Reduce short filling problem in Injection Molding

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Abstract

\textbf{Purpose:} To reduce short filling problem of doors in injection molding process at supplier end. This problem definition was studied over a six–month period and included an analysis of production yield and manufacturing costs.

\textbf{Design/Methodology/Approach:}

\begin{itemize}
  \item What is the current state of short filling rejection in injection molding process?
  \item Determine the process capability of Shot weight, Core temperature, and cavity temperature.
  \item Calculate the Measurement system analysis and agreement of operators with the measurement instruments.
  \item Determine the source of variability that influences the short filling problem in doors used in HVAC assembly.
\end{itemize}

\textbf{Findings:} Total in house rejection PPM of Molding shop is 9150 PPM for the year 13–14 (June-13 to Mar-14) against budgeted target of 8,000 PPM. There are different parts making in the injection molding shop e.g., covers, doors, bracket, expansion valve etc. There is high rejection in Doors. Further scoping down the problem, we find that we have different models i.e., XA, XB, XC, Car and others. In model XA having the high rejection as compared to other models. In XA model we have five different parts i.e., 191, 192, 193, 195, 195. The part having 191 and 195 more rejection ppm as compared to other. Short filling, flow mark, flatness are the common defects in the doors named XA. Short filling problem is thus selected for the six sigma project.

\textbf{Keywords:} Six Sigma, Quality, Yield, injection molding.

1. \textbf{Problem definition}

To reduce short filling problem of doors in injection molding process at supplier end. This problem definition was studied over a six – month period and included an analysis of production yield and manufacturing costs.

2. \textbf{Objectives}

\begin{itemize}
  \item What is the current state of short filling rejection in injection molding process?
  \item Determine the process capability of Shot weight, Core temperature, and cavity temperature.
  \item Calculate the Measurement system analysis and agreement of operators with the measurement instruments.
  \item Determine the source of variability that influences the short filling problem in doors used in HVAC assembly.
\end{itemize}
3. Selection of the problem

Total in house rejection PPM of Molding shop is 9150 PPM for the year 13~14 (June-13 to Mar-14) against budgeted target of 8,000 PPM. There are different parts making in the injection molding shop e.g., covers, doors, bracket, expansion valve etc. There is high rejection in Doors. Further scoping down the problem, we find that we have different models i.e., XA, XB, XC, Car and others. In model XA having the high rejection as compared to other models. In XA model we have five different parts i.e., 191, 192, 193, 195, 195. The part having 191 and 195 more rejection ppm as compared to others. Short filling, flow mark, flatness are the common defects in the doors named XA. Short filling problem is thus selected for the six sigma project. The graphs of the problem selection are shown below.

![Rejection PPM trend in Molding shop (June 13 to Mar 14)](image)

**Figure 3.1 Run chart for rejection PPM (june 13 to march 14)**

From the trend chart shown above we conclude that our rejection PPM is 9150 as compared to our budgeted target of 8000 PPM. Then we find the area where the problem exists in the company. This can be targeted by the scoping tree. We find that our main problem area is injection molding process. In injection molding process we have five main parts. Doors have the section in which the problem is more. We make doors for the five different models. The model named XA has the pain area. In XA we have five different parts, but 191 and 195 have the short filling problem. So, we select these two parts for short – filling problem.
Figure 3.2 Scoping tree for the problem selection

Figure 3.3 Pareto chart for rejection in Short-filling process (June 13 to March 14)
Figure 3.4 Pareto chart for the defect of Door 191.

4. Product detail

Doors are used to control air direction and flow in heating ventilation and air conditioning system (HVAC) assemblies of AC system of cars.

Figure 3.5 Product detail (a)
After selecting the problem area, we collect the data for the last six months and plot the trend chart. From there, we found that the problem is consistent outside the criteria having high PPM. We plot the trend chart for both the parts i.e., 191 and 195 shown in the figure below.

**Figure 3.6  Product detail (b)**

![Product detail (b)](image_url)

**Figure 3.7  Historical data for the short filling problem.**
From the above trend chart we conclude that the door 191 has the 11688 PPM and door 195 has 8650 PPM. We select the target for both doors, 11688 to 2104 and 8650 to 2163 PPM.

