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Diagnostic approach towards analyzing casting defects-An Industrial case Study

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ABSTRACT: Quality has become a key concern in Indian manufacturing industry since globalization. In foundry industry, as observed, generally 5 to 6% rejections are considered as an acceptable rejection level. But in actual practice, it is a tedious task to restrict the rejection to this level due to different variables which are difficult to control. It was observed during the initial visits to a number of foundries that most of the foundries develop new cast parts using traditional trial and error method, which leads to increase in cost due to poor casting quality, material, and energy wastage, cost of rework and excessive lead time for developing new cast products. The small-scale foundry industries are facing higher rejection levels. Hence, a study aimed at establishing rejection control can help the foundry industries in this area identify and control the factors contributing to rejection. The proposed work is challenging and involves a deeper study and understanding of the casting process and presents an opportunity to work on the shop floor and contribute to solving the real-life problems

KEYWORDS: Casting Defect, Sand Drop, Slag inclusion, Run-out, Cause and Effect analysis, Statistical Quality Control

I. INTRODUCTION

Foundry industry suffers from poor quality and productivity due to involvement of number of unavoidable process parameters, combined with lack of manufacturing automation and unavailability of skilled workers. Metal Casting process is known as process of uncertainty. Even though the process completely controlled, defects are observed which challenges explanation about the causes of casting defects. Higher levels of rejection of castings due to defects, is a matter of concern for any foundry industry. The quality of casting is influenced by various process parameters. The relationship between them and influence of different process parameters causing the heavy casting rejection needs to be identified and further be analysed process control and optimizing the process.

II. SCHEME OF LITERATURE REVIEW

There is a great variety and volume of literature published on foundry practices and process control. Different types of research work reported, related to casting defects are reviewed through published literature and physical visits to the foundries. They are categorized as follows, (i) Single Defect, (ii) Quality control Tools Used (iii) Effect of Gas Pressure and Gating System (iv) Process Parameters (v) Coatings and (vi) Human Factors.

Senthilkumar et al., (2009) [1] studied the pull down defect. The reasons for pull down effect are pouring temperature, CE Value and gating system design. Each factor was analysed for three signal levels. The estimated robust design factors values were analysed using ANOVA technique. Using Taguchi method with L18 orthogonal array, they used different combinations to form optimum levels of them to reduce rejection due to pull down effect and found the acceptance raise to 96% from 86%.

Chokkalingam and Nazirudeen, (2009) [2] presented a systematic approach to find the root cause of a major defect (mold crush) in an automobile casting produced in a medium scale foundry. The origin of the mold crush defect was identified by means of analyzing tools and processes using defect diagnostic approach as well as CED. Finally, it was found that the core was the root cause for this major defect. The necessary remedial actions were made in the core box to take the core as a single piece. The major mold crush defect was totally eliminated after using single core in regular production. The total rejection was reduced to 4% from 21%.

Joshi and Jugulkar, (2014) [3] helped a foundry to control their rejection. They had focused on the manual traditional metal casting operations. They have used different quality control tool such as Pareto analysis and CED (cause and effect diagram) to sort the defects and identify the root cause respectively. The defects are like mold shift, shrinkage, mis-run, cold shut, blow holes and porosity etc. Accordingly they suggested remedial actions by studying the roots of defect like automation at some stages e.g. change manual shakeout to vibratory shakeout system and use of automatic monorail. Initially the rejection was around 30%, after taking preventive actions it came down to around 10%.

Bhattacharya et al., (2012) [4] have carried out analysis of casting defects and identification of remedial measures. Diagnostic study was carried out on Trunion Support Bracket (TSB) Castings and it is revealed that the contributions of the four major common defects in casting rejections are sand drop, blowhole, mismatch, and oversize. It was noticed that these defects are frequently occurring at particular locations. Systematic analyses were carried out to understand the reasons for defects occurrence and suitable remedial measures were identified. Outcome of the validation trials showed substantial reduction in rejection of castings. They suggest standard operating procedure and sponsors accepted it and 7 % reduction in rejection was reported.

