QUALITY ANALYSIS OF AUTOMOTIVE CASTING FOR PRODUCTIVITY IMPROVEMENT BY MINIMIZING REJECTION

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Abstract- Casting defect can negatively impact the bottom line of a foundry. A defect in a casting deteriorates casting surface quality and mechanical properties. It is responsible for loss of profitability, quality level and productivity of component. So it is preferably necessary to reduce it as much as possible by appropriate analysis. This paper presents research work carried out in foundry to minimize casting rejection due to major defect. A problem is facing with the single cylinder head. Study focuses on analysis of Blow hole defect which contributes more in total rejection percentage. Quality analysis is carried out which includes the Root cause analysis to find out actual reasons behind occurring the blow holes. Quality control tools such as Pareto analysis, Cause and Effect (Ishikawa) diagram, and Why-why analysis are used for analysis. Accordingly corrective actions and preventive measures are suggested and implemented. Central gas vent cleaning practice is added as a check point in process control check sheet and Pasting of wet green sand on central gas vent during mould box assembly is added as process compliance. Evaluation of effectiveness after implementation of these changes shows significant reduction in rejection due to blow hole as well as in total rejection. Rejection due to blow hole is minimizes from 7.74% to 1.81%. It turns into considerable reduction in total revenue loss as well as productivity improvement by 8.60%.

Keywords- Casting Defects, Blow Hole, Pareto Analysis, Cause and Effect (Ishikawa) Diagram, Why-why analysis, Root Cause Analysis, Productivity Improvement.

I. INTRODUCTION

Foundry industry suffers from poor quality and productivity due to involvement of number of process parameters, combined with lower penetration of manufacturing automation and shortage of skilled workers [6]. Casting process is known as process of uncertainty. Even in a completely controlled process, defects in casting are observed which challenges explanation about the causes of casting defects [7]. Quality analysis is the process of finding the root cause of occurrence of defects in the rejection of casting and taking necessary corrective actions to reduce the defects and to improve productivity. Techniques like Design of Experiments (DoE), Casting simulation, and artificial neural networks (ANN) are used by various researchers for analysis of casting defects [9]. Single Cylinder Head selected for quality analysis is used for automobile application. As name suggest it fits on top of the cylinder block to complete engine assembly. It is manufactured by sand casting process which is common in producing automobile components. A high proportion of casting defects are caused due to evolution of gases. One of the most common defects in sand casting is Blow hole, which can be generally found on the casting surface [1]. It is important to have a control over sand casting processes to avoid this defect. Such casting defect should be diagnosed correctly for appropriate remedial solution otherwise new defect may get introduced [11].

Objective of this research work is to carried out quality analysis of single cylinder head by implementing some conventional Quality Control (QC) tools such as Pareto analysis, Cause and Effect diagram, and Why-why analysis in process to get root cause behind the occurrence of blow holes. Also recommend and evaluate the effectiveness of corrective actions and preventive measures. Finally create an implementation plan to control the standard practices in order to reduce rejection level of blow holes.

II. LITERATURE REVIEW

B.N. Rao and R. Ashokkumar (2008), studied on the effect of blow-holes on the reliability of a cast component, using the Most Probable Point (MPP)-based univariate response surface approximation. They conclude that blow holes have a significant effect on casting [2]. D. Mahito, A. Kumar (2008), conclude that conventional Root Cause Analysis tools and methods provide some structure to the problem solving process. [3].

D.N. Shivappa et al (2012), found the four prominent defects in casting rejections. They noticed that defects such as Sand drop, Blow hole, Mismatch, and Oversize in Trunion Support Bracket (TSB) castings are frequently occurring at particular locations [5]. V. Nerle, S. Shinde (2013), carried out work on minimizing sand drop casting defect in automobile cylinder block of grey cast iron in foundry. The quality tools are used in investigation process which works effectively to reduce rejection due to non measureable causes [8]. R. Rajkolhe, J. G. Khan (2014), are made attempt to list different types of casting defects and their root
causes of occurrence which is finally helps into improving the productivity and yield of the casting [10]. A. Joshi et al (2014), focuses on the manual metal casting operations. They used different QC tool such as Pareto analysis and Cause and Effect diagram to sort the defects and identify the root cause respectively. Accordingly they suggest remedial actions using automation at some stages [4]. C.B. Patel and Dr. H.R. Thakkar (2015), studied the research work made by several researchers for minimizing various defects and to improve the productivity. They conclude that quality tools are playing an important role in decision making during the defect analysis [12].

