measure the current state of quality and establish a baseline for improvement efforts.

Moving to the Measure phase, the research focuses on gathering relevant data from the production floor and quality records. This involves collecting information on defect rates, rejected parts, and other quality-related metrics to gain insights into the extent and nature of quality issues. Utilizing various quality tools such as Pareto charts, which help prioritize defects based on their frequency and impact, enables the team to pinpoint areas requiring immediate attention. Additionally, Ishikawa diagrams, also known as fishbone diagrams, aid in identifying potential root causes of defects by categorizing factors contributing to quality issues.

The subsequent Analyze phase delves deeper into the collected data to identify patterns, trends, and correlations that shed light on underlying issues affecting product quality. Through statistical analysis and root cause validation sheets, the research team scrutinizes the data to uncover critical factors influencing defects in the injection moulding process. This phase involves rigorous examination and validation of potential root causes to ensure accuracy and reliability in problem diagnosis.

Brainstorming sessions involving cross-functional teams are integral to the Improve phase, where a diverse range of perspectives and expertise converge to generate innovative solutions to address identified issues. The team evaluates proposed solutions based on their feasibility, effectiveness, and potential impact on quality improvement. Prioritizing improvement ideas ensures that resources are allocated efficiently, focusing on interventions with the greatest potential for positive outcomes.

Following the implementation of selected improvement measures, the Control phase is crucial for ensuring sustained improvement and preventing the recurrence of defects. Monitoring and control measures are put in place to track the effectiveness of implemented solutions and make necessary adjustments as required. This phase involves establishing standard operating procedures, conducting regular audits, and implementing feedback mechanisms to maintain quality standards over time.

4. Results and Discussions

4.1 Define Phase

In the Define stage of the quality improvement project at XYZ Company, extensive efforts were made to gather data and establish a clear understanding of the problem at hand. Data collection was meticulously carried out, with primary focus on the production and quality departments, while also considering inputs from maintenance, safety, and security departments for a comprehensive overview. To begin, historical data spanning one year was collected from the quality department to calculate the Parts Per Million (PPM) rejection rate, a key metric for assessing quality performance. This data provided valuable insights into the prevailing quality levels and served as a baseline for setting improvement targets. Subsequently, a Pareto chart was generated based on the collected data to prioritize areas for intervention.

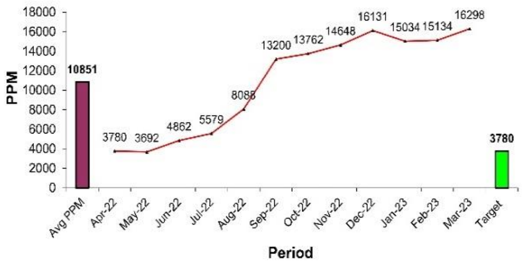

Figure 3. Inhouse Rejection (PPM)

Figure 3 illustrates the total in-house rejection PPM for the molding shop over the period from April 2022 to March 2023. The analysis revealed an average PPM of 10,851, significantly higher than the budgeted target of 3,780 PPM. This stark deviation from the target underscored the urgency and importance of implementing quality improvement measures.

Furthermore, Figure 4 presents the Pareto analysis conducted to identify the most significant contributors to defects in the injection molding process. Part-wise data was meticulously sorted, with the aim of pinpointing the primary areas requiring attention. It was found that the part named "LIGHT GUIDE KWPM" emerged as the focal point for the project, being the second most rejected part after the elimination of an obsolete component.

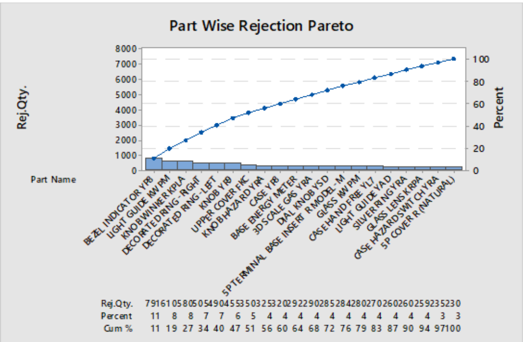

Figure 4. Part-wise Pareto Chart

The top most part was not considered for the study as it would become obsolete from April'23. Given the prominence of "LIGHT GUIDE KWPM" in the rejection data, it was selected as the target part for the quality improvement project. The Pictorial presentation of the Part is shown by Figure 5(a) and its detailed description is illustrated in Figure 5(b). This decision was informed not only by the Pareto analysis but also by the expectations of vendors for future growth over the next three years.

