DOI : https://doi.org/10.56452/7-8-42

ISSN: 0974-5823 Vol. 7 No. 8 August, 2022

International Journal of Mechanical Engineering

Overcoming Current Challenges and Implementing Failure Mode and Effect Analysis (FMEA) in small industry for Defect Reduction in Blow-Moulded High-Density Polyethylene (HDPE) Parts

Mr. Dipak U. Gopekar[1*], Dr. Raju S. Kamble[2], Dr. Lalit N. Wankhade[3]

[1] Research Scholar, Department of Production Engineering, SGGS Institute of Engineering and Technology, Nanded 431606, India

[2] Department of Mechanical Engineering, Gramin Technical, and Management Campus, Nanded 431606, India

[3] Professor, Department of Production Engineering, SGGS Institute of Engineering and Technology, Nanded 431606, India

*Corresponding Author: dipsgopekar@gmail.com

Abstract

Blow moulding is one of the important plastic working processes making hollow shapes, containers, bottles etc. Different materials like High-Density Polyethylene (HDPE), Low-Density Polyethylene (LDPE), Polyethylene Terephthalate (PET), Polypropylene (PP), Polyvinyl Chloride (PVC) can be easily worked with. Small units This paper describes the uses process FMEA as a tool for defect reduction in the SME plastic industry. Some of the challenges for the implementation of FMEA were identified and tried to be addressed carefully and successfully to the extent possible. The FMEA methodology is a process that can overcome and reduce defects and give the desired result. Current RPN is calculated with severity, occurrence, and detection for each failure, and related actions were taken to reduce this high RPN i.e., Decrease the failure. New RPN shows a reduction of problems, and defects as mentioned are reduced.

Keywords: Blow Moulding, FMEA, HDPE, Moulding Defects,

DOI : https://doi.org/10.56452/7-8-42

1- Introduction

Blow moulding is a manufacturing process used to produce hollow plastic or glass containers. It is commonly used for items such as bottles, containers, and other hollow shapes. The process involves extruding a molten tube of plastic material (called a parison) and then inflating it inside a mould to form the desired shape. Steps in the blow moulding process are as: Extrusion: Plastic pellets or granules are melted and extruded into a long tube called a parison. Mould Closure: The mould, which has two halves, closes around the parison. Inflation: Compressed air is blown into the parison, causing it to expand and take the shape of the mould cavity. Cooling: The material is allowed to cool and solidify while still inside the mould. Mould Opening: The mould opens, and the finished product is ejected.[1]

Blow moulding has Process Parameters such as Extrusion temperature: The temperature at which the plastic is melted and extruded. Blow air pressure: The amount of air pressure used to inflate the parison. Mould temperature: The temperature at which the mould is maintained to aid in cooling and solidification. The blow moulding process has some distinct advantages as Cost-effective for high-volume production, produces lightweight and durable containers, Suitable for various shapes and sizes, Minimal material wastage compared to other processes like injection moulding, and Rapid production rates for mass production. This process does possess disadvantages such as Limited design flexibility compared to injection moulding, Higher tooling costs compared to other processes like injection moulding, not being suitable for complex parts or intricate designs, and Potential for non-uniform wall thickness in the final product.[1]

Blow moulding has wide applications including bottles and containers for beverages, personal care products, household chemicals, etc. Automotive components like fuel tanks and ducts. Industrial and household containers, Toys and sporting goods, Medical and pharmaceutical containers. The common materials to work with are High-Density Polyethylene (HDPE), Low-Density Polyethylene (LDPE), Polyethylene Terephthalate (PET), Polypropylene (PP), Polyvinyl Chloride (PVC). Blow moulds are typically made from metal (aluminium or steel) and can be either single-cavity or multi-cavity, depending on production requirements. Mould cavities are machined to the desired shape of the final product. This process has defects in Blow Molding as uneven wall thickness: Caused by improper parison distribution or mould design. Flash: Excess material around the edges of the moulded part due to improper mould closure. Blow holes: Air pockets or voids in the material caused by inadequate air pressure during inflation. Parting line defects: Occur at the seam where the two halves of the mould meet. Warping: Deformation of the part due to uneven cooling or improper material distribution.

2- Literature Review

Tahboub and Rawabdeh [2] employed a design of experiments to optimize the operating conditions (screw speed, melt temperature, cooling time, blowing pressure, blowing time and mold temperature) that minimized the variability with time of the volume of the container. Agrawal et al. [3] applied a statistical data analysis based on the Taguchi method and a Grey relational analysis to establish the operating conditions that maximized the compressive strength and volume accuracy of the part. Likewise, Dohare et al. [4] found the operating conditions that maximized haze and clarity, hardness and compressive strength, based on experimental data. DiRaddo and Garcia-Rejon [5] proposed a simple iterative procedure (Newton–Raphson technique) to define the parison thickness profile capable of minimizing the overall thickness variations of the final part, the solutions proposed being obtained with a 3D.

Huang and Huang [6] determined the parison thickness distribution that produced apart with a predefined thickness profile. Hopmann et al. [7] determined the thickness distribution of the injected preform that created a blown bottle with a specific wall thickness distribution. The modelling results were obtained using a response surface methodology based on 3D numerical computations, while the optimization was supported by an empirical approach. Bordival et al. [8] applied a Simplex method (the Nelder–Mead optimization algorithm) to define the adequate axial temperature distribution of the preform making a bottle with uniform thickness, using results obtained with a 3D modelling software. The preform thickness profile was also optimized by Biglione et al. [9,10], who attempted to minimize the normalized square root of the difference between the predefined bottle thickness profile and the thickness profile calculated for the solutions by a 3D numerical software. For that purpose, the simplex method and a simple predictor/ corrector iterative method were used successively.