Various casting defects are reported along with the methodology to overcome them. Some authors present modern approach of rejection analysis by using DoE with Taguchi method (Hybrid approach), ANN, Most Probable Point (MPP)-based univariate response surface approximation along with Monte Carlo Simulation (MCS) etc. The problem of blow holes in steel casting is reported. It is solved by using simulation software. Study regarding the use of QC tools for productivity improvement in Grey iron sand casting by minimizing blow holes is not reported. So there is scope to carry out Quality analysis of blow holes by implementing QC tools.

III. PROBLEM STATEMENT

Foundry producing automotive castings is facing rejection problem for Single Cylinder Head component. The major rejection is due to the Blow Hole defect which contributes up to 7.74% from 12.79% of total rejection. For sustainable quality of component foundry requires to reduce the percentage of rejection to optimum level.

IV. METHODOLOGY

![Methodology Flowchart](image)

Fig.2. Methodology Flowchart

V. QUALITY ANALYSIS

5.1. Study and Analyse Casting Process of Single Cylinder Head

First step in the work is to study and analyse the casting process for single cylinder head in the foundry. Fig. 2 shows flowchart of casting process which is a graphical representation identifying the different steps in manufacturing. Foundry section consists of three different production lines. Manufacturing of Single Cylinder Head is carried out on WBQ3 production line. Casting process consists of different steps such as sand preparation, core making, mould making and assembly, melting and pouring, knockout, fettling, inspection and painting.
5.2. Record Different Defects in Selected Component and Find Major Defect Using Pareto Analysis

A. Data Collection: Past Two months (July-15 and Aug-15) data is taken for preliminary analysis. During the analysis data regarding pouring quantity, monthly rejection and defects occurred is collected as follow:

B. Finding Major Defect:
For prioritizing problem-solving work so that the first piece of work to resolve the greatest number of problems start with a simple technique Pareto analysis. Pareto Diagram is a tool that arranges items in the order of the magnitude of their contribution, thereby identifying a few items exerting maximum influence. It thus insures that the time in problem-solving is used efficiently.

Pareto principle is also known as 80/20 rule. It finds 20% of the causes account for 80% of the results.

<table>
<thead>
<tr>
<th>Defect</th>
<th>Rejection Qty. (Units)</th>
<th>Rejection Percentage</th>
<th>Cumulative Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blow Hole</td>
<td>558</td>
<td>7.71</td>
<td>60.52</td>
</tr>
<tr>
<td>Sand Drop</td>
<td>171</td>
<td>2.37</td>
<td>79.07</td>
</tr>
<tr>
<td>Shrinkage</td>
<td>94</td>
<td>1.3</td>
<td>89.26</td>
</tr>
<tr>
<td>Broken Casting</td>
<td>32</td>
<td>0.44</td>
<td>92.73</td>
</tr>
<tr>
<td>Box Leakage</td>
<td>19</td>
<td>0.26</td>
<td>94.79</td>
</tr>
<tr>
<td>Mold Rough</td>
<td>15</td>
<td>0.21</td>
<td>96.42</td>
</tr>
<tr>
<td>Cold Shut</td>
<td>11</td>
<td>0.15</td>
<td>97.61</td>
</tr>
<tr>
<td>Damage</td>
<td>9</td>
<td>0.12</td>
<td>98.59</td>
</tr>
<tr>
<td>Other defects</td>
<td>13</td>
<td>0.18</td>
<td>100</td>
</tr>
</tbody>
</table>

By taking the Defects on X-axis and Rejection percentage on Y-axis, chart is drawn and analysis is carried out to find out major defects from list.
The Pareto analysis shows that Blow hole and Sand drop defects are indicates higher proportion than other defects. Blow hole contribution is 60.52% of total rejection which shows how severe the problem is. Rejection percentage due to Blow hole is 7.74%. It is primary requirement to focus on minimization of rejection percentage due to Blow hole.

C. Carry out Quality Analysis to Find out Root Cause by Implementing QC Tools:

a) Identify Defect Location: Identification of defect location helps to avoid the deviation from root cause. Once we identify the defect location it is easy to find out various reasons behind the defect generation. For this purpose Six view (Rocker Face, Bottom View, Exhaust Face, Opposite Exhaust Face, Dowel Side Face and Opposite Dowel Side Face) picture sheet is form and trace defect location.

