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Identification and Mitigation of Risk Factors in The Injection Moulding Process for Automotive Plastic Components

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Abstract

Injection moulding process is used for manufacturing different kind of products such automobile parts, toys, plastic boxes, pocket combs, Mechanical parts, tables etc. There are different kind of process involved in injection Moulding. Initially all the moisture from the raw materials removed by using a dryer which will fed to each machine hopper through central feeding system. Injection moulding machine has two sections available. Injection unit has mainly two parts Injection unit and clamping unit. The components of injection moulding machine are Carriage unit, Barrel, reciprocating screw motor drive, heater and Thermocouple. Similarly, the clamping unit consist of mould, clamping motor drive, Tie bar. Initially the raw material from the central feeding system will be supplied to the hopper. From the hopper the material will be moved to the barrel on requirement. Inside the barrel the material will be heated and melted. The melted material will be injected to the mould through the nozzle and will be cooled down and final product is removed either by hand picking or using a robot. There are several kinds of hazards involved in injection moulding process such as crushing hazard, burn hazard, entanglement hazard, impact hazard, electric shock hazard etc. Necessary control measures and safety devices should be provided to the injection moulding machines to prevent accidents in the injection moulding process. Standard SOPs are available for each process in the moulding. Some of the safety devices available in the injection moulding are light curtain, emergency stop button, safety mat, interlocking door, limit switches for purge guard and rotating parts of the machine etc. A proper HIRA need to be maintained in which all the hazards associated with injection moulding machines should be identified and control measures such as engineering and administrative measure to mitigate the affect should be maintained.

Keywords: Injection Moulding Process, Automotive Plastic Components, Failure Mode and Effect Analysis, Communication Channels, Data collection.

1. Introduction

Injection moulding is one of the most widely used manufacturing processes for producing complex and high-volume plastic parts. This versatile technique is employed in a variety of industries, including automotive, consumer electronics, medical devices, and packaging. In this comprehensive guide, we will explore the principles, processes, equipment, materials, applications, advantages, and challenges of injection moulding. Whether you're a novice looking to understand the basics or an experienced professional seeking in-depth information, this guide will provide valuable insights into the world of injection moulding. Injection moulding is a manufacturing process where molten material is injected into a mould cavity under high pressure. The material solidifies in the mould and takes the shape

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of the cavity, injection moulding forming a finished part. The most common materials used in injection moulding are thermoplastics, but thermosetting plastics, elastomers, and even metals can also be injected into moulds in specialized processes. This process is used primarily for mass production, making it ideal for manufacturing large quantities of identical parts with high precision and repeatability.

2. Literature Review

Ahmad A. M. Idris, (2024) et al In this paper different perspectives about the injection moulding process was discussed and the most notable current trends that would streamline the industry was also highlighted. Firstly, the importance of reshoring in the industry was mentioned and its effect on the economy was highlighted. Similarly, the importance of process validation as another trend was thoroughly discussed which would help to maintain the quality of the product and keep customers happy and satisfied as injection moulding is used in industries such as pharmaceutical where quality is highly important. Micro moulding is considered a very important trend in the injection moulding process where high precision and accuracy matters. Computerized and hybrid injection moulding process along with the application of energy efficient drives create a cutting-edge technology and a growing trend in the industry that would help the industry maintain its name as an eco-friendly industry. Hence based on these trends it can be concluded that the future is bright for the injection moulding industry [1].

3. Problem Identification

Injection moulding is a widely used process in the automotive industry for producing plastic components, offering cost efficiency, high precision, and the ability to manufacture complex shapes. However, the process involves several risk factors that can negatively impact the quality, functionality, and cost-effectiveness of automotive parts. These risks, if not identified and mitigated early in production, can lead to defects, delays, and increased production costs, which are particularly critical in the automotive sector where safety, durability, and compliance with strict regulations are paramount. The primary challenges in this project stem from various risk factors that can occur during the injection moulding process. Material-related risks, such as contamination, incorrect material selection, and inconsistent material quality, can affect the physical properties of the plastic components, leading to part failures or reduced lifespan. Equipment-related risks include machine malfunctions, wear and tear of the mould, and inconsistent machine settings, which can cause production downtime, inconsistent part quality, and defects like flash or misalignment [2].

