DEFECTS ANALYSIS AND OPTIMIZATION OF PROCESS PARAMETERS USING TAGUCHI DoE TECHNIQUE FOR SAND CASTING

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Abstract - *Although Metal Casting is an earliest known process, industries are suffering from the poor quality of casting because of a large number of parameters are involved in the process. The quality can be improved by reducing the defect through optimization of process parameters. In this paper, a systematic procedure is given to analyze the cold shut defect and reduce it by optimizing the parameters. A cold shut defect is found in the delivery casing which is produced by using gray cast iron. The quality control tools like Check Sheets, Histograms, Pareto Analysis and Fishbone Diagrams are used to analyze the defect and to find the parameters which affect the final quality of casting. Three parameters are selected which affect most to the final quality which is Pouring Temperature, Pouring Time and Gating System. Taguchi Technique is used for optimization of the parameters and Orthogonal Array is used for experimental purpose. In trial and error method a large number of shop floor experiments are required, Taguchi Orthogonal Array reduces these number of trials and save time and cost and give accurate results. Minitab software is used to apply Taguchi Technique for optimization. Taguchi gives the optimum value of parameters, after applying the optimum values on shop floor the defects are reduced up to a minimum.*

***Key Words*: Sand Casting, Cold Shut defect, Quality Control tools, DoE, Taguchi, Optimization.**

1. INTRODUCTION

Metal casting is one of the earliest phenomenon known to a human being. It is the first step in the production and manufacturing of metallic components. It generally means pouring molten metal into a refractory mould with a cavity of shape to be made and allowing it to solidify. After solidification of the metal desired metal object is taken out from the mould either by breaking the mould in the case of expandable mould or taking the mould apart in case of permanent mould [9]. The process is called casting process and product is casting. Sand casting is also known as sand moulding process which is one of the cheapest methods. Over 70% of castings are produced by only sand casting processes. There are a number of parameters are involved in the sand casting process so it is very difficult to produce defect free casting. Number of defects occurs if the parameters are not optimized i.e. Cold Shut, Misrun, Blow hole, Flash, Swelling, and Mismatch etc.

A cold shut is formed due to the imperfect fusion of two streams of metal into the mould cavity. It may appear like a crack or seam with rounded edges. The reasons behind the occurrence of this defect are less fluidity of molten metal, less wall thickness, improper gating system and slow pouring.

Fig -1: Cold Shut defect in Delivery Casing

2. LITERATURE SURVEY

B.R. Jadhav and Santosh J Jadhav [1] Worked on Investigation And Analysis Of Cold Shut Casting Defect And Defect Reduction By Using 7 Quality Control Tools. This paper represents a systematic procedure to analyze and minimize the cold shut defect in an automobile cylinder block which has a material gray cast iron Grade FG150. In this paper, they reduce the defect by controlling alloy composition and pouring temperature. To analyze and reduce defects the seven quality control tools are used which Include check sheet, Pareto analysis, cause effect diagram, flow chart, scatter diagram, histogram and control chart. The trails show that temperature range 1418 to 1432 °C gives a reduction in cold shut while considering other defects. The recommended range of phosphorous is 0.12 to 0.2%, phosphorous increases flowability so percentage should be towards upper control limit. Silicon percentage limit is recommended between 1.83 to 2.0%.The total rejection of cold shut was reduced by 6.6% from 12.3%.

Borikar et al. [2] worked on Optimization of casting components by Minimizing cold shut defect. They observed that 80% of rejections are mainly due to cold shut. The authors carried out different techniques to minimize Cold Shut. This defect also in the moulds which are not properly vented because of the back pressure of the gases. By various control tools, the ranges of temperature, Phosphorous, and Silicon are find out. The temperature range for the minimum defect is 1362 - 1382°Cwhich reduces Cold Shut from 9% to 5% and Phosphorous percent is 0.06% maximum for minimum defect while Silicon range is 2.4-2.6%.

Harvir Singh and Aman Kumar [3] described the Minimization of the Casting Defects Using Taguchi's Method. The author used Taguchi's method for experimental purpose and used Minitab 17 to find the optimum solution. Three-month data has been collected from the foundry after analysis it has been found that the 80% rejections were only because of cold shut, scab, and shrinkage. The major cause of defects was analyzed through the fish bone diagram and the main cause is Pouring Temperature (°C), Sand Particle Size (AFS), Mould Hardness Number and Permeability Number. Taguchi L9 orthogonal array method is used for the experiments. MINITAB 17 is used to find the optimum solution which is for pouring temperature is 1340°C, for Permeability number is 150, for Sand particle Size is 42 AFS and for Mould Hardness Number is 91.132. By applying the optimum solution the rejections level reduced from 6.25% to 4.416%.