Binu Bose et.al, (2013) [5] have introduced a new Simulation model to reduce the rejection rate in foundry from 15% to 7%. From the analysis report of an Indian foundry the Milacron cylinder clamp product which is having high rejection rate due to major defects such as sand inclusion, cold shuts, shrinkage, mold breakage etc are solved using simulation software before its trial production. The rejection rate of this product is reduced by proper optimization of the process and through strategic solution from the simulation techniques. The proposed model coupled with process control has the potential to achieve null defect castings at the least cost.

D. Mahto et.al (2008)[6] have reviewed and studied different case studies and found that SQC tools like CED, pareto charts, X bar charts do, in fact, have the capacity to find the root causes with varying degrees of accuracy, efficiency, and quality and it is also found that , rejection has reduced from 11.87 % to 1.92 % with minor skill improvements.

Vivek Patil et.al (2015) [7] have summarized the General procedure for analysing casting defects using diagnostic approach. The rejection in Rear Crossover brake disc casting of Minibus (TATA) is analysed using various SQC tools.

Vaibhav Nerle et.al (2013)[8] have analyzed and minimized sand drop casting defect in automobile cylinder block of grey cast iron in foundry from 37.17% to 16.3%. He has represented the defect reduction by why-why analysis of non mea-surable rejection causes. Hence concluded that quality tools are effective way of in-vesting and minimizing rejections due to non measurable causes.

Bhushan Kamble (2016) [9] has collected and summarized various defects and their possible remedies. It is also focused that it is also important to identify a defect and its possible root cause and its remedies to overcome possible defects.

III. GENERAL PROCEDURE FOR CASTING REJECTION AND DEFECT ANALYSIS

Casting defect analysis is the process of finding root causes of occurrence of defects in the rejection of casting and taking necessary step to reduce the defects and to improve the casting yield. Figure 1 indicates a systematic procedure for defect diagnostic approach towards analyzing casting defect and to set a standard set up procedure to minimize defect.

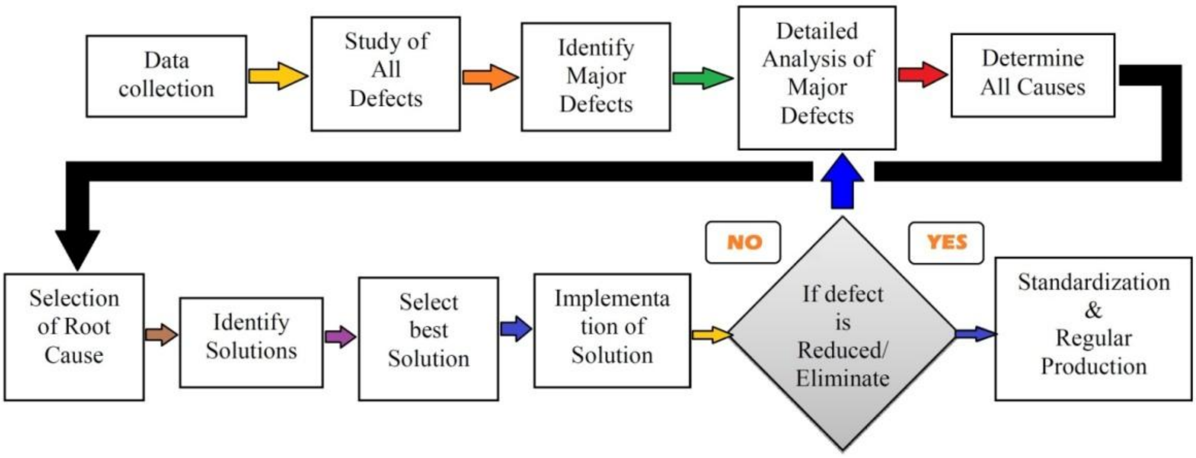

Figure1. Flow chart of casting defect analysis

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IV. PRELIMINARY STUDY AND PROBLEM DEFINITION

Figure 1.1. Bearing covers casting after machining

Bearing cover as shown in Figure 1.1 is major defective component noticed by the machine shop in a local foundry situated in Kolhapur.. It is noticed by quality control section that, the component is having eccentricity at the inner diameters. It was also found that some components are not getting fitted properly in the CNC machine fixture. The main reason found being, many of the components having run out between diameters. Higher rejection was observed for this part during peak period orders. Around 250 components are produced in every batch. It is part of a heavy duty application. The part is made of grey cast iron with FG-260 grade. It weighs about 4.8 kg and has 8 mold cavities mounted on two halves of pattern with a centralized gating system. There are different types of defects found in the casting after inspection. For analysis to carry out, the major defects which are having higher impact on the final quality of casting needs to be identified.