4. Methodology

Table 1 Risk Identification and Mitigation Framework for Injection Moulding Process

Identify Risk Factors in Each Stage of the Injection Moulding Process
↓
Assess the Potential Impact of Each Risk Factor
↓
Perform Root Cause Analysis
↓
Develop Mitigation Strategies for Each Identified Risk Factor
↓
Implement Preventive Measures and Monitoring Systems
↓
Analyze Data for Continuous Improvement
↓
Review and Update Risk Management Procedures Regularly
↓
Establish a Risk Communication Plan

5. Identify the Injection Moulding Process Stages

The injection moulding process consists of several key stages that are crucial for producing high-quality plastic parts. In Material Preparation, the plastic resin is carefully dried and mixed, if needed, to eliminate moisture and ensure consistent material properties. This step helps prevent defects like bubbles or cracks that can result from excessive moisture content. In

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Moulding Process, the prepared resin is melted and injected into a mould cavity under high pressure.

5.1.Stage 1: Material Preparation

Material preparation is the foundational step in the injection moulding process, ensuring the plastic resin is suitable for the moulding operation. The first part of this stage involves drying the plastic resin, as many types of plastic, such as nylon or polyethylene, are hygroscopic and absorb moisture from the air. Excess moisture can lead to issues such as bubble formation, poor surface finish, or even part failure [3].

5.2.Stage 2: Moulding Process

The moulding process is the core of the injection moulding operation, where plastic resin is transformed into the desired shape. In this stage, the prepared plastic resin is fed into the injection moulding machine, where it is heated to its melting point in a barrel. The temperature is carefully controlled to ensure the resin melts evenly without degradation, which could negatively affect the part's final properties. Table 1 shows Risk Identification and Mitigation Framework for Injection Moulding Process.

5.3.Stage 3: Cooling & Solidification

Cooling and solidification are critical steps in the injection moulding process, as they directly affect the part’s final shape, strength, and dimensional accuracy. After the molten plastic is injected into the mould cavity, it begins to cool and solidify. The cooling rate must be carefully controlled, as uneven cooling can lead to defects like warping, sink marks, or residual internal stresses. A cooling system, usually consisting of water channels or coolant systems embedded within the mould, maintains a consistent temperature throughout the cavity. Cooling time can vary depending on the material, part thickness, and complexity of the mould design.

5.4.Stage 4: Ejection

Ejection is the final stage of the injection moulding process, where the cooled and solidified part is removed from the mould. This step must be carefully controlled to avoid damage to both the part and the mould. After the plastic has cooled sufficiently, the mould opens, and an ejection system typically consisting of ejector pins, plates, or airbags pushes the part out of the cavity.

6. Identify Risk Factors in Each Stage of the Injection Moulding Process

In the injection moulding process, various risk factors arise at each stage that can impact the quality of the final product. In the material preparation stage, the primary risks are moisture content, which can cause defects like bubbles and cracks during processing, inconsistent material mixing, leading to uneven strength or color, and improper material storage, which can result in contamination or degradation due to exposure to moisture or temperature fluctuations. Moving to the moulding process, risks include incorrect temperature settings, which may lead to under or over-moulding, excessive injection pressure, causing defects like warping or flash, and inconsistent injection speed, which can lead to incomplete filling or air traps.

6.1 Material Preparation Risk Factors

- Moisture Content in Raw Material
- Inconsistent Material Mixing
- Improper Material Storage

6.1.1 Moisture Content in Raw Material

- Risk of Defects
- Moisture Evaporation During Heating
- Impact on Material Flow
- Degradation of Resin Quality
- Process Instability
- Poor Surface Finish
- Risk of Material Contamination
- Higher Scrap Rate

6.1.2 Inconsistent Material Mixing

- Uneven Resin Properties
- Defects in Product Strength
- Inconsistent Surface Finish
- Variation in Material Viscosity
- Poor Dimensional Accuracy
- Increased Scrap Rates
- Incompatibility of Additives
- Increased Wear on Mould

6.2 Improper Material Storage

Improper storage of plastic resins can result in contamination or degradation due to exposure to moisture, dust, or extreme temperature fluctuations. Moisture absorption, improper ventilation, and temperature changes can cause the resin to lose its integrity, affecting its physical properties. Contaminants like dirt or foreign particles can also affect material flow and lead to surface defects or product failure [5].

