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Process Improvement in Casting through Defect Minimization: A Case Study.

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Abstract -Process mapping is the detailed mapping of the real process. 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. A proper methodology is formed consisting of various quality control tools such as Pareto analysis, Ishikawa diagram (cause and effect diagram), brainstorming, why-why analysis. After Implementation of this methodology a better control over the process will be obtained. Detailed analysis of root cause will result into the permanent solution to the problem. This paper represents rejection details of casting under study with the help of quality control tools such as Pareto and Ishikawa diagram. Major defects contributing rejection of casting of Gear box housing are categorized into two parts. Namely methoding, filling and solidification related defects such as shrinkage & sand and mould related defects such as sand inclusion, sand drop etc. A methodology is formulated to improve the process and it will result into the minimisation of defects occurring with current casting process.

Keywords -Casting Design, Casting Defect, Pareto Analysis, Ishikawa diagram, Simulation, Optimization and Analysis.

1. INTRODUCTION

Process is a series of actions, changes or functions that bring about an end result. A Process is defined as one or more tasks that transform a set of inputs into a specified set of outputs it may be in terms of goods or services for another person i.e. customer or process via a combination of people, procedures, and tools. The sequence of procedures done to produce an output. A task is just one individual step in the process. Process mapping is the detailed mapping of the real process. Aim of Process maps are bringing clarity to complex processes, Highlight non-value adding activities and Start the process of thinking about improvements. There are five stages to the process activity mapping: (1) The study of the flow of processes; (2) The identification of waste/defects (3) A consideration of whether the process can be rearranged in a more efficient sequence; (4) A consideration of a better flow pattern, involving different flow layout or transport routing; and (5) A consideration of whether everything that is being done at each stage is really necessary and what would happen if superfluous tasks were removed [1].

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. During the process of casting, there is always a chance where defect will occur. Minor defect can be adjusted easily but high rejected rates could lead to significant change at high cost. Improvement can be achieved by either better control or by raising standards. Quality improvement will be achieved by using quality control tools. A proper methodology is formed consisting of various quality control tools such as Pareto analysis, Ishikawa diagram (cause and effect diagram), brainstorming, why-why analysis. After Implementation of this methodology a better control over the process will be obtained. Detailed analysis of root cause will result into the permanent solution to the problem. Successful implementation of the remedies results into reduced rejection rate of casting and quality improvement [8].

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2. LITERATURE REVIEW

A considerable research work in the area of casting process improvement through defect minimization of casting has been carried out. A brief Review of some selected references on this topic is presented here.

Pude et al [1] focused on three tools namely Process activity mapping, Quality filter mapping and Production variety funnel to reduce the wastes in foundry. The prime objectives of their work is to use of value stream mapping tools in identifying, quantifying and minimizing major wastes in a foundry production line. Their aim is to reduce lead time for process improvement. The results of Process activity mapping shows 23% waste reduction in the areas of unnecessary inventory, transportation and waiting. For Quality filter mapping it is difficult in actual practice to predict or analyze the defects at each foundry processes as the final inspection gives the clear picture of internal defects. But it is possible to reduce the chances of defects at the generic origin sources i.e. at melting, moulding, pouring, finishing and by controlling the melting parameters like pouring time, temperature etc. In their study they identified bottleneck product and key sources for internal scraps are identified and these are analyzed and improvement is carried out. After that future state quality filter map with findings are presented. Future state map revealed that about 700 castings per million are saved from defects.

Vante and Naik [2] discussed the research carried out in the foundry to control the increased rejection. The component under study is 3 cylinder metric block. The dimensional variations in casting wall thickness are analyzed as major defect contributing in rejection. Quality control tools such as Pareto analysis, cause and effect diagram, why-why analysis, are used for analysis of casting defects. Remedies to minimize the rejection are suggested and implemented. Various chaplets are tried and tested as remedies. The previously used 3 disc round chaplet is replaced by rectangular v-make chaplet. Pouring temperatures and chaplet size are optimized to lower the rejection percentage. Rejection percentage for dimensional variation at water jacket is decreased from 7 to 2.13. Reduced rejection indicates better control resulting in quality improvement of 3 cylinder metric block.

Joshi and Naik [3] aimed to reduce cycle time of an operation by using Single Minute Exchange of Dies (SMED). Their Study was carried out in one of the automotive industry. Single Minute Exchange of Dies (SMED) is the approach to increase output and reduce quality losses. SMED methodology applied to prepare an optimal standard procedure for changeover operations on defined machine. A Comparison of results and achievements before and after SMED implementation were made. The results Shows that their study has achieved more than 30% of Cost reduction, 97sec can be reduced which increases the productivity.