Chatrad et al [4] described A Study on Minimization of Critical Defects in Casting Process Considering Various Parameters. The author applies the process parameters optimization for reducing the defects like cold shut, blowhole, run, porosity and sand inclusion. The author collected the four months data from the industry for better understanding the occurrence of a defect. The cause effect diagrams were prepared for various defects. The 9 experiments were performed based on DoE by varying the main three factors which are pouring temperature, handling time and pouring time. The results give the optimum range of temperature which is 1420-1450°C, handling time is 9-11 second and pouring time is 4-5 seconds.

Shantanu Joshi and B.R. Jadhav [5] Described Casting defect reduction and productivity Improvement in Automotive Component. The author used the design of experiments technique to analyze the sand related defects in shell mould casting. Cause effect diagram used to find the root cause of defects and parameters identification. The most influencing parameters selected for the experimental purpose. Based on Taguchi 9 experiments conducted and responses measured. ANOVA analysis is done which defined that which casting process parameters significantly affect the percentage of rejection in casting. The defect is reduced from 3.2 % to a maximum up to 1.5%.

3. RESEARCH METHODOLOGY

The research methodology starts with the collection of data from the small scale foundry then the data analysis is done through quality control tools. After data analysis experimentation is done by varying the major parameters and optimization is done through Taguchi DoE in Minitab software.

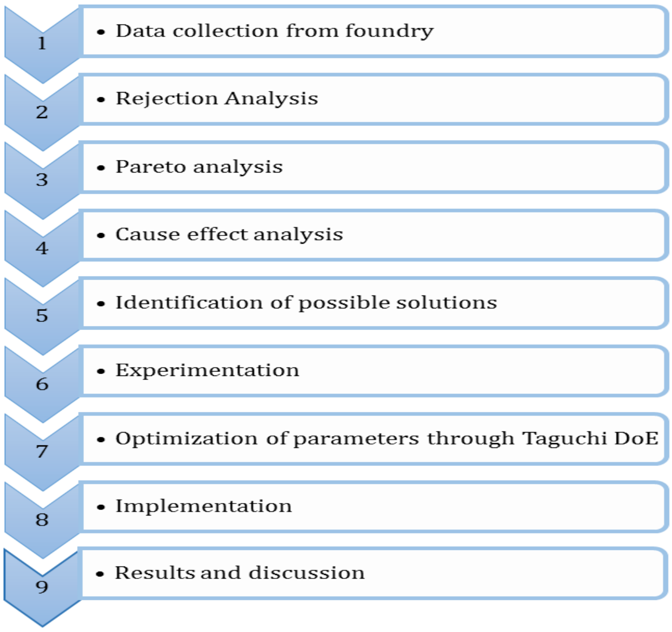

Fig -2: Research Methodology

4. DATA COLLECTION

The Three-month data have been collected from a small scale foundry, the material used for casting is Grey Cast Iron. The production and rejection data are collected from quality department and graph is plotted between the rejection percentage and types of components. The 10 components are selected which has high rejections and out of them a component which has high rejection is selected for research work.

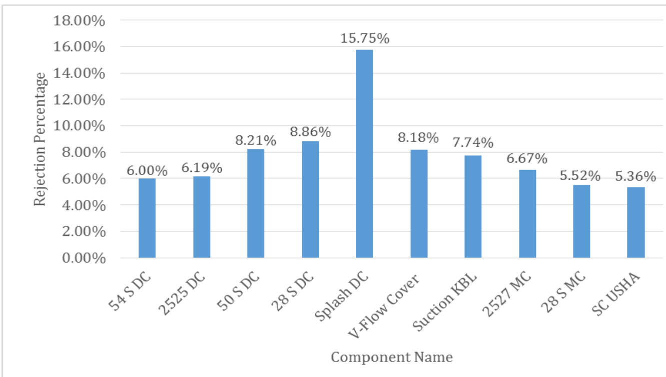

Chart -1: Histogram for rejection

The histogram shows the rejection data of one month. From data, it has been found that some components are suffering from high rejections. These rejections are mainly due to the sand related defects. From the analysis of above histogram, Splash Delivery Casing has maximum rejection percentage. Other two month data also shows that the Splash Delivery Casing has maximum rejection percentage so it is taken for the research work.