- Moisture Absorption
- Contamination
- Degradation of Resin
- Material Clumping
- Inconsistent Material Quality
- Loss of Material Integrity
- Increased Scrap and Waste
- Reduced Shelf Life

7. Assess the Potential Impact of Each Risk Factor

Product quality can be severely affected by several risk factors. For instance, moisture content in materials can lead to defects like bubbles, cracks, and poor surface finish, impacting dimensional accuracy. Inconsistent material mixing results in uneven strength and can cause dimensional inaccuracies. Incorrect temperature settings and poor material flow can affect the final part's shape and surface finish, leading to an overall reduction in product quality. Production efficiency can also be impacted. Factors like incorrect temperature settings, excessive injection pressure, or poor cooling control may result in longer cycle times and reduced throughput, as parts may need additional processing or may not be ready for the next cycle. Mould wear can also lead to slowdowns due to maintenance or retooling. Assess the Potential Impact of Each Risk Factor. Safety risks are always a priority. Inconsistent ejection timing or insufficient ejection force can cause parts to get stuck, potentially leading to worker injuries during manual interventions or equipment damage from improper handling. Furthermore, improper cooling and high pressures can lead to hazards in machinery operation. Lastly, costs are affected by defects such as scrap rates and rework due to subpar parts. Downtime from unexpected failures or mould damage also significantly raises operational costs. Reducing risk factors helps mitigate these negative impacts. defects like warping or flash, and inconsistent injection speed, which can lead to incomplete filling or air traps defects like warping or flash, and inconsistent injection speed.

8. Root Cause Analysis

8.1.Defect Overview

- Defects Identified: Warping, sink marks, dimensional inaccuracies, surface defects, incomplete filling.
- Total Defects Count: 125 defects observed over 1,000 units produced.
- Defect Rate: 12.5% (125/1000).

8.2.Data Collection

- Defect data was collected from production logs, quality control inspections, and operator feedback. Key parameters monitored included:
- Mould temperature
- Injection pressure and speed
- Material type and quality
- Cooling time
- Ejection system function

8.3.Statistical Tools Used

- Pareto Analysis: Identified the top 3 defects contributing to 80% of the total defect rate.
- Warping: 50%
- Dimensional Inaccuracies: 20%
- Surface Defects: 10%

8.4.Fishbone Diagram (Ishikawa): Root causes identified

- Material issues: inconsistent moisture content, incorrect polymer grade.
- Process control: temperature fluctuations, improper injection pressure.
- Machine issues: mould wear and tear, ejection system failures.
- Human factors: improper machine settings, lack of operator training.

8.5.FMEA (Failure Mode and Effect Analysis)

- Failure Mode: Warping
- Severity: 8/10
- Occurrence: 6/10
- Detection: 4/10
- Risk Priority Number (RPN): 192 (Severity x Occurrence x Detection)
- Corrective Action: Improve material moisture control, adjust cooling rates.

8.6.Root Cause Identification

- Inconsistent material quality was the primary

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factor contributing to warping and dimensional inaccuracies.

- Injection pressure variations led to surface defects.
- Mould wear caused incomplete filling in specific regions, increasing scrap rates.

8.7.Corrective Actions:

- Implement better moisture control and material inspection procedures.
- Optimize injection pressure and speed settings.

9. Develop Mitigation Strategies for Each Identified Risk Factor

9.1 Material Preparation Mitigation Strategies

To mitigate risks in material preparation, proper drying processes are essential to reduce moisture content in the resin, preventing defects like bubbles and cracks. Resins should be dried at recommended temperatures and humidity levels to ensure optimal material properties. Automated mixing systems should be used to ensure consistent resin quality by blending the correct amounts of additives, pigments, and resins, reducing the likelihood of material inconsistencies. Inconsistent mixing can lead to weak spots or uneven coloring. Additionally, material storage should be done in dry, controlled environments to prevent contamination and degradation [6].

9.2 Moulding Process Mitigation Strategies

For the moulding process, temperature monitoring and control systems should be implemented to maintain precise temperature settings throughout the injection cycle. Accurate temperature control helps avoid issues such as under or over-moulding. Adjustable injection pressure and speed parameters should be used to optimize material flow and prevent defects like flash or incomplete filling. Regular mould inspections and maintenance are critical to detect wear and tear, ensuring that the mould remains in optimal condition. Over time, moulds can degrade, leading to dimensional inaccuracies, so regular maintenance helps ensure precision [4]. ensure parts cool at the correct rate, cooling time optimization.