Demirel [11] used a design of experiments and a response surface method to define, based on experimental data, the operating conditions related to the blowing stage (mold surface temperature and residence time of the bottle in the mold) that optimized the performance of the part (in terms of mechanical and thermal properties). Lee and Soh [12] determined the thickness profile of a preform that created a part with a pre-defined thickness contour, while satisfying two constraints (a minimum wall thickness and the absence of undercuts in the inner surface of the preform). The Brent algorithm (a single objective optimization method based on gradient) was applied, and a 3D numerical modelling softwares applied the results. Thibault et al. [13] optimized the preform thickness and the operating conditions for injection stretch blow moulding, using a gradient-based optimization strategy.

The primary objective of this paper is to introduce an enhanced version of the Failure Mode and Effects Analysis (FMEA) that improves the reliability of assigning scores to the occurrence factor. Additionally, the paper aims to establish a direct correlation between the FMEA chart and maintenance activities.[14]

Brainstorming and fishbone diagrams serve as tools to gather information concerning the loss, specifically when the Blow Molding Machine encounters production process failure. Through the implementation of Failure Mode and Effect Analysis (FMEA), the contributing factors behind the failure are identified, and their risk priority levels are determined using the RPN (Risk Priority Number) value. The combined findings of the brainstorming method, fishbone diagram, and FMEA indicate that a significant potential failure factor is the cessation of operations in the Blow Molding Machine. Among the various factors analyzed, mold damage emerges as the primary contributor with the highest RPN value. Consequently, to mitigate the risk of the Blow Molding Machine's failure to operate, it is imperative to focus on conducting repairs and implementing mold control measures to minimize any potential damage to the mold.[15]

This article provides an extensive overview of research pertaining to the determination of process parameters in injection moulding. Numerous studies are explored, employing diverse approaches such as mathematical models, the Taguchi technique, Artificial Neural Networks (ANN), Fuzzy logic, Case Based Reasoning (CBR), Genetic Algorithms (GA), Finite Element Method (FEM), Non-Linear Modeling, Response Surface Methodology, Linear Regression Analysis, Grey Rational Analysis, and Principle Component Analysis. The utilization of cavity pressure signals is a key aspect in these investigations, contributing to a comprehensive understanding of the subject matter [16]

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The research introduces the utilization of soft computing technology for determining the optimal die gap programming in the extrusion blow moulding process. The study employs Taguchi's experimental design and back propagation network to establish a connection between the design variables and the response. To minimize the number of simulations and model the entire process efficiently, BlowSim, a Finite Element Method (FEM) software, is utilized to obtain the optimal parameters.[17]

The study utilizes the Pareto and Failure Mode and Effects Analysis (FMEA) methodology to systematically examine and analyze defects, aiming to enhance product quality. By implementing the suggested actions, significant improvements are achieved, leading to a reduction in individual Risk Priority Number (RPN) and lowering the associated risk level for each defect.[18]

The optimization strategy proposed in this study involves conducting Design of Experiments (DoE) to analyze various combinations of control parameters. Multiple levels of each control parameter are considered during the analysis. The Signal-to-Noise Ratio (S/N ratio) concept is applied to identify the optimal values of process control parameters for Pushing Zone Temperature, Dimmer Speed, and Die Head Temperature. Furthermore, a Confirmation Experimental Run is performed to validate the analysis and research findings. The results from this run demonstrate a significant improvement in the withstanding pressure, which aligns well with the main experimental conclusions.[19]

This Indian Standard IS 15550:2005 for FMEA was adopted by the Bureau of Indian Standards and is widely practised by the automotive component production industries of the Aurangabad region. FMEA is a problem-prevention technique for identifying or investigating potential failure modes and related causes. It is one of the methods of reliability analysis intended to identify failures having significant consequences on the system performance in the application considered. [20] The FMEA is an integral part of the Production Part Approval Process documentation (PPAP) to be submitted as a vendor to first-tier companies or OEMs of automotive parts in the Aurangabad region. Many of these industries are accredited by TUV Nord and requires ISO 9001:2015 and IATF 16949:2016 certifications which has the role of FMEA in it.

3.1- Industry Profile, Products

Shri Balaji Industries Pvt Ltd is an industry (SME) situated in Waluj MIDC Aurangabad manufacturing articles by Plastic Injection Moulding and Extrusion and Blow Moulding. The company product line has oil bottles (500 ml,1000ml), PET jars (200 ml, 500ml, 1000ml) & bottles (250ml,500ml,1000ml), pesticide and fertilizer bottles (250ml,500ml,1000ml round and square), 5 litres of edible oil PET, normal, HDPE can, phenyl bottles, round tool/cutter box, square tool holders, **cow money box/bank**.

3.2 Cow Money bank material and manufacturing details

Out of all the products cow money bank is one of the most produced as its demand is higher because it is directly given to the devotees by a nearby famous temple or people can also buy them on its premises. Created from High-density polyethylene (HDPE), a polymer with ethylene as its monomer, this product possesses several desirable qualities. HDPE is classified as a thermoplastic and exhibits an exceptional strength-to-density ratio. Its versatility allows for a wide range of applications, from pipes to storage bottles. Compared to other plastics, high-density polyethylene has a relatively high melting point. This attribute contributes to the durability and longevity of products made from HDPE. Additionally, HDPE is easy to maintain and ensures that food stored in HDPE containers remains uncontaminated, making it a safe choice for human usage.

The popularity of high-density polyethylene can be attributed to its low weight, high tensile strength, excellent impact resistance, resistance to chemicals and high temperatures, and its malleability, enabling easy moulding. High-density polyethylene bears the resin identification code of 2, signifying its recyclability. Even though it is non-biodegradable, HDPE is regarded as an environmentally responsible plastic. The recycling process allows for the reuse of HDPE in various applications, such as plastic furniture and automobile parts.

