Optimization of Process Parameters using Taguchi Design Approach in Automobile Component to Minimize Casting Defects

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Abstract— Casting process is the most widely used process in manufacturing industries especially in automobile products. Foundry industry suffers from the poor quality and productivity due the large number of process parameter. Since the quality of casting parts is mostly influenced by process condition, how to determine the optimum process condition becomes the key to improving part quality. Improvement in casting quality is the process of finding the root cause of occurrence of defects such as sand drop, blow hole and shrinkage in the rejection of casting and taking necessary steps to reduce the defects. Good quality of casting can be achieved by optimization of controllable process parameters such as compatibility, permeability and green compression strength. The effects of these parameters on casting defects and subsequent setting of parameters with the levels have been accomplished by Taguchi's parameter design approach. Taguchi based L9 orthogonal array have been used for the experimentation and result has been carried out using Minitab 14 software for analysis of variance. The selected process parameters and verification experiment has been performed for finding the optimal value.

Key words: Casting, Sand Properties, Casting Parameters, Taguchi Method, Design of Experiments

I. Introduction

Foundry engineering deals with the processes of making castings in moulds formed in either sand or some other material. Casting is one of the ancient methods of metal shaping process. Castings have several characteristics that clearly define their role in modern equipment used for transportation, communication, agriculture, construction, etc. cast metals which are required in various shapes and sizes are produced by melting the metal into liquid, pouring the molten metal in the mold, and removing the mold material or casting after the metal has solidified as it cools. Sand Casting is the most important and mostly used casting technique. The whole process of producing castings involves the following basic steps.

II. Problem definition

In Knuckle-RH SG iron casting component the major defects occurs during casting process and the rejection rate of the components are high. This leads to reduction in efficiency and increase in production cost. To minimize the defects occurring during the casting process, the causes should be identified and corrective action should be taken to obtain quality castings. If the proper root cause is not identified in a correct manner it will lead to decrease in efficiency of the company.

III. Defects in castings

The general origins of defects lie in three sectors:

– The casting design
– The technique of manufacture–the method
– The application of the technique–'workmanship'

A. Categories of Defects

Analysis of rejection report for the past three month's production schedule is considered and the major defects found are:

– Blow holes
– Mould sand drop
– Shrinkage
– Scab

Fig. 1: Defects in Castings

B. Pareto Analysis

Pareto analysis is a technique for ordering problems from the most to the least significant. Pareto diagram is a diagnostic tool commonly used for separating the vital few causes that account for a dominant share of quality loss. Pareto diagram is based on Pareto principle and can be applied to quality improvement that is, by solving key quality problems it lead to major improvements.

Pareto analysis is also called as 80/20 rule .it means only 20% of problems (defects) account for 80% of the effects. Pareto chart is constructed by obtaining complete details of the component from the rejection report chart from the past three month's record.

Component details	Quantity
Total number of components produced	8847
Total number of components rejected	1719
Rejection due to blow	915
Rejection due to mould sand drop	491
Rejection due to Shrinkage	208
Rejection due to scab	105

Table 1: Component Details

Defects	No of defects	Cum %
Blow holes	915	53.22
Mould sand drop	491	81.78
Shrinkage	208	93.88
Scab	105	100

Table 2: Pareto analysis for casting defects

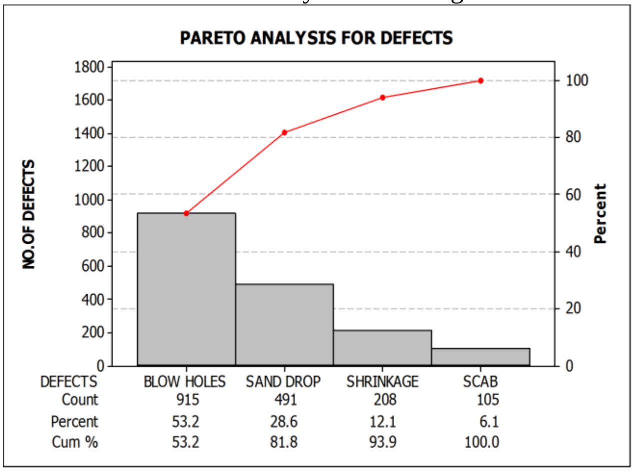

Fig. 2: Pareto chart for casting defects

IV. LITERATURE REVIEW

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V. PROJECT SCHEME METHODOLOGY

A. *Design of Experiments*

In casting processes, there are various parameters with different adjustment levels may influence the defects in casting. For each type of defect, several causes have been listed under differing categories such as design, moulding and pouring/melting related parameters. The focus of the design of experiment is on the robustness of the casting parameters. The methodology to achieve optimized process parameters are as given below:

Any defect is selected which is needed to be analyzed. For example, many internal defects (shifts, warpage, blow holes, drop etc.)largely depends on the moulding.

The target of process is to achieve "lower casting defects" by adjusting the process parameters.

Select the most significant parameters that cause the defects in casting. These parameters can be identified by the cause effect diagram.

Plan the experiments as per either design of experiments or orthogonal array(OA) and parameter levels. Based on the experimental conditions, collect the data.