9.3 Cooling & Solidification Mitigation Strategies

During the cooling and solidification stage, implementing uniform cooling systems is crucial to prevent issues like warping or internal stresses. Using strategically placed cooling channels and ensuring uniform temperature distribution across the mould help avoid these problems. To ensure parts cool at the correct rate, cooling time optimization through process simulations and monitoring can help adjust parameters based on the part's geometry and material properties. Additionally, real-time temperature control and monitoring systems can be used to track the cooling process and make adjustments dynamically, ensuring consistent part quality. Monitoring the temperature throughout the cooling phase helps prevent both over and under-cooling, which can cause shrinkage, cracks, or warping. These strategies are vital for ensuring that the part solidifies properly, maintaining the desired shape and mechanical properties.

9.4 Ejection Mitigation Strategies

In the ejection stage, calibrating the ejection force is essential to prevent parts from getting stuck or damaged. Ensuring that the ejection system applies the correct force helps avoid damaging the part during removal. Implementing automated ejection timing based on cycle time analysis ensures that parts are ejected at the optimal time, preventing part distortion or damage due to premature or delayed ejection. Additionally, regular inspection of ejector pins and related components is necessary to ensure that they are functioning correctly. Ejector pins that are misaligned or worn out can cause defects such as scratches or deformation on the part's surface. By maintaining these components and ensuring proper calibration, the risk of part damage and downtime is minimized, and the overall quality of the part is maintained. Ejection mitigation strategies in injection moulding focus on ensuring smooth and defect-free part ejection. Cooling time adjustments can also minimize shrinkage, preventing parts from becoming stuck in the mould. Implementing high-quality mould materials and ensuring regular maintenance of the moulds and ejection system help avoid wear-related issues.

10. Implement Preventive Measures and Monitoring Systems

Implementing preventive measures and monitoring

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systems is crucial to ensuring the success of the injection moulding process. Installing sensors and automation is a key strategy to monitor critical parameters such as temperature, pressure, and material flow in real-time. By integrating temperature, pressure, and flow sensors, operators can track conditions throughout the process, identifying deviations that could lead to defects. Additionally, automation allows for automatic adjustments or shutoffs, ensuring that any issues are addressed before they cause defects, such as warping or incomplete filling. Performing regular preventive maintenance is another essential measure. Scheduling routine inspections and maintenance of machines and moulds helps to detect early signs of wear and tear, preventing unexpected failures and ensuring smooth operations.

- Install Sensors & Automation
- Perform Regular Preventive Maintenance
- Staff Training

10.1 Install Sensors & Automation

The implementation of sensors and automation is a crucial step in maintaining control over the injection moulding process and preventing defects. Installing temperature, pressure, and flow sensors allows for real-time monitoring of critical parameters that directly impact product quality. These sensors provide immediate feedback on the system's performance, enabling operators to identify deviations from optimal settings before they result in defects. For example, a temperature sensor can detect overheating or underheating, while pressure sensors can prevent issues related to excessive injection force. Additionally, incorporating automated shutoff or adjustments ensures that the system can respond automatically when conditions fall outside the acceptable range. This proactive approach prevents defects such as warping, flash, or incomplete mould filling by adjusting critical parameters, like injection pressure or cooling time, in real time. With automated controls in place, human error is reduced, allowing for consistent quality and reducing the need for corrective actions after the fact.

10.2 Perform Regular Preventive Maintenance

Regular preventive maintenance is a vital practice in ensuring the longevity and optimal performance of both machines and moulds in the injection moulding process. Scheduling routine inspections allows for the early detection of potential issues, such as wear and tear on mould surfaces, heating elements, or cooling channels. By identifying problems before they result in failure, manufacturers can avoid costly repairs, unexpected downtime, or production delays. Maintenance tasks should include checking for wear on moving parts, ensuring proper calibration of temperature and pressure controls, and verifying the integrity of mould components. Furthermore, ensuring that moving parts are regularly lubricated reduces friction and minimizes wear and tear, improving the reliability of equipment and enhancing the overall efficiency of the process. Lubrication also helps to prevent the malfunctioning of mechanical parts like ejector pins, preventing issues such as part sticking or damage [7].

10.3 Staff Training

Comprehensive staff training is essential to ensure operators can effectively manage the complexities of the injection moulding process and mitigate risks. Proper training should focus on helping operators detect and respond to common issues such as incorrect material handling, inconsistent moulding conditions, or improper cooling times. Workers must be able to identify issues such as temperature fluctuations, material contamination, or improper mixing before they result in defects. In addition, staff should be educated on material handling techniques, ensuring proper storage, mixing, and drying of resins to prevent moisture-related defects or contamination. Training should also include troubleshooting skills, empowering operators to address potential risks and problems quickly, thus minimizing downtime. Operators need to understand the root causes of common issues, such as excessive pressure or cooling inconsistencies, and know how to adjust parameters accordingly. Moreover, safety training is crucial to protect workers from potential hazards in the workplace, such as equipment malfunctions, burns from hot components, or exposure to chemicals.