Figure 3.9 Target setting.

5. Process flow diagram
The above figure shows the process flow diagram for the process. We see that preheating and molding and inspection are our main focus area for investigation. We study the process thoroughly and check the preset standards for these two standards. Input/output sheet also contains the details of the process. By focusing on the input/output sheet we select the main factors on which we have to work.

Figure 3.10 Process flow diagram.
6. Inference of input output sheet

1) Total numbers of factors = 57
2) Controllable factors = 50
3) Non-controllable factor = 7
4) Quick win opportunities identified 6
5) Process capability is less than 1.33 for the following
   a. Shot weight
   b. Mold temperature (core and cavity)

7. Process Capability for Shot weight

Process capability for the shot weight process is not good. The Cp value is 0.69 and Cpk is 0.63 for the shot weight process. We have to improve the capability of this process to produce the good parts, and lowers the PPM level.

Table 3.1  Input/output sheet

<table>
<thead>
<tr>
<th>Process Steps</th>
<th>VA/WA</th>
<th>SOP</th>
<th>Equipment</th>
<th>Output</th>
<th>Feature (f)</th>
<th>Specification</th>
<th>MSA</th>
<th>Capability</th>
<th>Input(X)</th>
<th>CM</th>
<th>Feature</th>
<th>Specification</th>
<th>Test(s) / Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moulding</td>
<td>VA</td>
<td>SA-PROD-VA</td>
<td>Injection Moulding Machine</td>
<td>Moulded door</td>
<td>Finish</td>
<td>Finish as per Matting part</td>
<td>NA</td>
<td>IFV = 100%</td>
<td>Operator</td>
<td>N</td>
<td>Skill Level</td>
<td>Mkt, Level B</td>
<td>OK</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Appearance</td>
<td>Appearance as per first sample</td>
<td>Amilume, Age, Vs SM, result is &gt; 30%</td>
<td>IFV = 99%</td>
<td></td>
<td>Machine</td>
<td>C</td>
<td>Injection pressure</td>
<td>16 ± 5 kg/cm²</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Shot Weight</td>
<td>144 ± 3 gram</td>
<td>NA</td>
<td>Cpk = 0.43</td>
<td></td>
<td>C</td>
<td>Holding pressure</td>
<td>5 ± 2 kg/cm²</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>NA</td>
<td></td>
<td></td>
<td>C</td>
<td>Holding speed</td>
<td>4±1</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>NA</td>
<td></td>
<td></td>
<td>C</td>
<td>Clamping pressure</td>
<td>90 ± 5</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>NA</td>
<td></td>
<td></td>
<td>C</td>
<td>Clamping speed</td>
<td>15 ± 5</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>NA</td>
<td></td>
<td></td>
<td>C</td>
<td>Screw position</td>
<td>95 ± 5 MN</td>
<td>95</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>NA</td>
<td></td>
<td></td>
<td>C</td>
<td>Barrel temperature</td>
<td>240, 220, 200, 195 ± 10°C</td>
<td>254, 221, 198, 190</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>NA</td>
<td></td>
<td></td>
<td>C</td>
<td>Injecton time</td>
<td>4±2 sec</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>NA</td>
<td></td>
<td></td>
<td>C</td>
<td>Holding time</td>
<td>1±1 sec</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>NA</td>
<td></td>
<td></td>
<td>C</td>
<td>Cooling time</td>
<td>25±2 sec</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>NA</td>
<td></td>
<td></td>
<td>C</td>
<td>Total cycle time</td>
<td>40 ± 3 sec</td>
<td>39</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>NA</td>
<td></td>
<td></td>
<td>C</td>
<td>Mold temperature</td>
<td>Core 41°C &amp; Cavity 43°C</td>
<td>As per attached data</td>
</tr>
</tbody>
</table>
8. Process Capability for Core Temperature

Process capability for the core temperature is less. It shifts towards the Lower specification limit. The Cp value is 1.02 and Cpk is 0.50 for the core temperature process. We have to improve the capability of this process to produce the good parts, and lowers the PPM level.
9. Process Capability for Cavity Temperature

Process capability for the cavity temperature is less. It shifts towards the LSL and not centered. The Cp value is 1.02 and Cpk is 0.50 for the core temperature process. We have to improve the capability of this process to produce the good parts, and lowers the PPM level.