5. PARETO ANALYSIS

A trial has been conducted to find the various defects which occur in the casting of Splash Delivery Casing. Out of 484 Castings, 45.66% castings were rejected. It is seen that from 45.66% total rejection, **78.28 %** castings are rejected only because of **Cold Shut defect** and 21.72 % defects are because of Core Lift, Casting Break, Mould Break and Swelling.

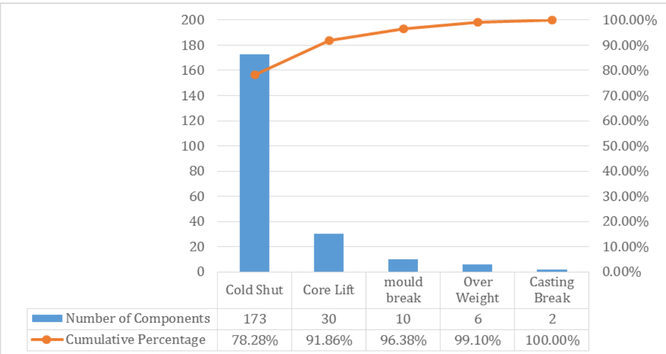

Chart -2: Pareto Analysis

Pareto analysis works on 80/20 principle which states that 80% of rejection occurs only because of 20% defects. From the analysis of above Pareto chart, it is clear that **91.86 %** rejections are only because of two types of defects which are **Cold shut and Core Lift**. So by working on cold shut defect we can increase the productivity and reduce overall defect.

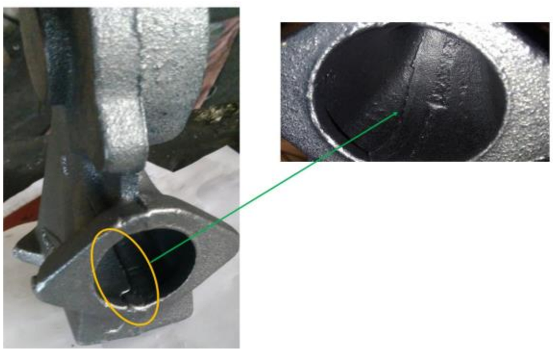

Fig -3: Location of defect in Splash Delivery Casing

A cold shut occurs in the curved wall at the intake of the delivery casing of monoblock pump.

6. CAUSE EFFECT ANALYSIS

Ishikawa Diagram for cold shut defect is shown in figure 4 which shows the major causes of the defect i.e. Cold Shut. There are six major causes for cold shut defect which are Man, Machine, Method, Material, Moulding Sand, and Environment. Each cause has multiple parameters which affect the final product. Each parameter which has influence in final casting is shown in the Cause Effect Diagram.

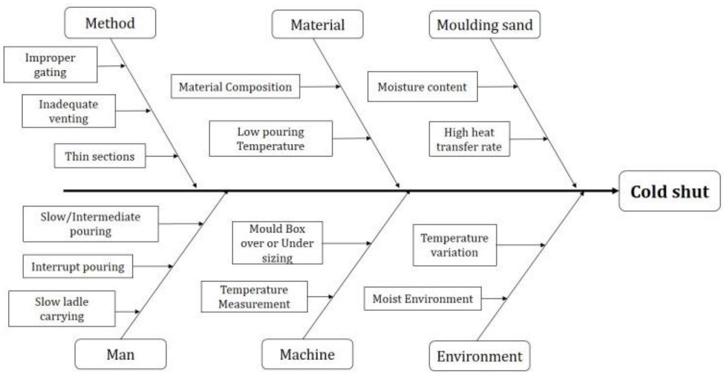

Fig -4: Fishbone Diagram for Cold Shut

The analysis gives all possible parameters which are responsible for cold shut defect but not all the parameters are equally responsible for the defect. Some parameters are less responsible while some have a major influence on the occurrence of defect. So it is necessary to identify those parameters which are highly responsible for the defect. The parameters which are major responsible for cold Shut defect are Less fluidity of molten metal, high moisture content in moulding sand, slow and intermediate pouring, slow ladle carrying, improper gating and less wall thickness.

7. POSSIBLE SOLUTIONS

The solutions for above causes follows:

1) **Increase the fluidity**: The fluidity can be increased by increasing the pouring temperature (Jadhav et al, 2013) and by changing the metal composition (increase the Silicone and Phosphorous content) (Kumar et al, 2015).
2) **Moisture Content:** By keeping the moisture up to optimum level Cold Shut defect can be reduced. (Kinagi et al, 2014).
3) **Skilled Manpower:** In manual pouring the pouring should be done by experienced person. The pouring time should be optimized. Intermediate pouring should not be done (chatrad et al, 2016).
4) **Methoding:** The design of gating system should be accurate. Gating design is such that the cavity should fill within minimum time without causing any defect.
5) **Sectional Thickness:** the component should be designed on the principle of Design for Manufacturing.