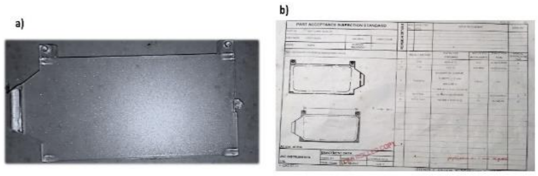

Figure 5. Light Guide KWPM

The chosen target part served as a focal point for subsequent phases of the project, guiding efforts to analyze, diagnose, and address the root causes of defects. By strategically focusing on a specific component with high rejection rates, XYZ Company aimed to achieve tangible improvements in product quality and operational efficiency.

4.2 Measure Phase

In the Measure phase of the quality improvement initiative undertaken at XYZ Company, a meticulous approach was adopted to gather comprehensive data and assess the current state of the injection moulding process. This phase aimed to provide a solid foundation for understanding the scope and nature of defects, thereby informing targeted improvement efforts.

One of the primary data collection methods employed was the recording of day-to-day data from the red bins positioned alongside the injection moulding machines. This data collection process spanned a month and was supplemented by historical data spanning the past year. The purpose of this exercise was to capture real-time information about defects and reject parts, allowing for a detailed analysis of trends and patterns over time.

Figure 6 provides a snapshot of the red bin rejection material, offering insights into the types and frequency of defects observed during the data collection period. This visual representation enabled stakeholders to identify common issues and prioritize areas for further investigation and improvement.

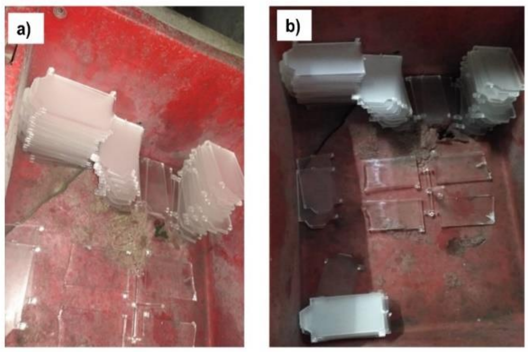

Figure 6. Red Bin Rejection

In addition to red bin analysis, various parameters of the injection moulding machines were meticulously measured to gain a deeper understanding of the production environment. This included detailed inspections using Vernier Callipers to verify critical dimensions and ensure compliance with specifications and quality standards. The Measure phase also involved gaining access to various departments and processes within the organization to gather additional insights into the production process. This cross-functional approach facilitated a more holistic understanding of the factors influencing product quality and defect occurrence.

A Defect-wise Pareto analysis was conducted utilizing the collected data to pinpoint the most significant contributors to defects in the injection moulding process. Figure 7 provides a visual representation of the rejection PPM (Parts Per Million) average for the designated part "Light Guide KWPM" over a specific timeframe, showcasing any deviations from the predetermined budgeted targets. The average rejection PPM for the "Light Guide KWPM" is 14574 PPM for the period spanning Apr'22 to Mar'23, in contrast to the budgeted target of 6000 PPM.

Figure 8 presents a detailed Pareto analysis of the factors contributing to defects in the production of "Light Guide KWPM" parts. This visual representation helped prioritize improvement efforts by identifying the most critical areas for intervention.