Raghupathy and Amirthagadeswaran [4] aimed at parametric optimisation for controlling casting defects in FG 200 Pump adapter was attempted by Box-Behnken design of experiments (DOE). Relevant experiments were conducted in a foundry producing pump components. The major parameters that were responsible for producing casting defects in pump components were identified as proportions of clay, moisture and Mold hardness respectively. Each parameter was analyzed with three different levels. Further the contribution of the parameters was analyzed using ANOVA technique to find their effects. Interaction effects between the factors were also studied. F-Test of the ANOVA revealed that the parameters of proportion of clay and Mold hardness were equally significant in the casting process. The optimized parametric setting was determined by Design expert software: Clay – 2%, Moisture – 3.87 to 4 %, Mold Hardness – 5.21 to 5.45 kg/cm2 as a range of values for the input conditions that can be easily practiced by workmen in industries.

HariPriya G et al [5] reviews the literature and some of the lean principles such as the Value Stream Mapping and Waste elimination by implementing 5S in the organization. Their paper also aims at reducing lead time by eliminating stress relieving cycle with extended cooling of castings in the mould and stabilizes the sand casting process by rationalization of the material grades. The lead time was reduced from 40.4 hours to 30.3 hours. The shrinkage defect was eliminated in HSTC table after the grade was changed to G4. Process FMEA and Process Control Plan were developed to control the process.

Gupta and Suri [6] focused on minimizing the defects in Al-Mg alloy castings in green sand casting process by optimizing the casting process parameters. Several process parameters contribute to these casting defects. Literature review reveals that moisture content, binder percentage and pouring temperature are among the most influencing parameters which contribute to the casting defects like sand drop, blow holes, scabs, and pinholes. In this paper these three process parameters are optimized by using the Taguchi's design of experiment method. The Taguchi approach is used to capture the effect of signal-to-noise ratios of the experiments based on the orthogonal array. Robust design factor values were estimated from the signal-to-noise calculations.

Shinde et al.[7] Studied the productivity of ductile iron foundries engaging in mass production of castings for the automobile and other engineering sectors depends on the number of cavities per mold. A denser packing of cavities, however, results in slower heat transfer from adjacent cavities, leading to delayed solidification, possible shrinkage defects, and lower mechanical properties. In this article, they propose a methodology to optimize mold yield by selecting the correct combination of the mold box size and the number of cavities based on Solidification time and mould temperature. Simulation studies were carried out by modeling solid and hollow cube castings with different values of cavity-wall gap and finding the minimum value of the gap beyond which there is no change in casting solidification time. Then double-cavity molds were modeled with different values of cavity-cavity gap, and simulated to find the minimum value of gap. The simulation results were verified by melting and pouring ductile iron in green sand molds instrumented with thermocouples, and recording the temperature in mold at predetermined locations.

Bose and Anilkumar [8] aimed at reducing rejection rate of castings in an Indian foundry. The overall goal of the project proposed here in is to reduce the rejection rate using simulation model in foundries. In this paper a case study on a cylinder clamp casting of Milacron product ,which is having high rejection rate in an Indian foundry is taken and the defects of casting are solved using the proposed simulation model with Magma 5 software and the effective solutions for reducing rejection rate for the product is also given. By replacing the existing trial and error method with computer simulation foundries reduces rejection rate from 8.5 to 3.5 %.

Jadhao and Salunkhe [9] observed that casting simulation shows the virtual process of casting like mould filling, solidification and cooling and also predicts location of internal defects hence optimization is possible. They give more emphasis on Feeder optimization. They explain 5 steps of simulation. They done casting simulation on feeder as an example & compared their results with respect to Quality and Yield for variety of feeder selected. Casting simulation is used for the production of reliable, economical and high accuracy cast component. Also it is used to increase the casting yield and reduce the shop floor trial time. With casting simulation technique, casting method and design optimization is possible. Casting simulation helps to predict the defects and their locations. With casting simulation technique, the Feed ability of casting process can be analysis and optimized.

3. Research Issues

In regards of process improvement of casting, research issues can be summed up as follows:

1) More research is targeted in the area of process parameters optimization by design of experiment for process improvement but less work has been reported in optimization of gating system for minimization of solidification defects and hence process improvement.

2) Researchers carried out number of virtual trials over software for defect minimization but very few explain theoretical calculations for design of gating system.