Bearing cover is major defective component noticed by the machine shop in a local foundry situated in Kolhapur.. It is noticed by quality control section that, the component is having eccentricity at the inner diameters. It was also found that some components are not getting fitted properly in the CNC machine fixture. The main reason found being, many of the components having runout between diameters. Higher rejection was observed for this part during peak period orders. Around 250 components are produced in every batch. It is part of a heavy duty application. The part is made of grey cast iron with FG260 grade. It weighs 4.8 kg. It has 8 mold cavities mounted on two halves of pattern with a centralized gating system. There are different types of defects found in the casting after inspection. For analysis to carry out, the major defects which are having higher impact on the final quality of casting needs to be identified.

Some of the defects do not impair the service life of the cast component and so can be salvage by repairing. Some defects causes' serious damage to the component and so such castings are rejected. So it is necessary for a foundry to maintain adequate records to enable quality performance to be assessed and to indicate the cause of the rejection. The following tools are adopted for rejection analysis and its control. The defects like sand drop, slag inclusion and run out Mold are analysed and solved by using the defect diagnostic approach, is presented in detail.

V. PARETO CHART ANALYSIS

Pareto analysis is used to sort for major and minor defects. The Vital few causes are identified by constructing the Pareto diagram. A special form of a bar chart which seeks to determine the most important factors in a situation. The Pareto chart provides the graphical representation of all the defects for selected components in a manner simple to read and interpret. It states that some issues (the vital few) result in the largest percentage of problem. A rule of thumb says 20% of causes account for 80% of variations. The rejection data is recorded for entire month, for different casting components, batches and shifts is taken under consideration. As shown in figure 2, Pareto analysis is used to sort the casting components according to their share in the cumulative rejection percentage for the respective month

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Table 1. Percentage wise rejection of castings.

Item Name	Poured Quantity	Poured Weight (Kg)	Total Rejected Weight In Month(Kg)	Unit Weight (Kg)	Rejected Quantity	Rejected Weight (Kg)	Rejection % By Weight
Cylinder block	5324	30613	39149	5.75	532	3059	7.81
BG 40 01	306	6403	39149	20.925	117	2448.23	6.25

Table 2. Number of castings rejected because of different defects

Defects	Runout	Sand Drop	Extra grinding	Slag inclusion	Leakage	Hard sand	Swelling	Cold shut	Core lift
Rejected castings	204	111	26	21	12	11	9	7	5

