Waste Reduction of Molded Plastic Parts by Applying Principles of Six Sigma

Hardik Shah, Sujay Karkera, and Sandeep Vaity

Abstract Six Sigma is a method that provides organizations tools to improve the capability of their business processes. This increase in performance and decrease in process variation results in defects reduction and improvement in profits, employee morale, and quality of products or services. The main objective of this research is to minimize the non-confirming products that are manufactured using plastic injection molding and reduce the waste using Six Sigma. Using statistical techniques to quantify variation, the Six Sigma Philosophy offers a step-by-step methodology for quality improvement. The study focuses on the application of Six Sigma in plastic injection molding to enhance the quality of the finished products by removing significant flaws that occurred utilizing low-cost techniques. In this case, mostly, the focus was on reducing shrinkage defects, which accounted for almost 39% of the overall non-confirming products manufactured. Another goal was to eliminate the root causes of product rejections, by using Six Sigma's define, measure, analyze, improve, and control (DMAIC) methodology. To achieve desired results, the proposed Six Sigma approach effectively integrates quantitative and qualitative tools such as control charts (p-chart), Pareto charts, histograms, Ishikawa diagrams, measurement system analysis, and checklists. The results show that by implementing the proposed Six Sigma approach can significantly reduce the rejection rate. It was observed that the final product quality had significantly improved, primarily in terms of defects per million opportunities (DPMO) and sigma level, which increased from 4.60 to 4.74.

Keywords DMAIC · Control charts (p-chart) · Ishikawa diagram · DPMO

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1 Introduction

One of the most challenging processes for producing high-quality and cost competitive parts is plastic injection molding. It is most widely used method because of its high rate of output. In this process, the part is made by injecting a molten material into the mold. Granular raw material is fed into the machine through a hopper that pre-heats the material. After that, the substance is heated in a barrel and maintained at ideal temperatures throughout various zones. The molten polymer is then injected into the mold at the required pressure from the nozzle. Once the part is cold enough to be expelled, the mold opens, and the part is taken out with the help of an ejector pin.

2 Literature Survey

Six Sigma may be summed up as an approach for reducing errors in processes that adds value for the customer by identifying sources of variation and removing them. Naumann and Hoisington [1] have pointed out that the concept of Six Sigma is the development of a regular way to measure and monitor the performance, set extremely high expectations, and improvement targets [1]. Hild et al. [2] stated three main goals of Six Sigma are to increase customer satisfaction, profitability, and productivity [2]. De Feo and Barnard [3] focused on Six Sigma's two main methodologies, define, measure, analyze, improve, and control (DMAIC), which is used for existing processes and define, measure, analyze, design, and verify (DMADV), which is used for designing new processes [3]. Brady and Allen [4] stated that Six Sigma has permeated most business disciplines since its introduction in the industry by Motorola's Bill Smith, two and a half decades ago, depending on the philosophy, principles, and techniques of overall quality management [4]. Radha Krishna and Dangayach [4] presented a case on implementation of Six Sigma at an auto-component manufacturing plant [5]. Falcón et al. [6] discussed Six Sigma methodology used to improve energy efficiency in a distillation unit of a naphtha reforming plant. The results revealed a significant annual savings of around 150,000€. [6]. Wyper and Harrison [7] focused on the application of Six Sigma being expanded to include service-provider organizations, additionally, in human resource roles [7]. Vijay [8] discussed on reduction in patients discharge cycle time in a multidisciplinary hospital process using the Six Sigma DMAIC model [8]. Gutierrez et al. [9] conducted a search based on analyzing the application of Six Sigma framework for supporting continuous improvement (CI) in logistics services which resulted in significant improvement and positively influenced company's annual income [9]. Uluskan [10] focused on increasing interest of Six Sigma which led to an extensive study of its tools, both statistical and managerial [10].

Fig. 1 Shrinkage example

3 Methodology

3.1 Define Stage

During the define phase, three steps were undertaken: determining a feasible project scope, establishing project goals, and defining project conditions. Due to resource constraints, the duration of this Six Sigma project could not exceed six months. It was observed that out of total products produced by the company each month, 8% were defective. The occurrence of shrinkage and short shot was maximum among the defective products. Other frequent defects found were flash, silver streaks, and flow marks. The primary goal of this project was to ensure a stable and robust manufacturing process with a low number of non-conforming parts. Figure 1 shows a sample with a shrinkage defect. Figure 2 shows injection molding process diagram.