The process typically used for manufacturing HDPE money banks is blow-and-blow moulding. From granules, the material is melted and extruded into a parison which again blew into product. Moulding is a common method for producing plastic products with complex shapes and precise details. In this process, HDPE resin pellets are melted, and the parison is made by extrusion which is then cut into a mould and blown with high air pressure inside a closed mould. The molten HDPE fills the mould cavities, taking the shape of the money bank, and then cools and solidifies to form the final product. Blow moulding offers efficiency, accuracy, and the ability to mass-produce identical items, making it suitable for producing HDPE money banks in large quantities.

The 13 heaters raised the temperature from 170 to 200^0c as per the environmental conditions for a charge and each shot is 250gm. Out of this 250gm, product weight is 150 ± 10gm and the remaining is waste (flash, sprues, gates, runners). This waste is grinded to recycle and mixed with virgin material up to 20-30% again to make the charge for shots.

3.3 Methodology

From past rejection data analysis and visual inspection by the author company engineer and operator key defects affecting quality were identified like surface roughness or poor surface finish, wall thickness variation, flash or excess material, mould sticking or difficulty in ejection, dimensional inaccuracy, leakage short shot, sink marks, flash, flow lines, and warpage. The detailed FMEA after 8 days of training to all and sample studies is done with a cross-function team of tooling and process engineer (one person do both the works), a quality person, and a machine operator along with research/author (done previous FMEA in Aluminium High-Pressure Die Casting, Shell moulding) for defect analysis. FMEA shows potential modes/causes and their effects (defects) which are critically analysed, and corrective action is taken for each assigned cause. After this new RPN is calculated and Both Old RPN and New RPN are compared for reduction of defects. The record of the same is documented for further reference and standardisation.

3.4 Defects

From a customer perspective, rework marks (scratches) unusual fitment of horns, slight or major colour variation, mismatching/misalignment, sink marks, flash, flow lines, and imperfect filling, some cow money banks have warpage at the stomach end of the product, are the key quality issues. Defects like surface roughness or poor surface finish, wall thickness variation, flash or excess material, mould sticking or difficulty in ejection, dimensional inaccuracy, leakage are occurring as per visual inspection and analysis.

4 The Purposes of FMEA

The FMEA serves multiple purposes: a) It can be implemented during the initial concept selection or design phase and then further enhanced and revised as the design progresses. b) It is employed to identify and evaluate potential failures of a product/process and their respective effects. c) It is valuable for identifying all possible causes, including root causes in certain cases, and establishing the relationships between these causes. d) It is used as a tool to facilitate the improvement of the design of any given product or process. e) It is utilized to document the entire process.

4.1 Challenges Encountered by Selected Foundry/Unit during FMEA Implementation

Implementing Failure Mode and Effect Analysis (FMEA) in small foundries may pose some unique challenges. Here are a few challenges that small units/foundries may encounter during FMEA implementation:

1. Limited Resources: The industry has limited personnel (4), time, and budget resources. Conducting FMEA requires dedicated resources for data collection, analysis, and implementation of corrective actions. So, they may struggle to allocate sufficient resources for effective FMEA implementation.
2. Lack of Expertise: FMEA requires a certain level of expertise and knowledge in casting processes, failure modes, and risk assessment. Small setups may have a limited pool of experienced personnel with the necessary skills and understanding of FMEA methodologies. This can hinder the accurate identification and assessment of failure modes.
3. Data Availability and Quality: FMEA heavily relies on accurate and reliable data to identify potential failure modes and evaluate their severity, occurrence, and detectability. Small industries may have challenges in collecting and maintaining comprehensive data due to limited documentation systems or historical records. This can lead to incomplete or inaccurate analysis, affecting the effectiveness of FMEA.
4. Resistance to Change: Implementing FMEA may require changes in existing processes, procedures, or practices. Small companies, particularly those with established traditional methods, may face resistance to change from employees or management. Overcoming resistance and fostering a culture of continuous improvement can be a significant challenge.
5. Complex Casting Processes: Analyzing failure modes and risks in processes can be more challenging due to the increased number of variables and interactions. It may require advanced knowledge and specialized tools for accurate analysis.
6. Lack of Standardization: FMEA implementation benefits from standardized processes and documentation. However, small foundries may have less formalized procedures or documentation systems compared to larger organizations. Lack of standardization

can hinder the consistency and effectiveness of FMEA across different projects or departments.

While small industries may face challenges in implementing FMEA, overcoming these obstacles can lead to improved process control, reduced defects, and enhanced product quality, ultimately benefiting the overall competitiveness and sustainability of the foundry.

4.2 Addressing the Challenges Encountered

To address these challenges, small foundries can consider the following steps:

a. Training and Education: Providing training and education to personnel involved in FMEA implementation can improve their understanding and skills. This can be achieved through internal training programs and external workshops. So, 8-day training was given to the personnel and sample studies were carried out for hands-on experience.

b. Collaboration and Support: Small foundries can collaborate with industry associations, universities, or research institutions to gain access to expertise, resources, and best practices related to FMEA implementation. The author was a part of cross-functional teams in ADC -12 High-Pressure Die Casting and Shell Moulding studies and did FMEA, so it was a supportive collaboration for both of us.

c. Prioritization and Phased Approach: Given limited resources, small industries can prioritize FMEA implementation by focusing on critical processes or high-risk components. They can gradually expand FMEA to other areas over time. So highly produced product and that products key defects were resolved on priority.

d. Process Documentation: Improving documentation systems and data collection processes can enhance the availability and quality of data for FMEA analysis. Implementing simple documentation templates or software tools can aid in capturing relevant information. The FMEA documents were retained with the industry and the MS-Excel sheet is asked to prepare for the FMEA so that this can be used as a standard template.