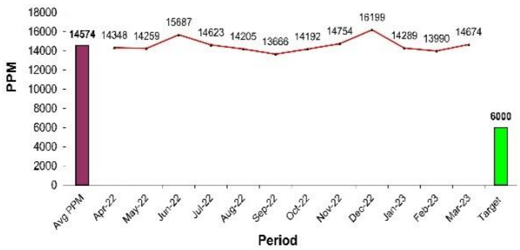

Figure 7. Light Guide KWPM Rejection PPM Pareto

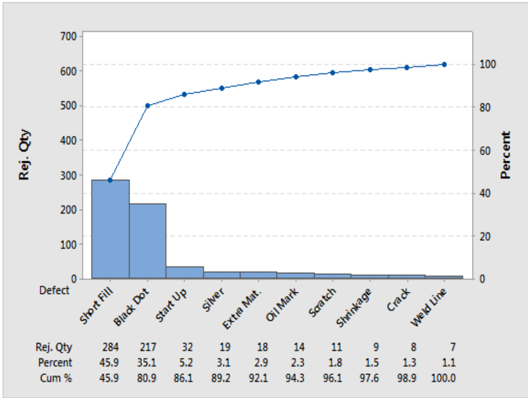

Figure 8. Defect Wise Pareto

Figures 9 (a and b) offers insights into specific defect types observed in the production process namely black dots and short fills in the "Light Guide KWPM" parts. These visuals aid in identifying areas for improvement and monitoring progress towards achieving quality targets.

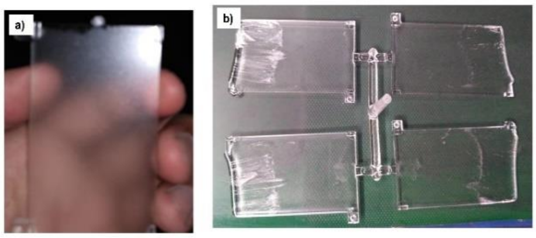

Figure 9. a) Image showing black dot defect; b) Image showing short fill defect

In Figure 10, the rejection PPM average for short fill defects in the "Light Guide KWPM" part is depicted, revealing a recorded value of 6691 PPM for the Apr'22~ Mar'23 period. This figure exceeds the budgeted target of 6000 PPM, indicating a notable occurrence of short fill defects during the specified timeframe.

Conversely, Figure 11 showcases the rejection PPM average for black dot defects in the same "Light Guide KWPM" part. The data reveals an average rejection PPM of 5079 for the Apr'22 ~ Mar'23 period, surpassing the budgeted target of 4500 PPM. This suggests that black dot defects were also prevalent during the specified timeframe, albeit at a slightly lower frequency compared to short fill defects. Both figures provide valuable insights into the specific types of defects affecting the production of the "Light Guide KWPM" part, highlighting areas that require focused improvement efforts to align with the predetermined quality targets.

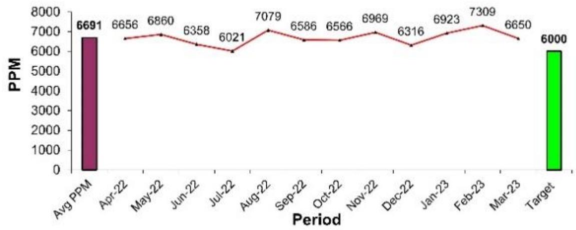

Figure 10. Light Guide KWPM Short Fill rejection PPM

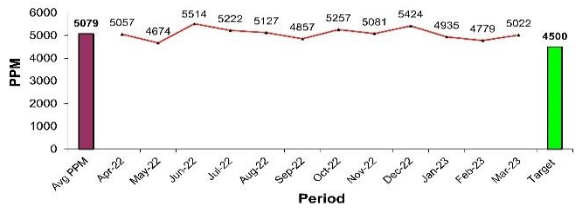

Figure 11. Light Guide KWPM Black Dot rejection PPM

4.3 Analyse Phase

The cause validation sheet serves as a structured tool to systematically analyze and categorize potential causes related to specific types of defects, namely black dot and short fill. Table 1 outlines the cause validation sheet, which includes columns for categorizing causes, their description, and their association with the identified defects. This sheet facilitates a comprehensive examination of various factors contributing to defect occurrences, allowing for targeted corrective actions.