3) Virtual trials do not involve wastage of material, energy and labour, and do not hold up regular production. However, most of the simulation programs available today are not easy- to- use, take as much time as real trials, and their accuracy is affected by material properties and boundary conditions specified by users. The biggest problem is the preparation of 3D model of the casting along with mold, cores, feeders, gating, etc., which requires CAD skills.

STUDY OF CURRENT PRACTICES.

Sponsoring Organisation-

Industry is established in 1960 and it is one of the leading foundry in India for manufacturing of “graded Gray iron and Nodular iron castings” with in-house machining facility. Total foundry capacity is 10,000 MT / month .Total manpower associated with Industry is around 600 and having turnover of 650 Cr/year. Manufacturing plant is equipped with automatic High Pressure moulding line, Auto pouring unit, sand plant, core setting unit, core shooter machines and robotic machined fettling facility. Company has their separate divisions as per work like Moulding, Melting, Core Shop, Finishing & Painting, Design and Engineering, Quality Assurance etc. The major products of Industry are various types of Gate valve, Ball valves, Mechanical Gear Box, Hydraulic Gear Box, Fluid Coupling, Torque Convertor, etc.

Problem Associated With Existing Casting Process-

Gear Box Housing product of a local foundry facing a problem of Heavy rejection due to different process related defects. Process was observed for six months to analyse current practices. It was observed that the rejection rate is about 15 %.Defects occurred in housing are sand inclusion (8%), Shrinkage(4%) and other defects such as cracks, mismatch etc. (3%).The monthly production of gear box housing is 1000 units. The price for one housing is Rs.5000/-.So loss of revenue due to poor quality casting is 7.5 lakhs per month approx. Organisation is facing loss of significance revenue due to cost of poor quality. Hence organisation is interested to minimise these defects to improve process. Investigation and analysis of problem leading to defect and increased rejection are needed for process improvement. A methodology for achieving consistent quality in production of the component Gear Box Housing needs to be developed. Fig 1 shows image of Casting under study.

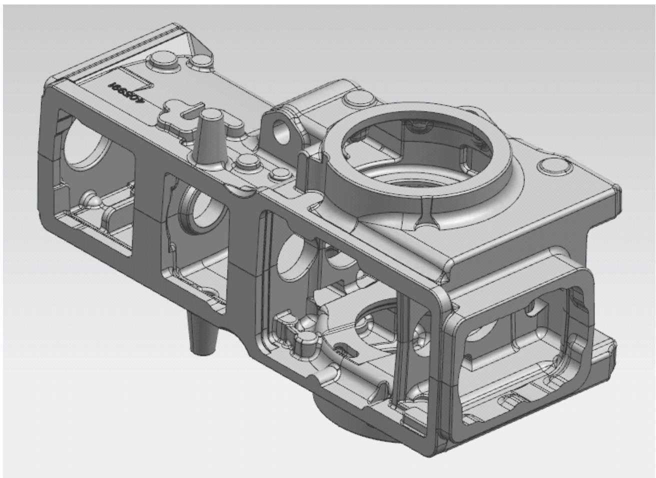

Fig 1 –Gear Box Housing under study.

Rejection Data Collected from Process Mapping-

Table 1 shows monthly rejection of casting under study for last 6 months. The average percentage of rejection for this time span is 13.02%.Data is collected from month of Aug 2016 to Jan 2017 and percentage of rejection varies from 09.58 to 18.2.

TABLE 1- PERCENTAGE REJECTION OF GEAR BOX HOUSING.

Month	Production	Total Rejection	Percentage of Rejection
Aug. 2016	793	137	17.28
Sept. 2016	1237	157	12.69
Oct. 2016	1318	137	10.39
Nov. 2016	1175	142	12.09
Dec. 2016	1033	188	18.2
Jan. 2017	1086	104	9.58
Total	6642	865	13.02

Fig 2 gives the graphical representation of the monthly rejection gear box housing with reference of values from table 1.

Rejection Details-

Table 2 shows rejection due to defects and their individual percentage of rejection. From data it is clear that most dominating defect is sand inclusion which is responsible higher rejection rate.

TABLE 2- DEFECTS AND AVG. REJECTION PERCENTAGE.

Month	Shrinkage	Sand Inclusion	Core Scab	Fettling Cracks	Other Defects	Total rejection
Aug. 2016	26	54	20	27	10	137
Sept. 2016	12	94	20	09	22	157
Oct. 2016	34	71	13	08	11	137
Nov. 2016	20	67	01	38	16	142
Dec. 2016	27	87	31	39	04	188
Jan. 2017	29	34	09	12	20	104
Total	148	407	94	133	83	865
Avg. Rej. Percentage	2.23	6.13	1.42	2.00	1.25	13.02

Revenue lost due to rejection in month of August 2016(Sample Calculation)

Table 3 gives loss of revenue due to poor quality of gear box housing. The number of casting produced in the month of Aug. was 793.Out of which 137 were rejected. Cost of housing is Rs 5000/-.So total revenue loss in that month is 685000/- approximately.