![Process Capability for Cavity temp.](image)

Figure 3.13 Process capability for cavity temperature.

10. Measurement System Analysis

Measurement system analysis for the attribute measurement is not acceptable. The assessment agreement within the appraisers has lower kappa value. The appraiser versus standard also has less agreement. There will be need to train the appraisers and also familiar with the measurement system. After completion of training to the operators again MSA will be conducted to check whether the operators are skilled or not.
11. Cause and effect diagram

Cause and effect diagram for the short filling is shown in the figure below. It is conducted by the operators following brainstorming and nominal group technique. The causes which are highlighted by the red circles are the probable causes for the process. These are further verified by conducting the experiment for the particular cause and its effect. They need to be validated by the process experts.

**Inference:**
1. Measurement System is not acceptable.
2. No significant difference between inspector’s decision (Assessment agreement is more than 70%)

Figure 3.14 Measurement system analysis for attribute system.

**Figure 3.15** Cause and effect diagram for Short filling.
12. **Identified Quick Win Opportunities after I/O Sheet (Test/Analysis) & cause & effect diagram**

1. Process is not running as per standard parameters e.g. core temperature up to 33.9 °C & cavity temperature up to 34.8 °C (Spec-41±5 °C).
2. Ring & plunger found worn out - was causing less feeding of molted material into mold.
3. Screw found worn out - Effecting feeding of material as per requirement.
4. Hopper filter cleaning is done but no frequency decided for cleaning and no monitoring is done for cleaning.
5. Nozzle condition to be checked on daily basis
6. Frequent Change Over of Mold due to Non Availability of Bins.
7. SOPs are not adequate e.g. contents are not legible clearly, revision details are not mention etc.

13. **Cause and effect matrix**

After completing the cause and effect diagram we need to form a cause and effect matrix, which involves the causes other than the diagram. The possible causes and their rating is shown in the table below, their probable causes are also shown in the table.

![Cause-Effect Matrix & Inference from Measure Phase](image)

- **Figure 3.16 Cause and effect matrix.**

14. **Analyze Phase**
After completing the cause and effect matrix, we find the causes by the failure mode and effect analysis process as shown in the figure below.

**PFMEA**

![PFMEA Table]

**Figure 3.17 PFMEA for the process.**

**X’s identified for data collection:**

1. Mold Core Temperature
2. Mold Cavity Temperature
3. Barrel temperature – Zone-1
4. Barrel temperature – Zone-2
5. Barrel temperature – Zone-3
6. Barrel temperature – Zone-4
7. Injection Pressure
8. Injection Speed
9. Hopper Temperature

**Data collection plan**

1. Sample size = 5 continuous shots after every 1 hr.
2. Min. 5 defective should be covered in total data set, as min. rejection is 1.1% so as per np ≥ 5 min. 500 shots data to be collected.
Note: Total 975 shots data was collected in 32 days.

15. Tools identified for graphical analysis

<table>
<thead>
<tr>
<th>S.No</th>
<th>Parameter (Xs)</th>
<th>Input type</th>
<th>Output type</th>
<th>Tools to be used</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Mould Core Temperature</td>
<td>C</td>
<td>D</td>
<td>Main effect plot, Interaction plot, Box plot</td>
</tr>
<tr>
<td>2</td>
<td>Mould Cavity Temperature</td>
<td>C</td>
<td>D</td>
<td>Main effect plot, Interaction plot, Box plot</td>
</tr>
<tr>
<td>3</td>
<td>Barrel temperature – Zone-1</td>
<td>C</td>
<td>D</td>
<td>Main effect plot, Interaction plot, Box plot</td>
</tr>
<tr>
<td>4</td>
<td>Barrel temperature – Zone-2</td>
<td>C</td>
<td>D</td>
<td>Main effect plot, Interaction plot, Box plot</td>
</tr>
<tr>
<td>5</td>
<td>Barrel temperature – Zone-3</td>
<td>C</td>
<td>D</td>
<td>Main effect plot, Interaction plot, Box plot</td>
</tr>
<tr>
<td>6</td>
<td>Barrel temperature – Zone-4</td>
<td>C</td>
<td>D</td>
<td>Main effect plot, Interaction plot, Box plot</td>
</tr>
<tr>
<td>7</td>
<td>Injection Pressure</td>
<td>C</td>
<td>D</td>
<td>Main effect plot, Interaction plot, Box plot</td>
</tr>
<tr>
<td>8</td>
<td>Injection Speed</td>
<td>C</td>
<td>D</td>
<td>Main effect plot, Interaction plot, Box plot</td>
</tr>
<tr>
<td>9</td>
<td>Hopper Temperature</td>
<td>C</td>
<td>D</td>
<td>Main effect plot, Interaction plot, Box plot</td>
</tr>
</tbody>
</table>