3.2 Measure Stage

To identify the issues, data for output line reject that happened during the 550 tons and 180 tons injection molding part production, which concentrated on the manufacturing of diverse parts, were continuously gathered for three months. These numbers were used to determine the defect per million opportunities (DPMO) and Six Sigma level for each month. Readings for production done in entire 1st month were taken. After taking the readings, the non-confirmed (rejected) products were taken for further

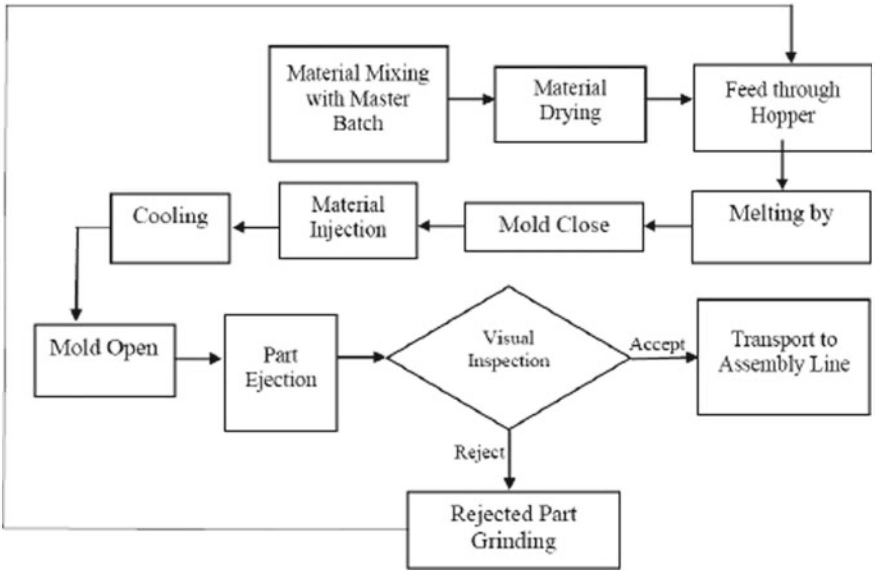

Fig. 2 Process diagram of injection molding production

analysis and segregated into defects, which lead to rejection of products. Table 1 shows the rejection quantity under different heads for 9 molds.

Based on Table 1, all the non-confirming products along with defects that led to their rejection are added in a cumulative fashion, and percentage wise calculations are shown in Fig. 3.

Defects per Million Opportunities (DPMO): This ratio demonstrates the number of defects per every million opportunities. In other words, how many times did you

Table 1 Overall production in the 1st month

Mold no	Total Qty	Accepted Qty	Rejected Qty	Shrinkage	Short shot	Flash	Silver streaks	Flow marks
668	3125	2878	247	93	62	34	32	26
50,200	1451	1325	126	48	36	17	14	11
91,653	4235	3933	302	113	104	41	31	13
2154	592	520	72	37	21	9	5	0
1301	1734	1587	147	61	43	18	14	11
50,203	1682	1526	156	61	44	18	21	12
202	2005	1780	225	104	75	24	16	9
625	2265	2055	210	85	59	27	23	16
188	1570	1420	150	31	37	29	29	21
Total	18,659	17,024	1635	633	481	217	185	119

Defects	Occurrences	Cumulative	Percent
Shrinkage	633	633	39%
Short Shot	481	1114	68%
Flash	217	1331	81%
Silver streaks	185	1516	93%
Flowmarks	119	1635	100%

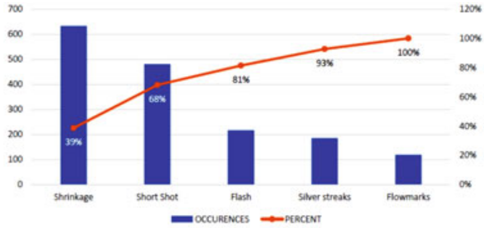

Fig. 3 Pareto chart of overall defects for the 1st month

make a mistake or have a flaw (defect) for each opportunity that presented itself. Can below Eq be written.