For complex component, the wall thickness should be sufficient to fuse the two metal streams properly.

8. SELECTION OF PARAMETERS & SIGNAL LEVELS FOR TAGUCHI ANALYSIS

Three parameters are selected for experimentation which is Pouring Temperature (℃), Gating system and Pouring Time (Seconds). Metal composition and other parameters are not taking because of some limitation. Parameters are described below:

1) **Pouring Temperature:** The temperature range in these case is from 1320 – 1450 ℃. The aim is to define a range of temperature which gives minimum rejections.
2) **Gating system:** The gating system is changed from previous gating and experiments are conducted for changed gating system and for the previous gating.
3) **Pouring Time:** Pouring is done manually so the pouring time varies according to the human's skills. In these research pouring time which has minimum rejection is found through optimization.

The selection of Signal levels are done for shop floor Experiments which are in the following table:

Table -1: Signal level for Experiments

S. No.	Parameter Name	level 1	level 2
1	Pouring Temperature (℃)	1320-1390	1390-1420
2	Gating System	No Change	Change
3	Pouring Time (Second)	15	13

9. SELECTION OF ORTHOGONAL ARRAY

The orthogonal array is selected from Array Selector. For three factors and two levels L4 orthogonal array is suggested so for experimentation the L4 orthogonal array is used which shown in below Table:

Table -2: Signal level for Experiments

Number of Experiment	Pouring Temperature	Gating System	Pouring Time
1	1	1	1
2	1	2	2
3	2	1	2
4	2	2	1

10. EXPERIMENTATION

Based on L4 orthogonal array four experiments are performed on the shop floor. A different set of the parameter is taken for each experiment and the output is recorded after each variation in response which is in the following table:

Table -3: Experimentation Results

Experiment Number	Signal level for parameters			Total Casting Poured	Number of casting approved	Percentage of Casting Approved
	Pouring Temp.	Gating System	Pouring Time			
1	1	1	1	36	27	75.00%
2	1	2	2	36	33	91.67%
3	2	1	2	36	31	86.11%
4	2	2	1	32	32	100.00%

11. OPTIMIZATION OF PARAMETERS

The responses of experiments are recorded for the optimization. The optimization of research parameters is done in the Minitab 16 software through Taguchi Design of Experiments Technique. In this research, the focus is on a single defect which is cold shut so while inspection there is the only single defect is considered in the results. Because the major problem is because of cold shut defect.

The Signal to Noise Ratio and mean is shown for the each experiment in table 4. Signal represents the desired value which is Percentage of approved casting in this case and noise represents undesirable value.

Table -4: S/N Ratio and Mean for the Experiments

Experiment Number	Percentage of Approved Casting	Signal to Noise Ratio	Mean
1	75.00%	37.5012	75.00
2	91.67%	39.2445	91.67
3	86.11%	38.7011	86.11
4	100.00%	40.0000	100.0

The SN ratios for different factors and different levels are shown in table 5. The rank is also given with the parameters. Rank shows that which factor has a high impact on the response. The average SNR for each signal level and for each factor is shown in Table 5 which is calculating by using following:

$S/N = -10\log \times (\Sigma(1/Y^2)/n)$ [5]

Where, n= Number of Experiments, and y= Percentage of approved casting.

Table -5: Response Table for S/N Ratio

Level	Pouring Temperature	Gating System	Pouring Time
1	38.37	38.10	38.75
2	39.35	39.62	38.97
Delta	0.98	1.52	0.22
Rank	2	1	3

12. RESULTS AND DISCUSSION

The results of optimization are shown below, the plots are shown for Mean and S/N Ratio in this section.

12.1 Main Effects Plot for Quality

The main effect plot is an outcome of the optimization that gives the uniform difference between the different levels of a factor. When there is a consistent trend among the different levels of a factor then the situation is same as these outputs. Figure 5 gives the main effect for Means for different Factors and for each level.