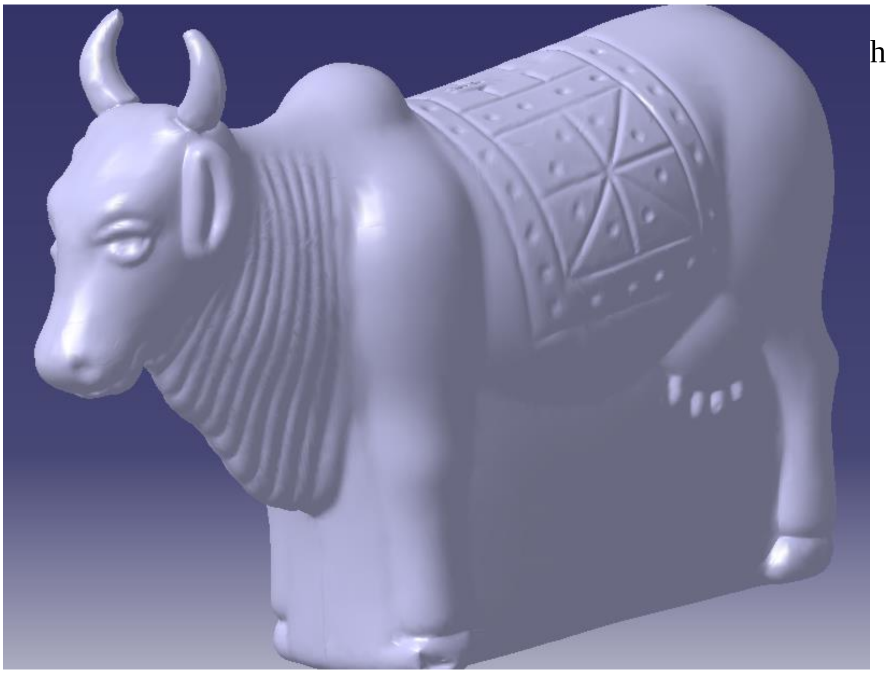
e. Continuous Improvement Culture: Creating a culture of continuous improvement and change management within the organization can facilitate FMEA implementation. Promoting open communication, feedback loops, and employee involvement can help overcome resistance and foster a proactive approach toward quality improvement. The owner is made aware of the role of communication, involvement, and feedback in the process of continuous improvement culture and so do all the employees.

4.3 Failure Mode and Effect Analysis

Failure Mode and Effects Analysis (FMEA) is a systematic approach used to identify potential failures in a process, system, or product, and analyze their potential effects. In the context of defects in plastic blow moulding, FMEA can be applied to proactively identify and mitigate potential failure modes.

Define the process or system: Plastic Extrusion and Blow Molding
Create an FMEA table with the following columns:
a. Failure Mode: Describe the potential defect or failure mode in plastic blow moulding.
b. Potential Effects: Identify the consequences or effects of the failure mode.
c. Severity: Assess the severity of each effect on a scale of 1 to 10, with 1 being the lowest severity and 10 being the highest.
d. Potential Causes: Identify the potential causes or sources of the failure mode.
e. Occurrence: Assess the likelihood of each potential cause occurring on a scale of 1 to 10, with 1 being the lowest occurrence and 10 being the highest.
f. Current Controls: Identify any existing controls or measures in place to prevent or detect the failure mode.
g. Detection: Assess the effectiveness of the current controls in detecting the failure mode on a scale of 1 to 10, with 1 being the least effective and 10 being the most effective.
h. Risk Priority Number (RPN): Calculate the RPN by multiplying Severity, Occurrence, and Detection values (RPN = Severity x Occurrence x Detection).
i. Recommended Actions: Propose actions to reduce the RPN and mitigate the potential failure mode.
j. Responsible Party: Assign responsibility to the appropriate person or team for implementing the recommended actions.
k. Target Completion Date: Set a deadline for completing the recommended actions.
l. Verification: Specify how the effectiveness of the recommended actions will be verified.

In the standard FMEA all these values are expressed on a 1 to 10 numeric scale. For early contributions on conversion tables for translating linguistic judgements in a 1-10 numeric scale, the reader can refer to Ben-Daya and Raouf (1996) and Gilchrist (1993). For instance, well-known published examples are available for the automotive (Ford Motor Company, 1988). From an analytic point of view, the evaluation of the RPN has several shortcomings. To the best of literature review on this topic was published by Liu et al. (2013).