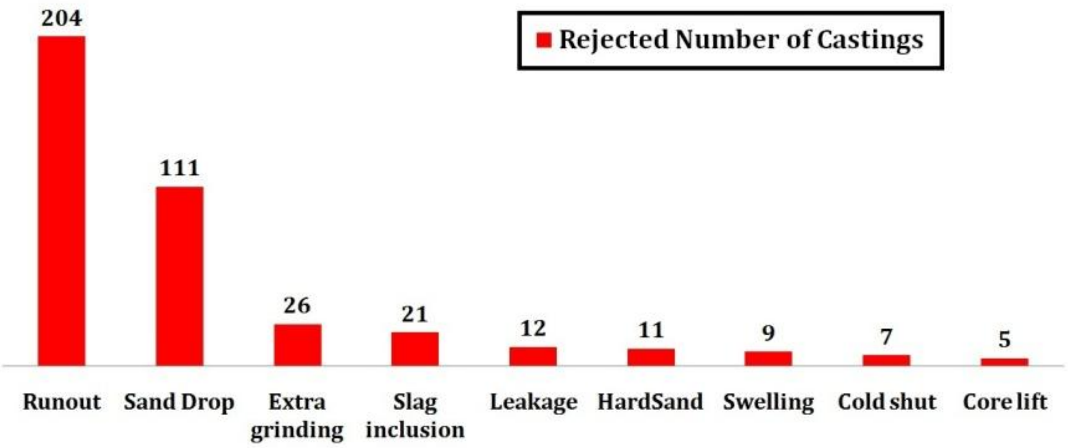

Figure 2. Pareto Chart defect analysis

Table 3. Number of castings rejected because of different defects

Poured Quantity	Rejected Quantity	Rejection (%)
1868	435	23.28

After collecting the defect wise data, major defects are sorted for further analysis. Sand drop, slag/sand inclusion and run out are the three major defects. The next step is to use quality tools to find the root causes for each defect.

VI. CAUSE AND EFFECT DIAGRAM

This diagram represents the relationship between a problem and its potential causes. It's also known as fishbone or Ishikawa diagram. It deals only with factors responsible and not quantities.

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A. Root- Cause Analysis for defects: CED for defects in bearing cover