TABLE 3- REVENUE LOSS FOR MONTH OF AUG.

Casting poured	Rejected castings	Cost of housing in Rs.	Total revenue lost
793	137	5000/-	685,000/-

Pareto Analysis for Defect Categorizations-

Pareto Analysis is conducted for identification of major defects those are contributing in major rejection percentage. This tool is used to find the 20% of work that will generate 80% of the results hence also named it as a 80/20 rule. Pareto gives correct identification hence it is conducted. The average rejection percentage for housing is 13.02.Various defects are contributed in rejection of product under study. These defects along with their avg. percentage are represented on a graph, from which it is clear that which defect contributing more in rejection.

From fig 3 it is clear that sand inclusion and then shrinkage defect greatly affects the quality of casting and hence causes higher rejection rate. Sand inclusion and shrinkage contributing 6.13 % and 2.23 % of Avg rejection respectively out of total avg. rejection of 13.02 %.

Cause and Effect Diagram (Ishikawa Diagram)

It is a tool of quality management also known as fishbone diagram. Cause and Effect Diagram is one of the approach to enumerate the possible causes of defects occurred in casting. It helps to separate the effects from causes of a problem and to minimise complexity of the problem.

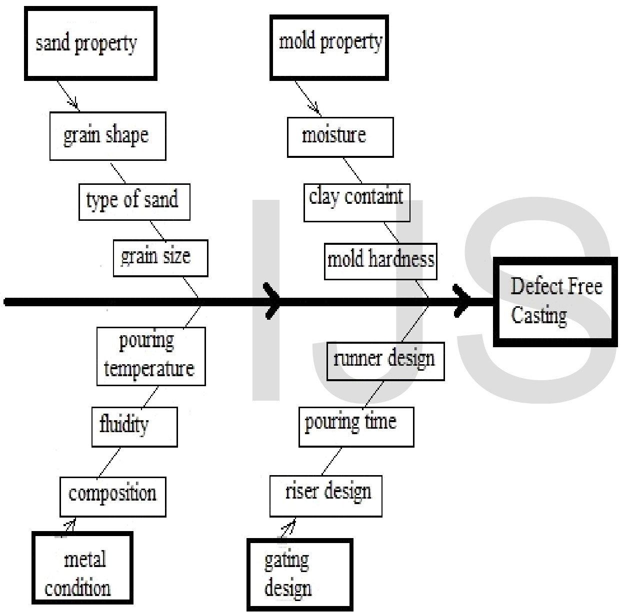

Fig 4- Cause and Effect diagram for Defect free casting [4].

4. Methodology.

A methodology is formulated to accomplish the objectives. This will form the guideline and it will result into the minimisation of defects occurring with current casting process. The methodology is as follows-

1) Process mapping of current casting process of Gear Box Housing.

2) Defects analysis by Pareto chart and Ishikawa Diagram.

3) Solidification related defects analysed by using techniques like simulation software.

4) Optimization of gating system is to be achieved by

a) Method design by theoretical formulae for gating system and

b) Modified gating system is to be simulated by simulation software.

5) Effects of process parameters of sand/mould to be analysed by Taguchi Method.

6) Selection of optimum process parameters of sand/mould.

7) Confirmation Experiment to be conducted at optimum level of process parameters.

5. Conclusion

The quality of castings depends on quality of sand, method of operation, quality of molten metal etc. To produce defect free casting attention have to be given towards controlling the process parameters. Most of the researchers in their study used Pareto principle and hence seven quality control tools, FMEA, Six sigma, 5S, Value stream mapping to identify and evaluate different defects and causes for these defects responsible for rejection of components. Also used simulation packages for simulation of component for process improvement. Preliminary stage of research discussed the application of quality control tools for reducing rejection rate of gear box housing. Initial study shows that casting under study facing higher rate of rejection due to defects occurred in it namely sand inclusion, shrinkage etc. Average percentage rejection for last 6 months was found to be 13.02. High amount of revenue is lost due to these defects considering per unit cost of housing is Rs. 5000/-. This indicates there is a scope for process improvement of casting so that loss of revenue will get minimised. It has been expected that by using combined approach of simulation technique and design of experiment defects in product under study will be minimised.

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