11. Analyze Data for Continuous Improvement

Data Collection: Effective data collection is the foundation for continuous improvement in the injection moulding process. By systematically collecting process data such as cycle times, pressure, and temperature profiles, manufacturers can track the performance of each production cycle. This data provides valuable insights into how well the process is functioning and highlights areas for improvement. Monitoring scrap rates allows for the identification of recurring defects or inefficiencies, helping operators understand where problems consistently arise and take corrective action. Customer feedback is also an essential data source, as it offers direct insight into product quality from the end-user perspective. By analyzing customer complaints or returns, manufacturers can identify recurring problems, such as dimensional inaccuracies or surface defects, and take proactive steps to resolve them. The data collected can then be used to adjust machine settings, improve material handling, or refine cooling times. With continuous data collection, companies can detect early signs of issues, allowing them to act quickly and maintain high-quality production standards.

12. Review and Update Risk Management Procedures Regularly

Regularly reviewing and updating risk management procedures is essential to ensuring the long-term effectiveness of the injection moulding process. As processes, equipment, and materials evolve, so do the risks associated with them. Conducting frequent risk assessments allows manufacturers to identify new potential risks and evaluate the effectiveness of existing mitigation strategies. This ongoing evaluation helps to detect any emerging issues before they lead to defects or production delays.

13. Establish A Risk Communication Plan

Creating a Risk Communication Plan is essential for ensuring that risks are quickly identified, reported, and addressed in the injection moulding process. The plan should begin by establishing clear channels for reporting risks at all levels of the production line. Operators should have a designated method whether through a digital system, a reporting form, or direct communication with supervisors to immediately notify management of any identified risks, such as equipment malfunctions, material inconsistencies, or safety hazards. This ensures that potential problems are communicated quickly and can be dealt with before they escalate. Additionally, fostering a culture of open communication between operators, supervisors, and management is key to successful risk management.

- Risk Identification and Assessment
- Stakeholder Identification
- Clear Communication Objectives
- Communication Channels
- Timely Updates
- Roles and Responsibilities
- Risk Mitigation Actions
- Feedback Mechanism
- Documentation and Reporting
- Training and Awareness
- Crisis Management

13.1 Injection Moulding Machine Hazards

- Crushing hazard
- Fire hazard
- Electrical shock hazard
- Burn Injury
- Entanglement Hazard
- Robot Hazard
- Slip Hazard
- Compressed air hazard

13.2 Safety Devices in Injection Moulding Machines

- Front door & Rear door electrical Limit switches
- Emergency Stop Bottom
- Safety Light curtain
- Fixed Guard
- Purge guard Interlocking:
- Ceramic cap cover for Barrel

Conclusion

The research aimed to address the critical risks within the injection moulding process, identify their potential impacts, and implement effective mitigation strategies to improve both quality and efficiency in production. The systematically identifying the stages of the injection moulding process such as material preparation, moulding, cooling, and ejection we were able to pinpoint specific risk factors at each stage, ranging from material inconsistencies and temperature fluctuations to ejection failures and human error. The potential impacts of these risks were then assessed, highlighting how they could lead to production delays, increased scrap rates, and defective parts, ultimately affecting product quality and customer satisfaction Surge Characteristics and Impact on Industrial Equipment. Root cause analysis revealed several recurring issues, including insufficient mould maintenance, inconsistent process control, and inadequate operator training. These insights led to the development of targeted mitigation strategies, such as optimizing machine settings, improving material quality control, implementing regular mould inspections, and enhancing staff training programs. Preventive measures were implemented, including the installation of monitoring systems to track key parameters like temperature, pressure, and cooling times, as well as the creation of a robust risk communication plan to ensure that all stakeholders were promptly informed of any potential risks and their corresponding corrective actions. The implementation of these strategies has not only mitigated immediate risks but also fostered a culture of continuous improvement. The regularly analyzing production data and updating risk management procedures, the process will remain adaptable and resilient to new challenges. The project has significantly reduced risk factors in the injection moulding process, ensuring higher quality automotive plastic components, improved production efficiency, and a more proactive approach to risk management.

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