Analyze the data. An analysis of variance (ANOVA) table can be generated to determine the statistical significance of the parameters. Response graphs can be plotted to determine the preferred levels for each parameter of the process.

Decide optimum settings of the control parameters. Verify the optimum settings result in the predicted reduction in the casting defects.

B. *Objective of the Taguchi Method*

The objective of Taguchi method is process and product–design improvement through the identification of easily controllable factors and their settings, which minimize the variation in product response while keeping the mean response on target. By setting those factors at their optimal levels, the product can be made robust to changes in operating and environmental conditions.

According to Taguchi, a product does not cause a loss only when it is outside specification but whenever it deviates from its target value. Taguchi is a quality improvement method and have its main objective the minimization of the variation of product performance about its target value.

C. *Experimental Procedure*

The following are the experimental steps suggested by Taguchi which should be followed in the parameter-design stage.

- Define the problem
- Determine the objective
- Design the Experiment
- Conduct the Experiment
- Analyze the data
- Interpret the Results
- Run a confirmatory experiment

D. *Selection of Process Parameters for Casting Process*

An Ishikawa diagram (cause and effect diagram) is constructed as shown in Figure 3 to identify the casting process parameters that may influence green sand casting defects. The process parameters can be listed as follows:

- Mould-machine related parameters
- Cast-metal related parameters
- Green-sand-related parameters
- Mould-related parameters
- Shake-out-related parameters

From the cause and effect diagram of green sand casting method between the different process parameters of green sand casting the sand related and mould related parameters are selected because, they have major impact on occurrence of selected casting defects. The selected knuckle-RH casting process parameters, along with their ranges, are presented in Table 3.

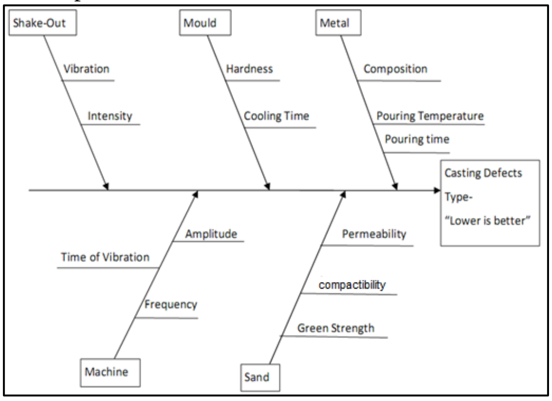

Fig. 3: Cause and Effect Diagram for casting defects

Selection of suitable process parameters should be based on the type of defects occurring during the casting process. The process parameters considered are

- Green Compressive strength (Kg/cm^2)in mould sand.
- Percentage Permeability of mould sand.
- Percentage Compactibility of mould sand.

For each factor three levels are selected ranging from minimum value to maximum value based on standards and suggestions given by the foundry men. The three levels are selected within the range specified as indicated in the table below.

Sl. No	Factor	Control factor	Range	Level 1	Level 2	Level 3
1	A	Green compressive strength (Kg/cm^2)	1.57 to 2.0	1.57-1.73	1.73-1.88	1.88-2.0
2	B	Permeability	140 to 185	140-156	156-173	173-185
3	C	compatibility	35 to 42	35-38	38-40	40-42

Table 3: Parameter and their levels

Using Minitab software L_9 orthogonal array is constructed.

Standard experiment number	Green compressive strength (Kg/cm^2)	Permeability	compatibility
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

Table 4: L9 orthogonal array table

The casting defects are the "smaller the better" type of quality characteristics. Smaller the better S/N ratios are computed by using equation 1 for each of the 9 experiments and the values are recorded in table 5 as shown below.

Casting defects was selected as a quality characteristic to be measured. The most common defects occurring in the foundry were monitored and recorded. The smaller the better number of casting defect implies better process performance. For minimizing the performance characteristic, S/N ratio is calculated by using the following formula:

$$S/N = -10 \log10 (1/n) [\sum in (yi)2]$$

Maximizing η' leads to minimization of quality loss due to defects. Where S/N ratio is used for measuring sensitivity to noise factors, n is number of experiments orthogonal array and yi the ith value measured.

Sequence number	Green compressive strength (Kg/cm^2)	Permea bility	compati bility
1	1.57-1.73	140-156	35-38
4	1.57-1.73	156-173	38-40
7	1.57-1.73	173-185	40-42
2	1.73-1.88	140-156	38-40
5	1.73-1.88	156-173	40-42
8	1.73-1.88	173-185	35-38
3	1.88-2.0	140-156	40-42
6	1.88-2.0	156-173	35-38
9	1.88-2.0	173-185	38-40

Table 5: Experimental layout of process parameters to conduct the experiment

The experimental layout above shows the combinations of process parameters with various levels to identify the optimized process parameter combination values by conducting the experiment so that defect free castings are produced.

VI. Experimental Procedure

A. Procedure to Conduct the Experiment

The experiment is conducted as per Taguchi orthogonal array design. The green sand is prepared with varying parameter levels as shown below in the table. Preparation of moisture content with compatibility levels with proper combinations and strength of green sand is done and arranged. The mouldings are numbered for easy identification.