From the cause validation sheet, insights were derived to develop cause and effect diagrams for black dot and short fill defects. Figure 12 and Figure 13 illustrate these cause-and-effect diagrams, respectively. These diagrams visually represent the relationship between potential causes and the observed defects, providing a clear understanding of the underlying factors influencing defect occurrences.

In Figure 12 and Figure 13, the cause-and-effect diagrams depict the primary factors contributing to black dot and short fill defects, respectively. These factors are categorized based on the 4M framework, which includes Man, Machine, Material, and Method. Each category is represented by a branch on the diagram, with specific causes listed under each branch. For instance, under the "Man" category, factors related to human error or operator skill are identified as potential causes contributing to defects. Similarly, the "Machine" category encompasses factors associated with equipment malfunction or inadequacies.

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The cause-and-effect diagrams provide a visual representation of the complex interplay between various factors and defect occurrences. By identifying and addressing root causes within each category, organizations can implement targeted interventions to mitigate defects and improve overall product quality.

4.4 Improve Phase

Following the analysis conducted in the measure phase, a series of improvement initiatives were proposed to address the identified issues and enhance product quality in the injection moulding process. These improvement suggestions were meticulously deliberated with the management of the vendor company and subsequently submitted to relevant departments for implementation.

For addressing the issue of short fill defects, several improvement measures were recommended as listed in Table 2. These included optimizing the injection speed and pressure parameters to ensure adequate material flow and cavity filling during the moulding process.

Additionally, adjustments to the melt temperature and cooling time were proposed to enhance the solidification of the molten plastic, thereby reducing the occurrence of short fill defects. Furthermore, measures to improve tooling and mould design were suggested to minimize defects arising from inadequate cavity geometry or improper venting.

In parallel, improvement strategies targeted at mitigating black dot defects were proposed as illustrated in Table 3. These initiatives focused on enhancing the cleanliness and maintenance of mould surfaces to prevent the deposition of contaminants during the injection process. Regular inspection and cleaning protocols were recommended to remove any foreign particles or residues that could contribute to black dot defects. Moreover, optimization of processing parameters, such as melt temperature and injection pressure, was advised to minimize the likelihood of material degradation and surface imperfections. To ensure the successful implementation of these improvement measures, collaboration and coordination among various departments were emphasized. Cross-functional teams were formed to oversee the execution of improvement initiatives and monitor their effectiveness. Additionally, training programs were conducted to familiarize operators and technicians with revised procedures and protocols aimed at defect reduction.

Continuous monitoring and feedback mechanisms were established to track the progress of improvement efforts and identify any emerging issues promptly. Regular performance reviews and data analysis sessions were conducted to assess the impact of implemented measures on defect rates and overall product quality. Adjustments and refinements to improvement strategies were made iteratively based on real-time insights and feedback from the production floor.

Table 1. Cause Validation sheet

S.No.	**Category**	**Cause**	**Investigation Results**	**Relationship**	
				Short Fill	**Black Dot**
1	Man	Operator not trained	Trained operator on line	△	/ \
2	Man	Operator fatigue	No fatigue	△	/ \
3	Man	Lack of skill	Trained manpower on line	/ \	[redacted]
4.	Machine	More heating plate temperature	While doing more heating temperature, issue of burning was reported.	/ \	○
5.	Machine	Less Heating plate temperature.	Less heating temperature causes short fill issue to occur.	◗	/ \
6.	Machine	Less heating time	Less heating time. Causes short fill issue	◠	X

7.	Machine	More heating time	More heating time caused fabric burning issue		○
8.	Machine	Insert Damage	Insert found OK, No damage		
9.	Machine	Pressure less	Less pressure caused hole shift issue in trimming stage		
10	Machine	Pressure more	More pressure caused tool mark in part	△	
11	Machine	Less molding time	Less molding time caused shape deformation & hole shift in trimming stage		
12	Machine	More molding time	No impact		
13	Material	Less elongation	Less elongation of fabric causes short fill issue		
14	Material	More elongation	No impact		
15	Material	Blank weight less	Sometimes causes short fill issue		
16	Material	Blank weight more	No impact		
17	Material	Less Strength	No impact		
18	Material	More strength	No impact		
19	Material	Loose punching	No impact		