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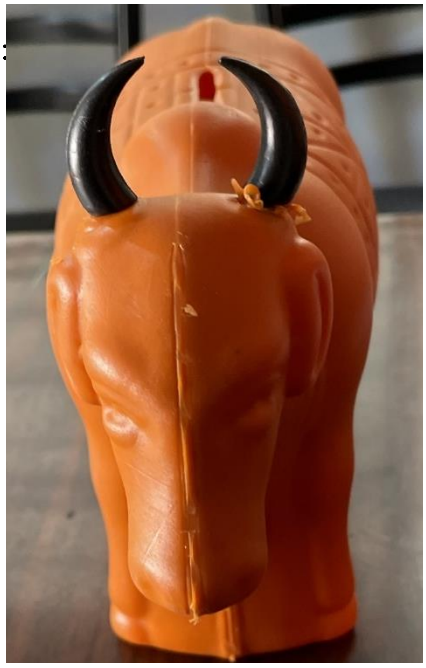
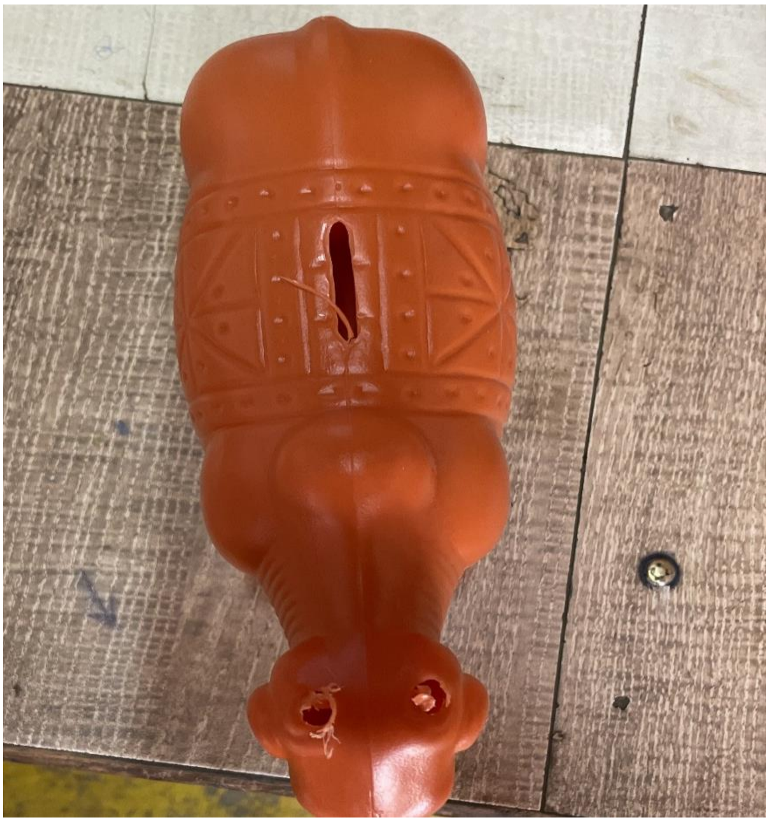
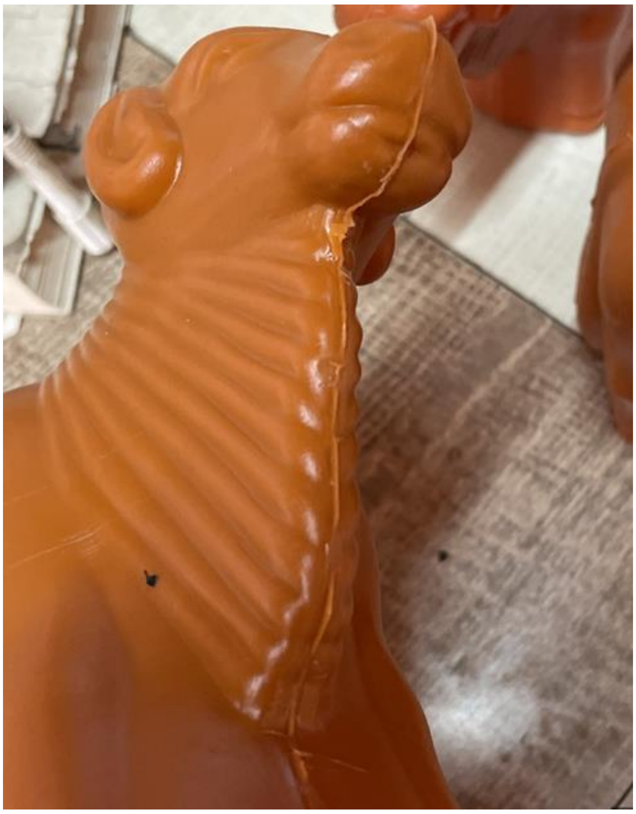
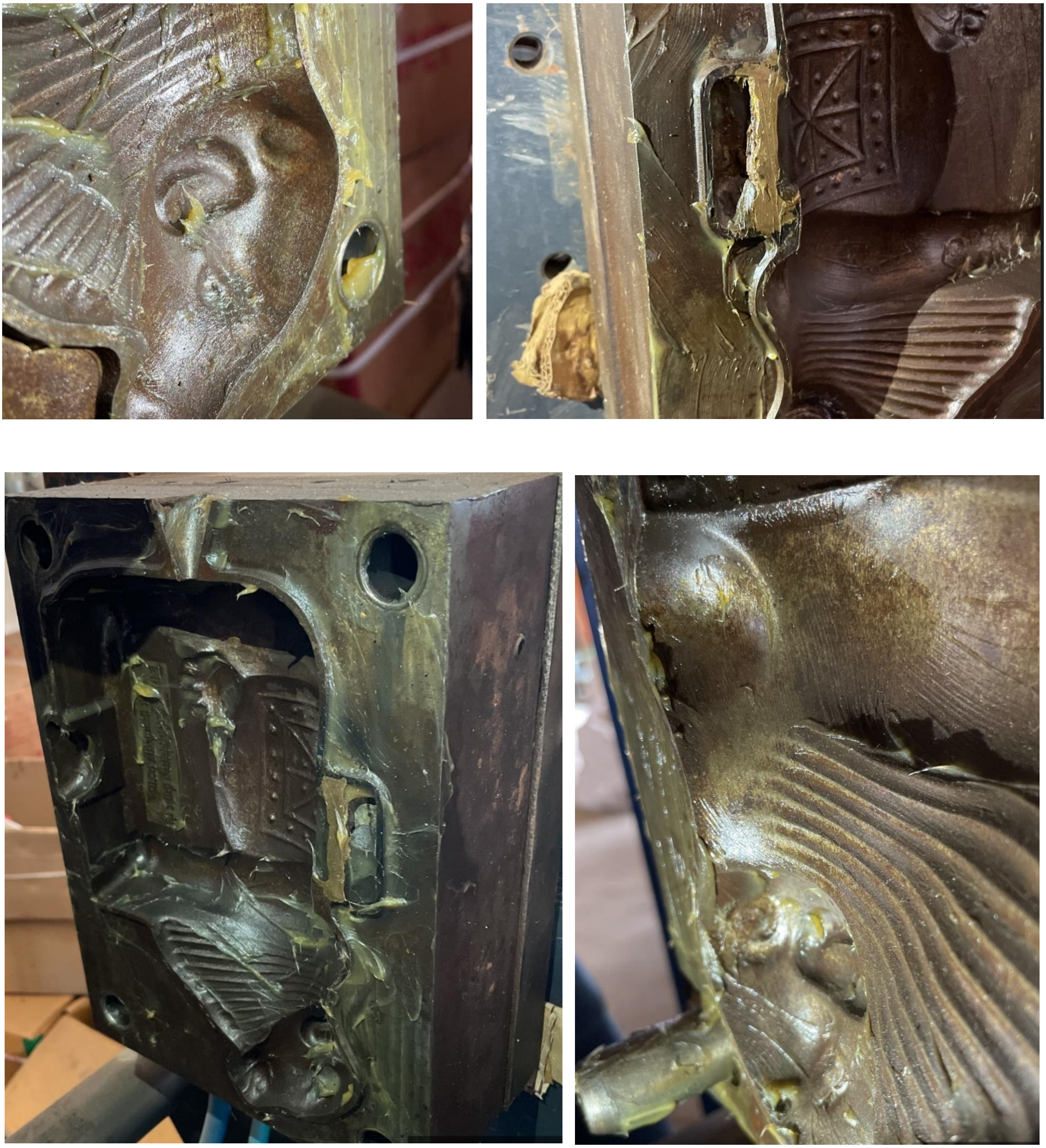