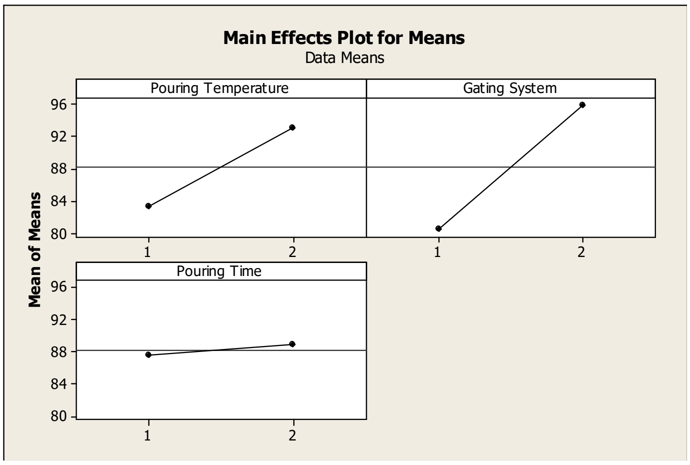

Fig -5: Main Effect Plot for Means

The Main Effects Plot indicates following for given factors:

I. **Pouring Temperature:** At level 2 (1390-1420°C) the Percentage of Approved Casting is between 92 and 96 which is higher than level 1 (1320-1390 °C) in which Percentage of Approved Casting is between 80 and 84.

I. **Gating System:** Plot shows that after changing the gating system at level 2 the Percentage of Approved Casting is near about 96 while at level 1 where gating is not changed the Percentage of Approved Casting is between 80 and 84.

II. **Pouring Time:** At level 2 (13 Second) the Percentage of Approved Casting is between 84 and 88 which is higher than level 1 in which Percentage of Approved Casting is Between 88 and 92.

12.2 Main Effects Plot for SN Ratios

The Main Effects Plot for SN ratios is shown in figure 6 which shows the SN ratios for different factors. The Signal to noise ratio is plotted for the condition of Larger is better. For the higher value of Percentage of approved Casting, the SN Ratio should be as high as possible. The high value of Signal to Noise ratio required for a robust system.

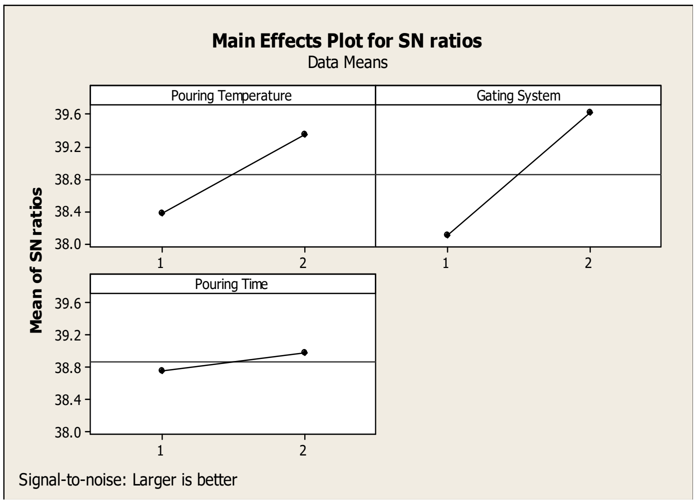

Fig -6: Main Effect Plot for SN Ratio

The optimized value of parameters for Splash Delivery Casing is shown in the following table:

Table -6: Optimum values for Parameters

Parameters	Level	SNR	MEAN	Optimum Value
Pouring Temperature (°C)	2	39.35	93.06	1390-1420
Gating System	2	39.62	95.84	Change
Pouring Time (Second)	2	38.97	88.89	13

13. IMPLEMENTATION

The corrections are made in gating system and the pouring is done under controlled condition between temperature 1390 to 1420 °Cand pouring time is 13 Second. From optimization, the first priority is for Gating System and the second priority is for Pouring temperature so all three parameters are implemented and results are recorded which are following:

Table -7: Implementation Results

Total Number of Casting Poured	Number of Approved Casting	Percentage of Approved Casting
72	71	98.61%

14. CONCLUSION

The research work can be concluded by following points:

- The Quality Control tools like Histograms, Pareto Analysis and Fish bone Diagrams are used to analyze and identify the most defective component, major defect and various causes for the defect respectively.
- Four experiments are conducted on the shop floor for the component based on Taguchi L4 Orthogonal Array method and responses are recorded.
- Optimization of the parameter is done by Taguchi DoE Technique with the help of Minitab Software and the graphs are plotted for Larger is better condition.
- The optimized value of parameters for Splash Delivery Casing are Pouring Temperature 1390-1420 ℃, Gating System should be changed and Pouring Time is 13 second. The highest priority is for Gating system.
- By applying the optimal values for the production an Experiments is conducted and it has been found that the Cold Shut defect is reduced from 35.74% to 1.4%.

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