DPMO calculation for 1st month	Six Sigma calculation for 1st month
$\text{DPMO} = \dfrac{\text{No. of defects}}{\left(\text{No. of units}\right) \times \left(\text{No. of defect opportunities per unit}\right)} \times 1000000 = \dfrac{1635}{5 \times 18659} \times 1000000 = 17525.05493$	$\text{Sigma level}(Z) = 0.8406 + \sqrt{29.37 - 2.221\ln(\text{DPMO})} = 0.8406 + \sqrt{29.37 - 2.221\ln(17525.05493)} = 3.6096$

Similar method was followed, and readings for production done in the 2nd and 3rd month were taken. After that, the non-confirmed products were taken for further analysis and segregated into defects which lead to rejection of product. Pareto charts were made, DPMO and Six Sigma level calculations were done. Six Sigma level for 2nd month was found to be 3.6020, and for 3rd month, it was 3.6111.

3.3 Analysis Stage

Choosing which defects to start with during this phase was the first step. The Pareto chart for the sorts of defects that occurred in the study's 3 months demonstrates that shrinkage defect, and short shot is the biggest factor in the rejection. When compared to other problems, shrinkage accounts for about 39% of all rejects each month. Figure 4 shows few reasons for production of defective products.

Overall defects in 3 months were added to get a gist of how much rejections were each of the defects responsible for, which is shown in Fig. 5.

Root cause analysis for shrinkage defect

A depression that forms in a casting during the solidification process is known as a shrinkage cavity. Unlike gas porosity, which has rounded surfaces, shrinkage porosity has angular edges. Dendritic fractures or cracks may coexist with cavities in some cases. All the causes and significant variables were visually represented on a cause-and-effect diagram during brainstorming sessions. There are five main variables that contribute to the defective component defect: the machine, mold, operator, procedure, and material. Figure 6 shows the Ishikawa diagram for shrinkage defect.

Large shrinkage cavities might compromise the castings integrity and potentially lead to its eventual failure under stress. A die casting alloy has a lower density while it is liquid than when it is solid. As a result, when a substance changes from the liquid state to the solid state, its size always decreases. When the casting is solidifying inside a die casting die, shrinkage occurs. This shrinkage can result in numerous tiny spaces, or "shrinkage porosity," toward the center of thick parts of a casting. It can, however, seriously weaken a casting if it is bigger or connected. It is apparent that an operator would produce more defects than the others when they lack sufficient experience and

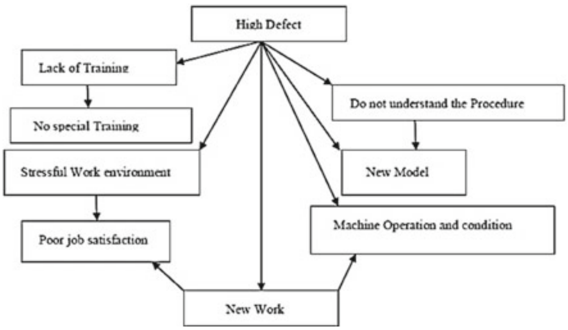

Fig. 4 Some reasons for production of defective products

DEFECTS	OCCURANCES	CUMULATIVE	PERCENT
Shrinkage	1980	1980	39%
Short Shot	1524	3504	68%
Flash	684	4188	82%
Silver Streaks	525	4713	92%
Flowmarks	425	5138	100%

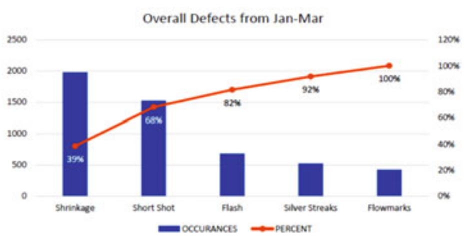

Fig. 5 Pareto graph for overall defects between 1st and 3rd month

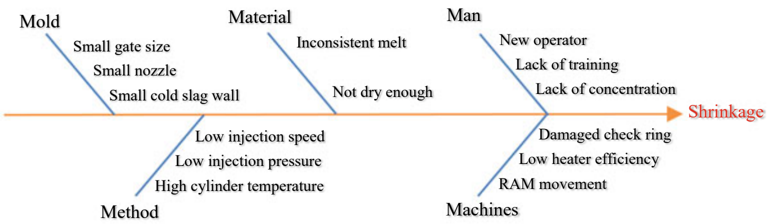

Fig. 6 Ishikawa diagram for shrinkage

practice. In addition, when a material contaminated with foreign particles is used, the part's quality will be affected, which can result in serious flaws.