20	Material	Wrong fitment	Causes improper alignment	(	\
21	Method	No prescribed way for part ejection	No impact		\
22	Tool	Improper clamping	Caused crease issue	(	\
◎ Strong Relationship		○ Medium Relationship		△ Weak/No Relationship	

4.5 Control Phase

In the final phase of the DMAIC approach, known as the control stage, the focus shifts towards ensuring the sustainability of the implemented improvements and maintaining the achieved level of quality. This phase entails monitoring the production process closely to verify that the recommended changes have been effectively implemented and are yielding the desired results.

Following the implementation of improvement measures, ongoing data collection and analysis are conducted to assess the impact of the changes on key performance indicators. Comparisons are made between the new data and the targets specified in earlier stages to evaluate deviations and identify areas for further refinement. This iterative approach allows for continuous fine-tuning of processes to optimize performance and minimize defects.

Figure 14 and Figure 15 depict the post-implementation PPM (Parts Per Million) levels for short fill and black dot defects, respectively. These figures serve as visual indicators of the effectiveness of the implemented improvements in reducing defect rates and achieving the desired quality standards. By closely monitoring PPM levels and other quality metrics, deviations from targets can be promptly identified and addressed, ensuring that the production process remains on track towards meeting quality objectives.

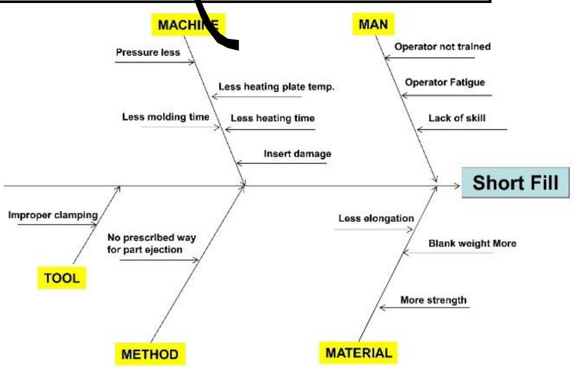

Figure 12. Cause and Effect diagram to analyse the root cause of the defect short fill

Table 2. Improvement measures to address the issue of short fill defect

S. No.	Parameter	Before	After
1	Pressure	Less	Suggested to increase (Production & Maintenance Department)
2	Heating Plate Temperature	Less	Increased Hopper Temperature by 5-10 degree at intervals.
3	Heating Time	Less	Suggested to increase (Production & Maintenance Department)

`4	Insert	Found to be damaged	Informed Tool room and suggested to update their schedule
5	Molding Time	Less	Suggested to increase (Production & Maintenance Department)
6	Clamping	Minor Loosing	Screw was tightened
7	Method	No proper instructions to remove piece	Instruction was installed and added in their training schedule

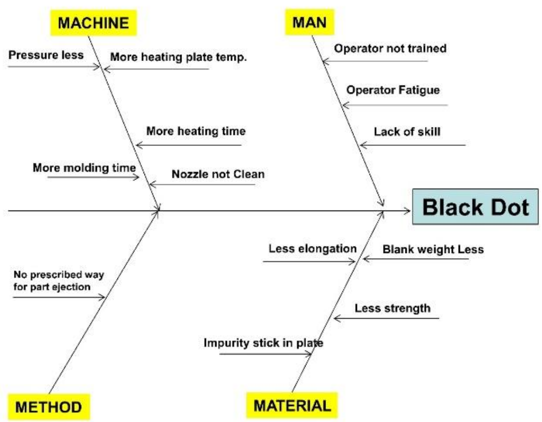

Figure 13. Cause and Effect diagram to analyse the root cause of the defect Black Dot.