The molten metal after tapping from the furnace is poured into the respective moulds with different temperatures as per the experimental layout. During pouring of molten metal the temperature is measured so that there is no variation in the set level value. After two hours of cooling the solidified casting is shaked and knocked out from the mould.

A GCS	B PER	C COM	1 A1B1C1	2 A2B1C2	3 A3B1C3
A1 1.57-	B1 140-	C1 35-	4 A1B2C2	5 A2B2C3	6 A3B2C1

1.73	156	38			
A2 1.73-1.88	B2 156-173	C2 38-40			
A3 1.88-2.0	B3 173-185	C3 40-42	7 A1B3C3	8 A2B3C1	9 A3B3C2

Table 6: Arrangement of Moulds – Experimental Layout

After cleaning the castings, it is numbered for identification of parameter combinations. The components are checked first by means visual inspection.

Fig. 3: Numbering of moulds and castings

The defects occurred during inspection are noted and the parameter combination level are identified. The experimental results obtained is fed in Minitab software to calculate signal to noise ratio. As the response considered is percentage defective, Smaller the SN ratio gives the better results that is smaller is better .Based on the result the optimum parameter combination is selected.

Standard Experiment Number	% of Total Rejection in Experiment			Avg. Rejection %	S/N Ratio
	Trial 1	Trial 2	Trial 3		
1	8.03	10.76	12.9	10.55	-20.465
2	14.28	12.69	13.14	13.37	-22.522
3	14.28	11.29	16.12	13.9	-22.860
4	13.97	13.17	10.76	12.63	-22.028
5	17.54	20.03	21.2	19.6	-25.845
6	10.16	12.9	12.69	11.92	-21.525
7	17.46	22.2	17.54	19.07	-25.607
8	18.46	20.33	19.69	18.36	-25.277
9	17.53	15.25	10.52	14.43	-23.185

Table 7: Signal to noise ratio values for percentage defective

VII. RESULTS AND DISCUSSIONS

A. Experimental Result

After analyzing the experimental results the optimal parameter values are determined from the main affects plot graph. The values of SN ratio are plotted for percent defectives. The optimized process parameter values are:

- Green compressive strength (kg/cm^2)=1.57-1.73
- Permeability =173-185 %
- Compatibility=35-38 %

B. Main Effects Plot (Data Means) for SN Ratio

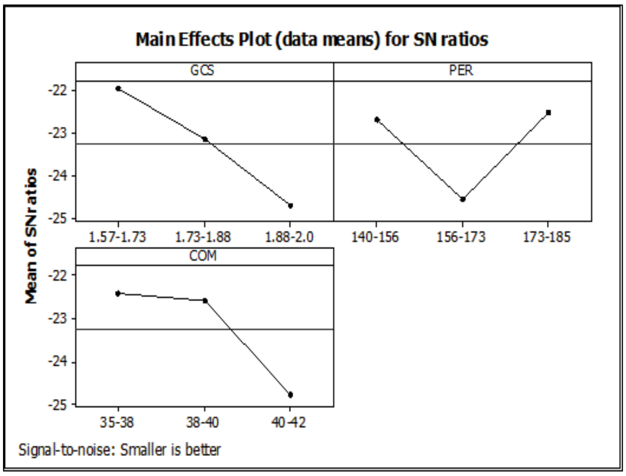

Fig. 4: Main Effects Plot (Data Means) For SN Ratio

The graph below shows the Main Effects Plot (Data Means) For SN Ratio for % defective. The graph is plotted considering signal to noise ratio values verses green compressive strength, permeability and compatibility is plotted.

Level	Green compressive strength (kg/cm^2)	Permeability	Compatibility
1	-21.95	-22.70	-22.42
2	-23.13	-24.55	-22.58
3	-24.269	-22.52	-24.77
Delta	2.74	2.02	2.35
Rank	1	3	2

Table 8: Signal to Noise Ratio for Delta & Rank value

C. Confirmation Experiment

The confirmation experiment is carried out based on the output result. Sixty components have been produced with the combination of optimized process parameters obtained from the trial experiments conducted and the results obtained by signal to noise ratio calculations. The combination is (A1, B3, C1) – Green compressive strength in sand at 1.57-1.73 kg/cm^2, Permeability at 173-185 %, and compactibility at 35-38 %.

The castings obtained from the confirmation experiments are tested and inspected. It was found that only four defective components occured. The confirmation experiment reveals that with the optimized parameter settings, percent defectives have been minimized to 6.67 %.The table below shows the reduction of % defective after optimization process.

Sl. No	Period of Experiment	Components Produced	Defective Components	% Defect
1	After Optimization	60	4	6.67

Table 9: Reduction of defect percentage after optimization.

VIII. Conclusion

In Knuckle-RH Automobile casting component the causes for the major defects are identified. Process parameters with various levels are selected. Using Mini Tab software Taguchi orthogonal array design was selected to obtain various process parameter level combinations. Experiments have been conducted based on the design and the results obtained were analyzed and optimized process parameters are identified. Sixty Components were poured based on optimized process parameter values .It is observed that the defects are minimized to 6.67%.

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