3.4 Improve Stage

An action plan is made and executed to eliminate the root causes that led to the shrinkage defect and to increase the ability to detect them as quick/early as possible. The fundamental technique for improvement centers on the idea that we should be able to anticipate when the shrinkage will occur. As a result, this process will reduce the faulty rate. The root cause analysis serves as the foundation for the countermeasures. The following arguments were presented to machine operators and are supported by research papers.

3.4.1 Countermeasures for Tackling Defects

Countermeasures against shrinkage in simple terms:

- Use a commercial decontamination product to clean the machine or take out the screw and clean the barrel.
- Store the raw materials in dry areas away from moisture.
- Check the cooling system to ensure that the mold temperature is consistent.
- Lower the temperature of the cylinder and increase the holding force.

Countermeasures against short shot in simple terms:

- Increase the charge.
- Increase injection speed.

Countermeasures against silver streaks in simple terms:

- Preheat the powder to be used in production properly.
- Increase back pressure and reduce the barrel temperature.

Countermeasures against flow marks in simple terms:

- Adjust injection pressure and holding time.

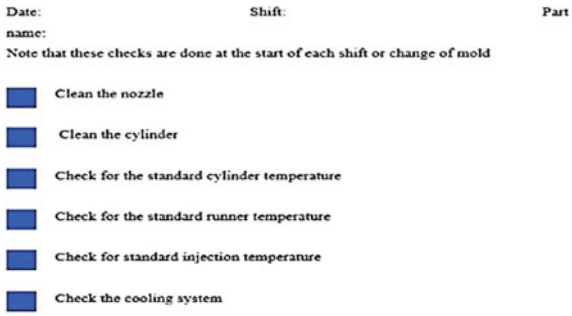

Fig. 7 Suggested checklist

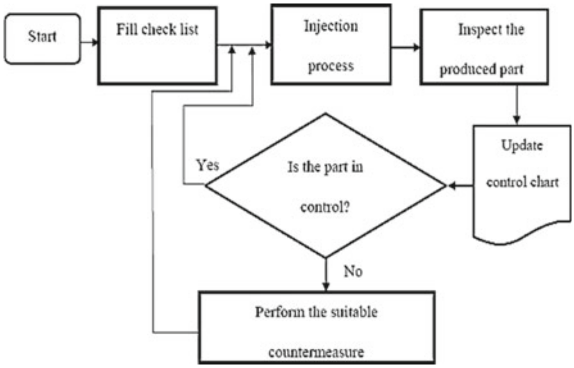

Fig. 8 Suggested process flow

Figure 7 shows the checklist to be followed before starting every production, and Fig. 8 shows the flowchart during every production.

3.4.2 Control Chart (p-chart)

A graph used to examine how a process evolves over time is the control chart. Data are plotted according to time. An average line in the middle, an upper line for the upper control limit and a lower line for the lower control limit are always present on a control chart. In statistical quality control, the p-chart is a type of control chart used to monitor the proportion of non-conforming units in a sample with data collected in subgroups of varying sizes, where the sample proportion non-conforming is defined as the ratio of the number of non-conforming units to the sample size. Figure 9 shows the p-chart for 3rd month, and Fig. 10 shows the p-chart for 4th month, which were made using the Minitab software for the data gathered with various sample sizes.

As seen in Fig. 9, the test failed at 5 points that are 6, 7, 9, 10, 11 and one point more than 3.00 standard deviations from center line which shows how important it was to implement a specific methodology like Six Sigma to reduce overall waste produced and hence boost the productivity.