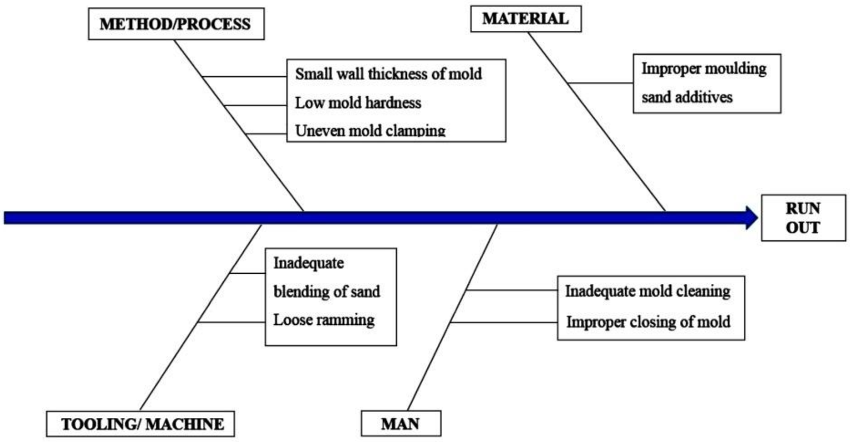

Figure 3. Cause and Effect Diagram for Run out Defect

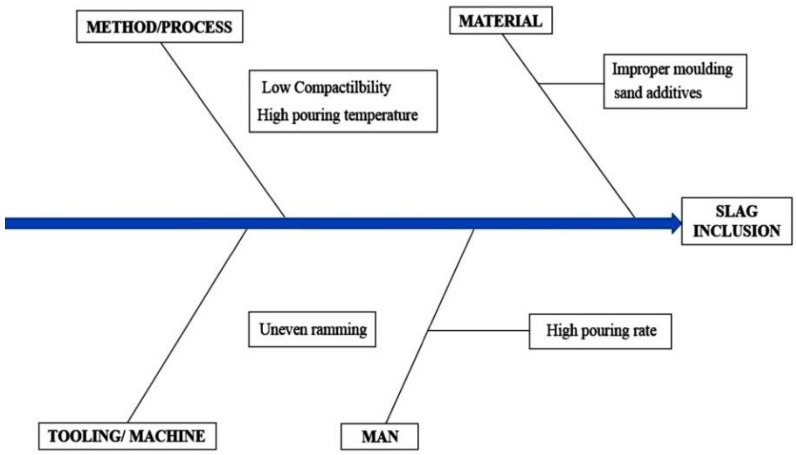

Figure 4. Cause and Effect Diagram for Slag Inclusion Defect

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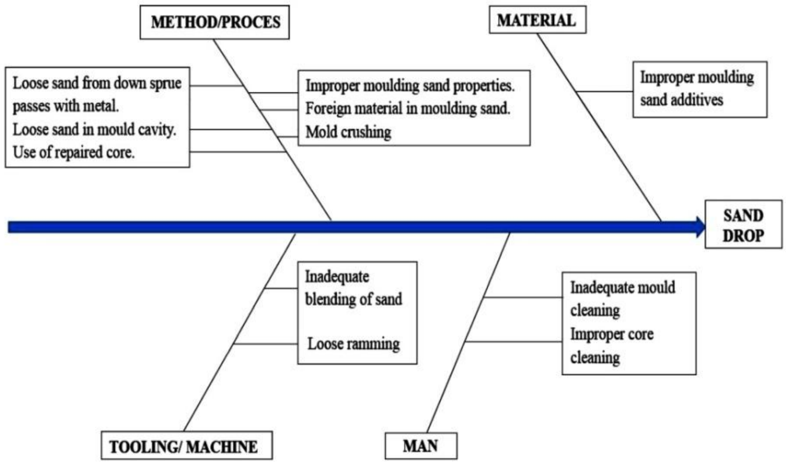

Figure 5. Cause and Effect Diagram for Sand drop Defect

VII. ANALYSIS OF DEFECTS OCCURRING IN BEARING COVER

The Bearing cover is the component for rejection analysis. All the defects which are occurred in the components are recorded with their quantities. The casting is produced in three shifts. This component is produced mostly in second and third shift. Due to less manpower, the supervision in these shifts is not very effective. Hence, the production of this component is planned during first shift to facilitate the analysis. From CED, it is observed possible cause of sand drop defect and Run out. From this tool, the first impression is loose sand is falling in drag part of mold cavity. Inadequate binder proportion is the cause for loose sand/ green compressive strength. Hence the proportion of binder i.e. Bentonite in making green sand should be reviewed avoiding reduced green compressive strength

A. Green sand:

Green sand is an important ingredient for final quality of castings. The Bearing cover should have better quality of casting as most of its portion is "as-cast". There is certain sand properties which are need to be kept at required range. As the company produces around 150 different types of castings in batches that always needs to keep an eye on the appropriate sand properties. Table 4 indicates the green sand properties for the acceptable quality of the green sand.

Table 4. Green Sand Properties:

Green compression strength	1000 to 1200 gm/cm^2
Moisture Content	3 to 3.5 %

Table 5. Possible root cause and its effective remedies to overcome the sand drop defect.

Cause for sand drop	Contribution to Sand drop defect	Remedial action
Sand additives	Not proportionate mixing of sand additives	Check proportion of green sand additives
Loose sand or foreign material	Less binding property and Compatibility	Check binder proportion in sand and green sand properties
Mold or core cleaning	Improper cleaning of mold reflects this defect at as-cast part	Completely clean mold cavities
Mold crush	Crushing of halves causes fall of sand in mold cavity	Check balancing of match plate

Run out defect is where the concentricity of circular component lags. In case of casting there might be several possible

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reasons as loose ramming, inadequate proportion of sand binder, mold hardness are the possible reasons for runout.

Table 6. Possible root cause and its effective remedies to overcome the Runout defect

Cause for run out	Contribution to Runout defect	Remedial action
Low Mold hardness	Inadequate proportion of binder and loose ramming give low mold harness	Hardness should be 80-90 nos.
Small wall thickness of mold	There are eight mold cavities which cause congestion in mold give smaller side sand wall thickness	Reduce number of cavities
Inadequate cleaning	The sand on upper surface of drag mold can lead uneven or unbalanced mating of two halves	Clean mold surface

Slag inclusion and sand inclusion is the defect where the slag or sand gets stuck to the component surface. The sand can also penetrate the metal surface; this defect is called metal penetration. There are different causes responsible as improper mixture of sand additives, high pouring temperature or high pouring rate might be the reason for occurring slag inclusion.