Table 3  Graphical analysis for the factors identified.

Interval plot for Z – 3 Temperature
Figure 3.18  Interval plot for Z – 3 temperature

Inference: There seems relationship between Z-3 Temp. and short filling.

Interval plot for Injection Pressure

Figure 3.19  Interval plot for injection pressure

16.  Binary Logistic Regression for Short Filling problem
Inference of Statistical Analysis

1. Following Factor are found statistically significant after application of various graphical and statistical tools:
   a. Injection Pressure

2. Following Factors are also taken for improvement based on statistical analysis-
   b. Mould Core Temperature
   c. Barrel Temperature Z3

Remark- DOE will be done on 3 factors

17. Improve Phase
Table 3  DOE data collection plan

Figure 3.21  Pareto chart for short filling problem.
Figure 3.22  Main effect plot for short filling problem.

**DOE – Minitab output for Short Filling**

Factorial Fit: REJ% versus Injection Pr, Mould core t, Heater barrel temp. (Z 3)

Estimated Effects and Coefficients for REJ % (coded units)

<table>
<thead>
<tr>
<th>Term</th>
<th>Effect</th>
<th>Coef</th>
<th>SE Coef</th>
<th>T</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>0.8544</td>
<td>0.1913</td>
<td>4.47</td>
<td>0.011</td>
<td></td>
</tr>
<tr>
<td>Injection Pressure</td>
<td>-1.5525</td>
<td>-0.7762</td>
<td>0.2029</td>
<td>-3.83</td>
<td>0.019</td>
</tr>
<tr>
<td>Mould core temp.</td>
<td>-0.2975</td>
<td>-0.1488</td>
<td>0.2029</td>
<td>-0.73</td>
<td>0.504</td>
</tr>
<tr>
<td>Heater barrel temp</td>
<td>-1.5475</td>
<td>-0.7738</td>
<td>0.2029</td>
<td>-3.81</td>
<td>0.019</td>
</tr>
<tr>
<td>Injection Pressure*</td>
<td>1.1775</td>
<td>0.5888</td>
<td>0.2029</td>
<td>2.90</td>
<td>0.044</td>
</tr>
</tbody>
</table>

Model Equation: Short Filling = 0.1822 - 0.7762*(Injection Pressure) - 0.7737*(Barrel temp Z3) + 0.5888*(Injection Pressure*Heater barrel temp Z3)

Figure 3.23  Minitab output for short filling problem.
Global Solution

Injection Pressure = 13.6911 Heater barrel temp (Z3) = 230

Predicted Responses REJ % = 0.1 desirability = 1.000000

Composite Desirability = 1.0

18. Control Phase

After improving the process, we take the regular data to monitor the process that the process is running the prescribed conditions or not. In control phase, we regular plot the control charts of the process which are variable parameters. The I-MR chart of the Barrel temperature of zone – 3 is shown in the figure. It seems within the control limits.
19. Result

After implementing the solution the results of the process are shown in the below graphs. The first graph is the rejection trend for short filling on door 191 and the second graph is rejection PPM for the door 195. Both the charts shows that after implementing the solution the PPM trend is decreasing day by day. This is approximate to the target which is taken in the define phase.

![Rejection PPM Trend for Short filling Door 191](image1)

**Figure 4.1** Rejection PPM trend for short filling door 191.

![Rejection PPM Trend for Short filling Door 195](image2)

**Figure 4.2** Rejection PPM trend for short filling door 195.

References