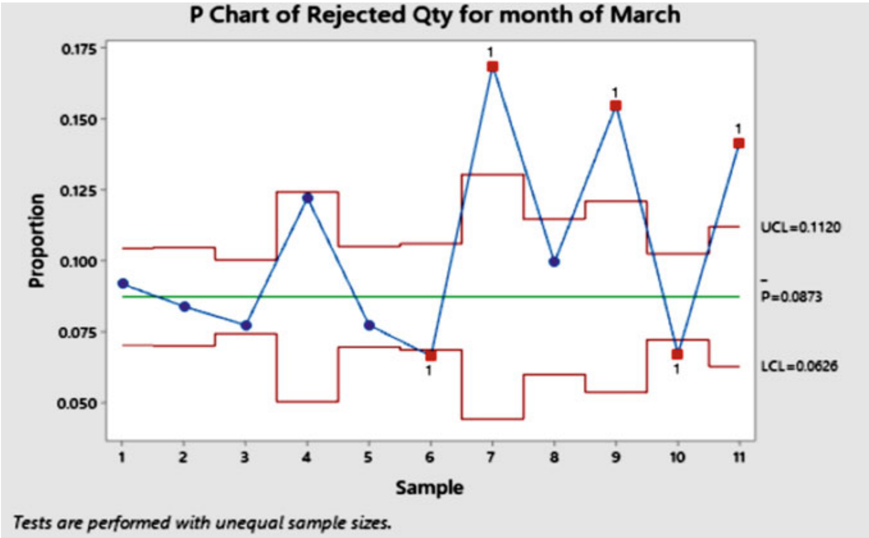

Fig. 9 P-chart for the 3rd month

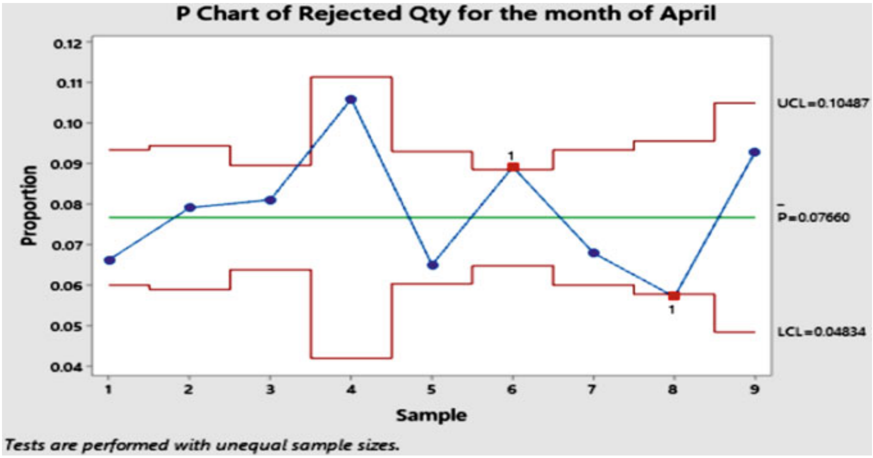

Fig. 10 P-chart for 4th month

As seen in Fig. 10, the test failed at merely 2 points that are 6 and 8 and one point more than 3.00 standard deviations from center line. This indicates that after following standard operation procedures that are implemented, Six Sigma methodology helps in reducing waste generated and thereby boosting overall manufacturing productivity.

3.5 Control Stage

This phase is to make sure that the upgraded conditions can be sustained and kept up in future. The following are some surveillance practices and suggested enhancements:

- Establishing a maintenance checklist sheet and keeping track of the production procedure so that it can be used as a guide in future. The next control involves routinely doing thorough maintenance on the machine by setter.
- Strengthen work inspection and monitoring. To reduce the creation of defective products brought on by human factors, this control can be achieved by strengthening the leader's oversight of the operators' adherence to discipline.
- Improving workspace and surrounding. This type of control can be accomplished by decreasing the amount of noise the engine of crusher machine makes while being reworked, shutting the doors, and installing a silencer in the crusher room.

4 Results and Discussion:

Table 2 shows overall observations of production for month 6, after implementing Six Sigma.

Table 2 Overall production in month 6 (for first 15 days)

Mold no	Total Qty	Accepted Qty	Rejected Qty	Shrinkage	Short shot	Flash	Silver streaks	Flow marks
668	1209	1120	89	23	21	25	8	12
50,200	1091	1000	91	17	22	29	9	14
91,653	2341	2210	131	61	39	17	8	6
31,625	1098	1020	78	19	21	17	8	13
2218	2320	2218	102	35	24	11	14	18
2107	569	510	59	22	18	9	6	4
898	1514	1420	94	25	24	20	14	16
Total	10,142	9498	644	202	169	128	67	83

Post Six Sigma implementation, readings for production done in month 6th (partially) were taken. After taking the readings, the non-confirmed products were taken for further analysis and segregated further into defects which lead to rejection of product.