Table 7. Possible root cause and its effective remedies to overcome the Slag inclusion defect

Cause for Slag inclusion defect	Contribution to Slag inclusion defect	Remedial action
High pouring temperature	High pouring temperature can induced impurities (slag/sand) in metal	Maintain pouring temperature (1380-1420 oC) in range
High pouring rate	High pouring rate can cut the edges in penetrate the metal surface	Uniform pouring rate
Low compatibility	Uneven ramming can penetrate metal surface to sand or slag	Even ramming

VIII. CORRECTIVE ACTION

Analysis through Ishikawa diagram shows first process parameter which causes the rejection is exposed i. e. Green sand properties. Green sand is a basic and an important ingredient to the molding process. There are several other reasons for these major defects such as low mold hardness and pouring temperature. Inadequate use of binder sand is one of the reasons for low mold hardness. Temperature is different entity. The first focus is on sand properties. After analysing all views and observations the foundry head finds that the bunch weight is more result in less sand to metal ratio. This is sufficient to lose the strength of the mold. But the reduction in mold cavities can hamper the production plan and unable to achieve the demand levels. The mold cavities shall be reduced to six to get optimum results. Through the discussion following points are highlighted,

Bunch weight: The bunch weight is nothing but the weight of metal in one mold box. The bunch of Bearing cover front is 49.1 kg. Bunch weight is the addition of number of casting in mold box and runner and riser weight.

Sand to Metal ratio: This ratio is nothing but weight of sand in one mold box to bunch weight. The ratio for this component is 3.17.

Mold cavity: The Bearing cover is having 8 mold cavities. Due to this bunch weight is more and less sand to metal ratio. The metal is more in one mold box which makes weaker side walls of mold. The weaker mold wall cannot handle pouring pressure as well as the temperature. The thickness of side walls of mold is 1.5mm which is small

A. Why-Why Analysis Method

The conclusion of brainstorming is to reduce the number of mold cavity but without spoiling production plan. If mold cavities are reduced to four then production time will be more. The efforts of worker will be doubled. Six mold cavities will be optimum for production plan. The gating system will be at center and three-three mold cavities will be on either sides of the runner bar. Every mold cavity will have attached ingate for mold filling.

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Figure 6. Drag half of Bearing cover mold box

IX. ANALYSIS FOR RUN OUT DEFECT

Run out is the major defect for selected bearing cover component. Run-out is an inaccuracy of rotating mechanical systems, specifically that the tool or shaft does not rotate exactly in line with the main axis. Figure 7 shows the runout defect in bearing cover. It shows that the machining is done on the half side of inner diameter and haft part still as-cast and hence not able to remove extra material from casting diameter. This component is a portion of heavy duty application. It will have rotary motion when it fits in its place. The shop floor representatives have demonstrated that, most of the components are unable to fit in fixture. To resolve this problem the work pieces are grinded manually along the curve surface shown in figure. It is a time consuming for a CNC operator. If the runout occurs in this component then whole mechanism where is going to be fitted will get disturbed.

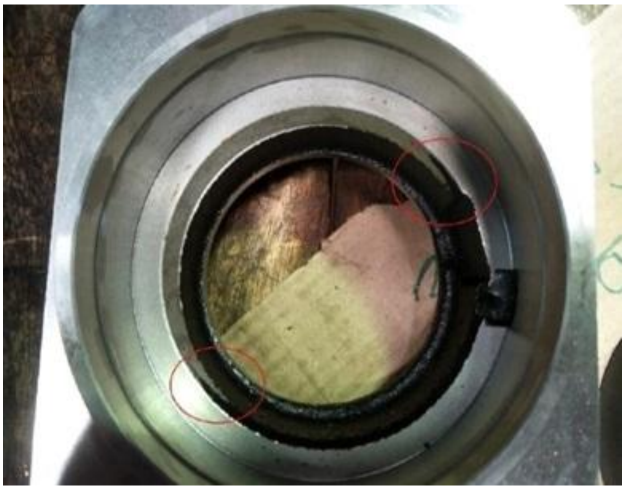

Figure 7. Runout defect in bearing cover

Figure 8. Casting swell

A. Brainstorming on Runout defect:

To find the root cause for sand drop and run out needs participation of every person of different department who is related to the final quality of castings. Following are the participants for brainstorming,

1. Foundry Head: This person is a key person for brainstorming owing to his knowledge and experience. He is ultimately responsible for quality of casting. He also has the authority to make decisions necessary to ensure the quality.
2. Quality Head: The Quality Head is directly responsible for certifying the quality of casting. He is responsible for monitoring the green sand properties.
3. Development head: He gives all technical terms related to pattern and development of pattern.
4. The author of this report as an analyst.