Figures in Clockwise Direction: - Image of 3D CAD Model of Cow Money Bank, Actual Assembled Model (With Horns) Cow Bank, Flash, Incomplete Shot and Dimensional Inaccuracy (Center), Burrs (Bottom Left), Flash, Sharp Parting Lines (Bottom Right)



Figures in Clockwise Direction: - Die Modifications First- Grooves/Hole to be increased in depth, Second Image (Top Right) -Brazing, Die Issues addressed with brazing for Dimensional Accuracy, Good Surface Finish, No Flow lines, Surface Irregularities etc.

4.4 Key insights in FMEA

The following points were clearly explained with examples, presentations and pictures from previous studies to the cross-functional team before the beginning of actual FMEA.

1. Process FMEA is centered around identifying and mitigating manufacturing-related factors rather than focusing on design-related issues.
2. For Design FMEA, the focus is on design-related causes, not manufacturing.
3. A reduction in the severity ranking index can be affected only through a design change.
4. Current Controls are methods that prevent and/or detect Causes or Failures of the product or service during (or after) production.
5. Prevention Controls help to prevent a manufacturing problem from being present.
6. Examples: Work Instructions, Procedures, SOP’s, Training
7. Prevention controls directly impact the Occurrence of Ranking
8. Detection Controls are those that detect manufacturing or product defect:
9. Examples: Contact Methods: measurement/detection through physical contact (e.g. – calipers, micrometers, surface roughness, etc.), Fixed-value Methods: Errors are detected through counting
10. Detection controls only impact the Detection, Ranking, not the Occurrence Ranking
11. To achieve a lower ranking, the planned controls have to be improved:
12. Improved effectiveness in detecting the failure mode or cause
13. Implementation of additional controls
14. Risk Priority Number (RPN) RPN = Severity × Occurrence × Detection
15. RPN is to be used as a guide to help rank design concerns.
16. RPN works like the Golf score concept (lower is better)
17. There should not be a “threshold” value.
18. Special attention should be given when the severity is high
19. RPN is a relative value.
20. RPN’s indicate the relative importance (urgency to address) of the different failures within the context of a specific FMEA review.
21. Comparing the absolute values of Risk Priority Numbers (RPNs) from different Failure Modes and Effects Analyses (FMEAs), even if they pertain to similar items or failure modes, should be avoided. Furthermore, it is not advisable to establish a threshold value for RPNs within the same FMEA.

22. The conclusions drawn from a Process FMEA should result in the following types of recommendations:

Design change to reduce Severity ranking (e.g., redundancy, change effect, etc.)

Design/Process change to remove a failure mode or cause from the process.

Implement additional prevention controls to reduce Occurrence ranking.

Enhance the efficiency of the detection method (e.g., through improved Measurement System Analysis, increased sensitivity, adopting a new method, etc.) to lower the Detection Ranking.

Recommended Actions Goal is to reduce the RPN (reduce risk)

23. A thorough FMEA will be of limited value without positive and effective actions to prevent Failure Modes/Causes or mitigate their effects. The FMEA team leader is responsible to implement a follow-up program to ensure all Recommended Actions have been adequately addressed. It’s all about continuous improvement and reducing risk to the organization.

4.5 FMEA of Cow Money Bank

The Complete FMEA of currently observed defects like Surface Roughness or Poor Surface Finish, Wall Thickness Variation, Flash or Excess Material, Mould Sticking or Difficult Ejection, Dimensional Inaccuracy, Leakage is shown in Table 1 with Before and After Severity, Occurrence, Detection and Risk Priority Number.