It is observed that blow holes are frequently occurs on ROCKER FACE of the single cylinder head. Also these blow holes are mainly spotted in two specific (extreme left centered and right side lower) areas on ROCKER FACE. These blow hole areas are then named as Centre Boss area and Emblem area. The rejected castings with marking on that defect areas are shown in Fig. 6.

b) Use of Gemba Kaizen Improvement Principle: Quality analysis to identify root cause for Blow hole in single cylinder head is carried out with the help of a Cross Functional Team (CFT). According to Gemba Kaizen principle CFT arrange visits during the analysis phase. Gemba means the real place in company where problems and abnormalities happen i.e. where single cylinder head is developed or made. It will definitely beneficial in brainstorming session.

c) Brainstorming Session: All CFT members are gathering together for Brainstorming session. Major focus is on to collect all possible causes according to defect location. CFT sets the target value of 50% reduction in rejection percentage during analysis. In the preparation of Cause and Effect (Ishikawa) diagram, brainstorming technique is used to generate various possible causes. Besides, Cause and Effect diagram is used to structure a brainstorming session. Before going to conduct brainstorming session CFT carry out primary Gemba visit to plant and observe all basic manufacturing processes related to the component carefully.

d) Preparation of Cause and Effect (Ishikawa) Diagram: It is an effective tool to immediately sort ideas about the causes for problems into useful categories as it displaying the hierarchy of causes. It shows and identifies systematic relationships between blow hole defect and its possible causes. Five main groups are defined by CFT such as Man, Machine, Tooling, Method and Materials which are relevant to the production process.
Important possible root causes are short listed (Table 3) which are then first examined under secondary Gemba visit. It is perform on the basis of finalizing their importance with the help of work experience and process knowledge gained in primary Gemba visit.

Table 3: Short List of Possible Causes from Ishikawa Diagram

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Possible Cause</th>
<th>Secondary Gemba Obs.</th>
<th>Check By</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Water Jacket gas vent oblong</td>
<td>YES</td>
<td>CFT members</td>
</tr>
<tr>
<td>2.</td>
<td>Multiple vents not correctly connected</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>Improper sealing of shell core vents</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>Incorrect size of vent rods</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td>Mismatch of gas vent- Top tray and Top mould</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.</td>
<td>Vents not opened to the atmosphere or not opened</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.</td>
<td>High pouring rate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8.</td>
<td>Gas not ignited while pouring</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9.</td>
<td>Bubbling during pouring</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10.</td>
<td>WJ core breaks after pouring</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11.</td>
<td>Intake/ Exhaust core break after pouring</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

All possible causes are observed one by one. During this visit team found single process non-compliance. Evidence is seen during pouring of molten metal in to the mould box at pouring line. It is observed that, bubbling of molten metal take place which is in general abnormal process and comes under the non-compliance.

Table 4: Part of Check Sheet for Probable Causes Identification

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Possible Cause</th>
<th>Secondary Gemba Obs.</th>
<th>Check By</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Bubbling during pouring -Gas blockage of vents due to metal entry</td>
<td>YES</td>
<td>CFT members</td>
</tr>
</tbody>
</table>

e) Why-why Analysis: An important component of root cause analysis is a thorough understanding of “what happened”. It is a question asking method used to explore the cause-effect relationships underlying the problem. The CFT begins after reviewing an “initial understanding” of the event and with collection of data related to unanswered questions and information gaps. This information is synthesized into a “final understanding” and arranges in a logical sequence (Fig. 8) to find a logical solution (i.e. KEY WORD) to the problem of rejection due to blow hole. The key word denotes root cause of the rejection due to blow hole. No central gas vent checking at core assembly inspection area (before mould box assembly) is the reason for occurrence of Blow holes.
D. Determine and Suggest Corrective Actions and Preventive Measures:

a) Determination of Corrective Actions: The base for deciding corrective actions is the key word obtained in why-why analysis as it represents the root cause behind the formation of blow hole. Considering all the reasons behind the blow hole formations total two corrective actions are suggested by the CFT. These corrective actions are listed below:

(i) Inspection of Water jacket core central gas vent for vent blockages with the help of air jet before moulding.
(ii) Paste wet green sand on the outside shoulder vents of Water jacket core with soft hand to avoid entry of any foreign material inside the vent passage during mould box assembly at moulding line.