Following are the points for discussion, Sand swelling, Dimensional check, Number of mold cavity and Sand to weight ratio. By taking the above points into consideration the brain storming taken place with all the participants mentioned above. The conclusion of brainstorming is to reduce the number of mold cavity but without spoiling production plan. If mold cavities are reduced to four then production time will be more. The efforts of worker will be doubled. Six mold cavities will be optimum for production plan. The gating system will be at center and three-three mold cavities will be on either sides of the runner bar. Every mold cavity will have attached ingate for mold filling.

Figure 9. Bearing cover Old pattern (Cope half)

Figure 10. Bearing cover Modified pattern (Cope half)

X. IMPLEMENTATION OF SOLUTION

Figure 9 and 10 indicates changes made in the pattern layout. The mold cavities are reduced to 6 and the runner bar came in place of centralized gating system.

Table 8. Monthhwise casting rejection after implementation of solution.

Month	Sand Drop	Slag Inclusion	Run Out	Others	Rejected Quantity
April	111	21	204	81	417
May	182	14	410	54	660
June	82	10	531	73	696
July	26	7	206	31	270
August	17	11	12	29	69

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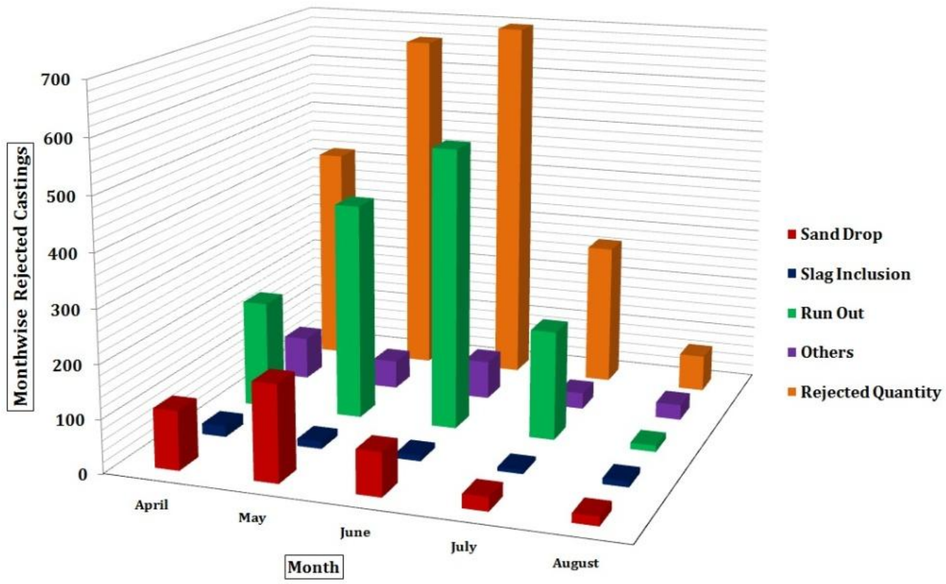

Figure 11. Month-wise rejection analysis of major defects of bearing cover

XI. OBSERVATIONS

The occurrences of all three major defects for five months are shown in Figure 11. It shows the defect sand inclusion and sand drop are reduced by controlling the sand properties, but the main concern was of run out defect. By using all three quality tools, the conclusion was made to change the pattern layout and also reduced the number of cavities. After changing the pattern the result shows that the all three major defects i.e. sand drop, slag inclusion and runout are reduced to their lower most rejection quantity 17, 11 and 12 respectively

XII. CONCLUSION

The above work was a systematic approach towards quality control through reduced rejection level. The rejection percentage of bearing cover was reduced from 23% to 3%. The major defect, sand drop and slag inclusion are reduced to 30% from the start of work. The root cause analysis showed that excessive number of mold cavities caused the lesser mold wall thickness and lower sand to weight ratio of mold box. The Case study showed that the quality tools like pareto chart brainstorming and CED are an effective way minimizing rejections due to non measurable causes.

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