In addition to monitoring quality metrics, standardization efforts are carried out during the control phase to institutionalize the implemented improvements and establish consistent operating procedures. Scheduled trainings covering technical skills, safety protocols, and motivation are conducted to ensure that personnel are equipped with the necessary knowledge and competencies to uphold quality standards. Increasing the frequency of rough cleaning in and around machines daily helps to maintain cleanliness and prevent contamination, further contributing to defect reduction.

Table 3. Improvement measures to address the issue of black dot defect

S. No.	**Parameter**	**Before**	**After**
1	Pressure	Less	Suggested to increase (Production & Maintenance Department)
2	Heating Plate Temperature	More	Increased Hopper Temperature by 5-10 degree at intervals.
3	Heating Time	Less	Suggested to increase (Production & Maintenance Department)
`4	Nozzle	Carbonized	Suggested cleaning after every hour of interval
5	Die	Having dust particles	Clean after every 2 hours with spray (Cleaning agent) for better life
6	Molding Time	More	Suggested to Decrease (Production & Maintenance Department)
7	Clamping	OK	No change
8	Method	No proper instructions to remove piece	Instruction was installed and added in their training schedule

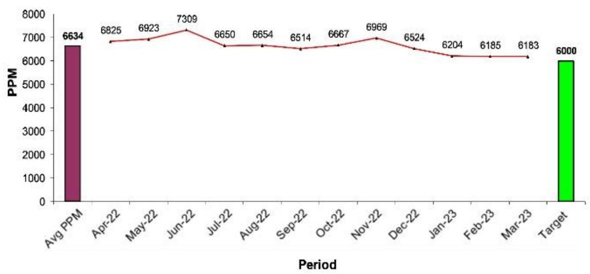

Figure 14. PPM after implementations Short Fill defect

To reinforce adherence to standardized processes, proper instructions are installed, and work instructions are regularly updated to reflect any changes or improvements. Improvement sheets are created and submitted to the engineering team for review and action, facilitating continuous improvement efforts and ensuring that any issues or opportunities for enhancement are promptly addressed. Additionally, the PFMEA (Process Failure Modes and Effects Analysis) is updated to incorporate any new insights or learnings gathered from the implementation phase, enhancing the robustness of the quality management system.

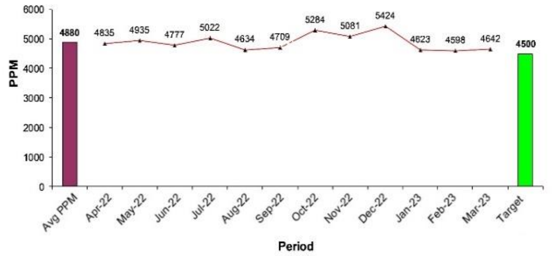

Figure 15. PPM after implementations in case of Black Dot defect

5. Conclusions

Based on the findings derived from the present study on quality improvement strategies in injection moulding, the following conclusions can be drawn specifically from the conducted work:

- The analysis of historical rejection data revealed a significant deviation from the budgeted targets, indicating a pressing need for quality improvement measures in the injection moulding process at XYZ Company.
- Pareto analysis identified "Light Guide KWPM" as the focal point for the quality improvement project, highlighting its prominence in rejection data and justifying its selection as the target part for intervention.
- The investigation into specific defect types, such as short fill and black dot defects, provided valuable insights into the prevalence and nature of defects affecting the production of "Light Guide KWPM" parts.
- Cause validation sheets and cause-and-effect diagrams facilitated a structured analysis of potential root causes associated with the identified defect types, guiding the development of targeted improvement strategies.
- Proposed improvement measures aimed at addressing short fill and black dot defects included optimizing processing parameters, enhancing tooling and mould design, and implementing rigorous cleaning and maintenance protocols.
- The control phase emphasized the importance of ongoing monitoring and standardization efforts to sustain improvement gains and ensure consistent product quality over time.
- Collaboration among cross-functional teams, data-driven decision-making, and adaptation to emerging technologies emerged as critical factors for success in quality improvement initiatives within the injection moulding process.

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