b) Determination of Preventive Measures: Determination of preventive measures along with the corrective actions is essential to prevent reoccurrence of defect. These measures are suggested based on quality analysis and process non-conformities observed during Gemba visits. All these preventive measures are listed below:

(i) Check drilling of WJ core gas vents to avoid oblong shape.
(ii) Check whether the multiple vents on WJ core are connected correctly or not as per compliance provided.
(iii) Check whether the plugging of multiple vents on WJ core is done properly or not as per compliance provided.
(iv) Check and confirmed through opening of Water jacket central gas vent with air before mould box assembly.
(v) Check and confirmed closing of Water jacket central gas vent by pasting of wet green sand before mould box assembly.
(vi) Neat cleaning of Cope and Drag mould with medium pressure air jet, especially at the edges of moulds to remove loose sand from boundary region.

F. Evaluate Effectiveness of Corrective Actions and Preventive Measures:

Before making any changes in previous control plan of single cylinder head, it is an essential to check the effectiveness of corrective actions and preventive measures after implementation. It is done by comparing the results obtained with previous status of work and initial target set by the CFT. For this purpose data is gathered for analysis of effectiveness and also study its impact on the other process parameters. Detail analysis with the help of recorded observations, pictures, QC rejection details and interpretation of graphs is carried out.
a) Rejection Trend Analysis: By using the statistics of single cylinder head production in before and after trial period of corrective actions and preventive measures graph is plotted as shown in Fig. 12 for rejection trend analysis. It shows total rejection as well as blow hole rejection is reduced to more than half i.e. the target of 50% reduction is achieved.

![Single Cylinder Head Rejection Trend](image1.png)

Fig.12. Before and After Phase: Rejection Trend

From pictorial analysis (Fig. 13) it is observed that blow holes are significantly reduced from Center boss and Emblem area of the component.

![Before and After Phase: Rejection Trend](image2.png)

Fig.13. Before and After Phase: Rejection Trend

b) Productivity Trend Analysis: To analyse the effectiveness in terms of productivity, a graph showing productivity trend is plotted as shown in Fig. 14. From this graph it is conclude that productivity of Single Cylinder Head is going to improve after implementation. It shows that for same input expenditure production quantities are going to increase. It indicates 8.60% improvement in Productivity.

![Single Cylinder Head Productivity Trend](image3.png)

Fig.14. Before and After Phase: Productivity Trend

c) Cost Estimation: Costing figures are summarized in tabulated form as below:

<table>
<thead>
<tr>
<th>Description</th>
<th>Before</th>
<th>After</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blow Hole Rejection (%)</td>
<td>7.74</td>
<td>1.81</td>
</tr>
<tr>
<td>Rejection Qty due to Blow Hole (Units)</td>
<td>558</td>
<td>130</td>
</tr>
<tr>
<td>Total Revenue Loss (Rs.)</td>
<td>3,60,668.88/-</td>
<td>84,026.80/-</td>
</tr>
</tbody>
</table>

G. Suggestion of Control Plan for Reducing Rejection:
According to quality analysis performed, sustenance plan is suggested with two changes.

- **Sustenance Plan:**
  1. Vent cleaning practice is added as a check point in process control check sheet.
  2. Pasting of wet green sand on Central gas vent is added as process compliance.

As per results obtained during evaluation of effectiveness, process details as well as process control check sheet are updated. Fig. 15 shows part of updated process control check sheet.

![Process Control Check Sheet](image4.png)

Fig.15. Process Control Check Sheet
CONCLUSIONS

This work presents a systematic approach for minimizing blow holes in sand casting. Quality analysis using different quality control tools is carried out to identify the major defect and its root cause. Blow hole on rocker face of single cylinder head is identified as major defect. Central vent cleaning practice before mould box assembly and pasting of wet green sand on central gas vent both are suggested and implemented as corrective actions to minimize the rejection. These actions are work effectively during the trial period without affecting on past processes and results into following benefits:

1. Productivity is improved by 8.60%.
2. Minimization in rejection due to blow hole is achieved by 5.93% and in total rejection by 7.51%.
3. Reduction in Total Revenue Loss due to blow hole by Rs. 2,76,642.08/- and due to total rejection by Rs. 3,49,680.76/-
4. Delivery achieved as per target i.e. SEPT-15: Plan- 4000 units, Actual- 4751 units (Target is achieved after 5 months).
5. Efficient team work.

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REFERENCES