Table 1- Failure Mode and Effect Analysis of Commonly Observed Defects

Defect	Potential Causes	Before Severity	Before Occurrence	Before Detection	Before RPN	After Severity	After Occurrence	After Detection	After RPN
Surface Roughness or Poor Surface Finish	Mould surface wear or roughness	7	6	5	210	5	4	3	60
	Improper cooling or inadequate cooling time	5	6	5	150	4	5	4	80
	Contaminants in the mould cavity	5	5	5	125	5	3	5	75
Wall Thickness Variation	Improper material distribution or inconsistent material flow	8	6	4	192	5	5	4	100
	Mould wear or damage	6	5	6	180	4	4	5	80
	Insufficient cooling or inadequate cooling design	7	4	5	140	7	4	5	140
Flash or Excess Material	Mould wear or damage at the parting line or sealing areas	8	5	5	200	6	4	5	120

DOI : https://doi.org/10.56452/7-8-42

Defect	Potential Causes	Before Severity	Before Occurrence	Before Detection	Before RPN	After Severity	After Occurrence	After Detection	After RPN
	Insufficient clamping force causing misalignment	6	6	6	216	4	5	4	80
	Excessive material feed or improper blow parameters	7	5	6	210	4	4	5	80
Mould Sticking or Difficult Ejection	Accumulation of plastic material on the mould surface	5	4	5	100	5	4	5	100
Dimensional Inaccuracy	Mould wear or deformation leading to incorrect dimensions	8	5	6	240	6	4	5	120
Leakage	Improper mould sealing or damage to mould components	7	4	6	168	5	4	5	100

4.6 Potential Effects, Current Control, Failure Mode, Recommended Action, and Verification

The Table 2 shows **Potential Effects, Current Control, Failure Mode, Recommended Action and Verification** Methods for Complete FMEA of currently observed defects like Surface Roughness or Poor Surface Finish, Wall Thickness Variation, Flash or Excess Material, Mould Sticking or Difficult Ejection, Dimensional Inaccuracy, Leakage.

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Table 2- Potential Effects, Current Control, Failure Mode, Recommended Action, and Verification

Potential Effects	Current Control	Failure Mode	Recommended Action	Verification
Aesthetic defects, reduced product quality	Regular mould maintenance, periodic polishing	Rough surface finish	Polish or repair the mould surface	Visual inspection, surface measurement
Warping, dimensional inaccuracies	Optimize cooling system design, monitor cooling process	Dimensional inaccuracy due to cooling issues	Optimize the cooling system design and adjust the cooling time	Temperature monitoring, visual inspection
Surface defects, compromised product integrity	Strict cleanliness protocols, use of filtered air	Contamination of mould cavity	Clean the mould cavity thoroughly and use proper filtration	Visual inspection, cleanliness check
Inconsistent product strength, poor structural integrity	Optimize material distribution, control material flow	Inconsistent wall thickness across parts	Optimize material distribution and adjust blow parameters	Wall thickness measurement, visual inspection
Dimensional inaccuracies, reduced product performance	Regular mould inspection, timely repairs	Inconsistent wall thickness due to mould wear	Repair worn or damaged mould surfaces, Cu brazing is done at these locations	Mould inspection, dimensional measurement

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Potential Effects	**Current Control**	**Failure Mode**	**Recommended Action**	**Verification**
Warping, deformation, dimensional inconsistencies	Optimize cooling system design, monitor cooling process	Warping and dimensional inconsistencies	Optimize the cooling system design and adjust the cooling time	Temperature monitoring, visual inspection
Cosmetic defects, compromised part functionality	Regular mould inspection, repairs or replacements	Excess material flash	Repair or replace worn or damaged mould surfaces by brazing	Visual inspection, functional test
Misalignment, cosmetic defects	Ensure proper clamping force, regular maintenance	Misalignment due to insufficient clamping force	Ensure proper clamping force during moulding	Clamping force measurement, visual inspection
Excessive flash compromised part functionality	Optimize material feed, and adjust blow parameters	Excessive flash due to improper parameters	Adjust material feed and optimize blow parameters	Material weight measurement, visual inspection
Difficult ejection, surface defects	Regular mould cleaning, effective release agents	Sticking or difficult ejection due to buildup	Regularly clean the mould and remove any material buildup carefully	Visual inspection, ejection force measurement
Out-of-spec dimensions, assembly issues	Repair or replace worn or deformed mould components	Dimensional inaccuracies due to mould wear or deformation	Repair or replace worn or deformed mould components	Dimensional measurement, functional test

Potential Effects	Current Control	Failure Mode	Recommended Action	Verification
Leakage, compromised product integrity	Repair or replace worn or damaged mould components	Leakage due to improper mould sealing or damaged components	Repair or replace worn or damaged mould components	Visual inspection, pressure testing

4.7 Summary of Defects, Causes and Remedies

Table 3 shows summary of Defects, their causes, and remedies. It highlights the current issues and remedial measures that can be taken to reduce defects.

Table 3- Defects, Causes and Remedies

Defect	Causes	Remedies
Wall Thickness Variation	Improper material distribution: Inconsistent material flow or improper distribution during the blowing process can result in uneven wall thickness.	Optimize material distribution: Adjust the parison programming, mould design, or blow air pressure to ensure proper material distribution.
	Inconsistent cooling: non-uniform cooling across the moulded part can lead to variations in wall thickness.	Adjust cooling system parameters: Optimize cooling channel design, cooling time, or cooling medium temperature to promote uniform cooling.
	Incorrect blow air pressure: Inaccurate or inconsistent blow air pressure can affect the material stretch and distribution.	Optimize blow air pressure and timing: Set appropriate blow air pressure and timing to achieve consistent stretching and distribution of the material.