Based on Table 2, all the non-confirming products along with defects that led to their rejection are added in a cumulative fashion, and percentage wise calculations are shown in Fig. 11.

Defects	Occurrences	Cumulative	Percent
Shrinkage	202	202	31%
Short Shot	169	371	57%
Flash	128	499	77%
Silver streaks	67	566	87%
Flowmarks	83	649	100%

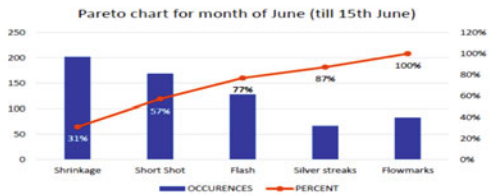

Fig. 11 Pareto chart of overall defects for the month 6 (For 1st 15 days)

DPMO calculation for month 6	Sigma level calculation for month 6
$\text{DPMO} = \dfrac{\text{No. of defects}}{\begin{pmatrix}\text{No. of}\\ \text{units}\end{pmatrix} \times \begin{pmatrix}\text{No. of defect}\\ \text{opportunities}\\ \text{per unit}\end{pmatrix} \textit{gathered}} \times 1000000 = \dfrac{1635}{5 \times 18659} \times 1000000 = 17525.05493$	$\text{Sigma level}(Z) = 0.8406 + \sqrt{29.37 - 2.221 \ln(\text{DPMO})} = 0.8406 + \sqrt{29.37 - 2.221 \ln(17525.05493)} = 3.6096$

4.1 *Comparison of Waste Before Versus After Implementing Six Sigma*

As clearly seen in Fig. 11, shrinkage and short shot defects, which accounted for almost 68% (refer Fig. 5) of total non-confirming products manufactured in the 1st month, have been reduced and brought down to 57% (by the 6th month), over the course of six months after application of Six Sigma Principle. Figure 12 shows comparison of individual defects occurred in first and sixth month.

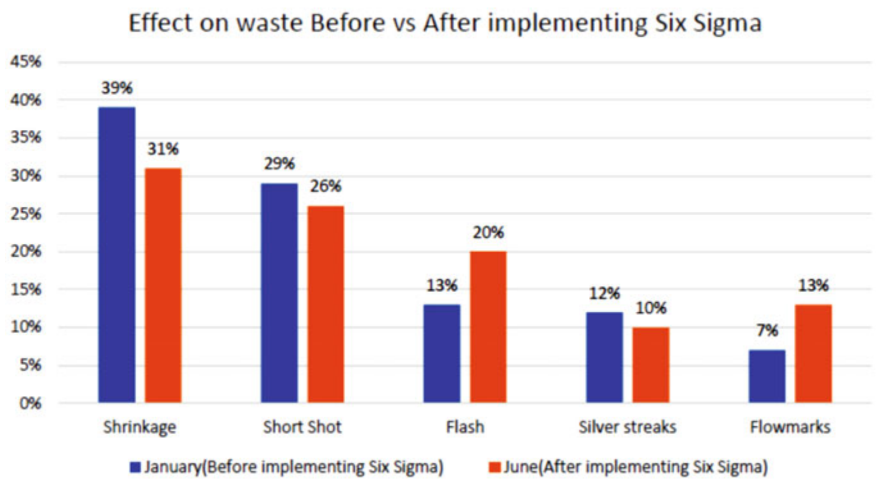

Fig. 12 Bar graph comparing individual defects occurred in 1st and 6th month

5 Conclusion

Based on results of data collection, processing, and the analysis, it was concluded that:

- Defects per Million Opportunities (DPMO) decreased from 17,500 (approx.) which was observed in 1st month to 12,700 (approx.) which was observed in 6th month.
- The sigma level increased from 3.60 to 3.74 during the span of six months.
- The overall defectives rate dropped from 9 to 6.3%.
- Talking in terms of products, 360 more confirming products are manufactured each month now using same amount of raw material.
- A checklist was made which contains specific set of instructions that are to be followed before starting every production.

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