Flash	Excessive mould closing force: Excessive force during the mould closing process can cause the material to escape through small gaps.	Adjust mould closing force: Optimize the mould closing force to ensure a proper seal without excessive pressure.
	Worn or damaged mould components: Damaged or worn-out mould surfaces, seals, or parting lines can result in material leakage.	Repair or replace worn or damaged mould components: Regularly inspect the mould surfaces, seals, and parting lines for wear or damage and repair or replace as necessary.
	Improper mould alignment: Misalignment of mould halves can create gaps where the material can escape.	Ensure proper mould alignment: Align the mould halves precisely to ensure a tight seal and prevent material leakage.
Sink Marks	Inadequate material cooling: Insufficient cooling can result in uneven shrinkage and sink marks.	Optimize cooling system parameters: Adjust cooling channel design, cooling time, or cooling medium temperature to promote uniform cooling and minimize sink marks.
	Inadequate material distribution: Improper material flow or distribution during the blowing process can cause variations in wall thickness and sink marks.	Optimize material distribution: Adjust parison programming, mould design, or blow air pressure to ensure uniform material flow and distribution.
	Excessive material shrinkage: HDPE material with high shrinkage properties can lead to sink marks if not properly controlled	Adjust material shrinkage factors: Use HDPE materials with lower shrinkage properties or adjust processing parameters to minimize shrinkage and sink marks.
Surface Imperfections (Scratches, Streaks,	Contaminants in the resin: The presence of dust, dirt, or other contaminants in the HDPE resin can cause surface defects during	Ensure clean resin and proper filtration: Use clean and properly filtered HDPE resin to prevent contaminants from entering the

Blisters)	blowing.	blowing process.
	Improper mould surface preparation: Inadequate cleaning or improper surface treatment of the mould can transfer contaminants or create imperfections on the part surface.	Maintain proper mould surface condition: Thoroughly clean the mould surfaces, apply suitable release agents, and ensure proper maintenance and polishing to prevent surface defects.
	Inadequate cooling: Insufficient cooling or non-uniform cooling can cause surface defects due to improper material solidification.	Optimize cooling system design: Ensure sufficient cooling time and appropriate cooling channel design to promote proper material solidification and minimize surface defects.
Flow Lines	Insufficient melt temperature: If the temperature of the molten plastic is too low, it may not flow smoothly, resulting in flow lines.	Optimize melt temperature: Ensure the plastic material is at the correct temperature range to promote smooth and consistent flow.
	Inadequate material flow: uneven material flow during the blowing process can cause flow lines where the material meets.	Improve material flow: Adjust the blow air pressure, parison programming, or mould design to optimize material flow and distribution.
	Improper mould temperature: Improper mould temperature can lead to premature solidification and interrupted material flow, causing flow lines.	Control mould temperature: Maintain proper mould temperature to allow the material to flow and solidify uniformly.
	Mould design issues: Poor mould design, such as inadequate venting or improper runner and gate design, can contribute to flow line formation.	Enhance mould design: Optimize the mould design by incorporating adequate venting, proper runner and gate design, and appropriate wall thicknesses to minimize flow line

		formation.
	High injection or blowing speeds: Excessive injection or blowing speeds can create turbulence in the material flow, resulting in flow lines.	Optimize injection or blowing speeds: Adjust the injection or blowing speeds to reduce turbulence and promote smooth material flow.

5- Conclusion

This paper has described the use of process FMEA as a tool for defect reduction in the SME plastic industry. Some of the challenges identified in the context of a small foundry/unit like limited resources, lack of expertise, data availability and quality, complex nature of the process, and lack of standardization. These issues can be successfully overcome through Training and Education, Collaboration and Support, Prioritization and Phased Approach, Process Documentation, and Continuous Improvement Culture. Authors recognize the need of developing a new ecosystem with support from quality circles, researchers, government bodies, and OEM CSR for supporting activities like training the stakeholders of these tiny or small-scale industries with modern problem-solving and defect-reducing tools to improve productivity.

The FMEA methodology is a process that can overcome and reduce defects and give the desired result. Current RPN is calculated with severity, occurrence, and detection for each failure, and related actions were taken to reduce this high RPN i.e., Decrease the failure. New RPN shows a reduction of problems, and defects as mentioned are reduced. The current 5% defects out of monthly 6000 parts (15000 per setting) are reduced to 1%. This is saving average of Rs 5400/- for the industry. For 6000 parts Rs 5400/- were the savings by defect reduction and 1% is the activity waste in recycling Most of the defects were related to mold which was linked with wear, breakage, and maintenance. As a small unit, they cannot change the Rs 80000/- die soon as only a quarter of useful life (200000 parts) is utilized so necessary Copper Brazing and minor modifications for perfect alignment and minimum flash have been done. The defected products are reused on the same running line after regrinding (Rs 3 per kg for labour and Electricity charge). This recycled plastic is mixed (20-30% by weight) in the virgin HDPE material. The remaining 1% is wastage in the process of grinding mixed on the floor or waste in sweeping mishandling. Once this mould ends its life new mould with slightly deeper grooves/cavities, sharp edges, high clamping force resistant narrow sections, additional cooling, and impact resistance mould will be designed. Numerical simulation for new mould for solidification-related and other mould-related defects also be done.

6- Further Recommendations

The following are the recommendations for the reduction of rework and defects for Shri Balaji Industries, Waluj MIDC, Aurangabad

1. Creating a maintenance checklist sheet and monitoring the production process.
2. Enhancing the work supervision and inspection, and everyday use of QC tools.
3. To perform numerical simulation for mould, solidification related defects
4. Improving the work environment, material handling, and storage of parts.

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Acknowledgement: - The authors are thankful to Mr. Anjan Patil and Mrs. Kavita Anjan Patil, Owner of Shree Balaji Industries, Waluj MIDC Aurangabad for their permission to access FMEA challenges and implementation, the opportunity to train the manpower on FMEA, availing all the resources for experimentation.