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Reducing Blowholes in Casting using Robust Design

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Abstract— The purpose of this paper is to optimize the casting parameters by maximizing the signal to noise ratios and minimizing the noise factors using Robust Design. Analysis of Variance (ANOVA) is utilised to find optimum conditions. This paper demonstrates a robust method for formulating a strategy to find optimum factors with small number of experiments. The process parameters considered are moisture, sand particle size, and permeability. The results indicated that the selected process parameters significantly affect the casting defects in the foundry.

Key words: Robust Design, Orthogonal Array, Optimization, S/N Ratios, ANOVA, Taguchi Method

I. INTRODUCTION

Casting process starts by creating a mould. The mould is made from a refractory material, sand. The metal is heated in a furnace till it melts, and the molten metal is poured into the mould cavity. The metal takes the shape of cavity, which is required shape. It will be left for cooling. Finally, the solidified metal part is detached from the mould. One of the most significant metals casting process is sand casting process. A casting defect is unevenness in the metal casting process that is undesired. Some defects can be tolerated while others can be repaired, otherwise they must be removed. They are cracked down into generally into 5 groups' viz., gas penetrability, contraction defects, mould material defects, pouring metal defects, and metallurgical defects. The elimination of all the casting defects from a casting procedure is impossible as there are a number of factors disturbing it but the optimization of the control parameters can lead us to achieve better results. This paper tries to reduce blowholes by optimizing its regulatory constraints.

II. LITERATURE REVIEW

A detailed literature review was done on studying about the common casting defects, the ways of reducing it and the software packages used for optimizing the factors.

R. B. Heddure et al puts forward that the casting defects can be minimized by taking corrective actions in the tools like pattern, mould making, core making and melting process. This paper identifies two major defects slag and porosity. There are many reasons to generate these defects. So it preferably necessary to reduce it as much as possible by appropriate analysis of the defects which includes the root cause analysis so that actual reasons behind occurring the defects can be find out to make the corrective action. In this paper use six sigma technique and Shainin tool for identify and analysis casting defect. Shainin tool works on elimination principle. Final result of this work has to be reducing slag and porosity defect by taking corrective action. Tool should be identifying the sources of variation clearly. [1]

Uday A. Dabade et al combined and used the design of experiments and computer assisted casting simulation techniques to analyse the sand related and method related defects in green sand casting. The green sand related process parameters considered are, moisture content, green compression strength, and permeability of moulding sand and mould hardness (in horizontal direction). In first part of this paper Taguchi based L18 orthogonal array was used for the experimental purpose and analysis was carried out using Minitab software for analysis of variance (ANOVA) and analysis of mean (AOM) plot. ANOVA results indicate that the selected process parameters significantly affect the casting defects and rejection percentage. Number of iterations using casting simulation software was performed for mould filling and solidification analysis to reduce the level and intensities of shrinkage porosities in cast component. [2]

B.R. Jadhav et al puts forward in their paper that it is almost impossible to produce defect free castings. Occurrence of the defect may involve single or multiple causes. These causes can be minimized through systematic procedure. The paper finds that gaiting systems are not always responsible for the defect occurrence and the defect reduction by controlling alloy composition and pouring temperature is done. The seven quality control methodology is used to analyse and reduce defects which includes check sheet, Pareto analysis, cause and effect diagram, flow chart, scatter diagram, histogram and control chart. [3]

III. METHODOLOGY

The objective of this paper is on optimizing parameters of sand casting process. The Taguchi method is applied by using eight experimental steps as follows:

- Identify the main function of casting process.
- Identify the quality characteristic to be observed and the objective function to be optimized.
- Identify the control factors and their alternate levels.
- Identify noise factors and the testing conditions of the process.
- Design the matrix experiment and define the data analysis procedure.
- Conduct the matrix experiment.
- Analysing the data, determining the optimum levels for the control factors, and predicting performance under these levels.
- Conducting the verification (also called confirmation) experiment and planning future actions.

The simple stages for attaining the overhead aim are précised underneath

- To select the most significant parameters that causes variations in the quality characteristics.
- Casting defects have been selected as the most representative quality characteristics in sand casting process. The objective of sand casting process is to attain "lower casting defects".
- Make sand casting process under the investigational circumstances verbalized by the selected orthogonal array and parameter levels. Based on the investigational circumstances, data was collected.

- ANOVA table is generated to conclude the statistical significance of the parameters. Response graphs are plotted to determine the preferred level for each parameter.
- Predict the results of each of the parameters at their new optimum levels.
- Verify the optimum settings result in the predicted reduction in the casting defects.

Sand casting is used to manufacture complex shapes of various sizes depending upon the customer requirements. The basic requirements casting are pattern making, preparing a mold, pouring a molten metal, cooling of mold, shakeout, fettling. The chosen process parameters are listed as follows:

- Moisture percentage in sand
- Sand particle size
- Permeability

For each process parameter two/three levels are selected which define the experimental region. The levels selected are based on the standards acceptable and foundry men experience in this organization. Significant interactions within control parameters are also considered. The parameters, along with their ranges are given in Table 1.

Parameters	Level 1	Level 2	Level 3
Moisture	3.0	3.6	4.0
Sand particle size	48	50	52
Permeability	180	200	225

Table 1: Level of the control variables

The study is associated with four factors with each at three levels. Table 1 indicates that the best suitable orthogonal array is L9.Table 2 shows the design matrix for L9 array for four factors 1, 2 and 3. Next conduct all the nine experiments and observe the surface defect counts per unit area. The arrangement of the factors in L9 array in MINITAB software is given in Table 3.

Experiment No.	Control Factors		
	1	2	3
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	3
5	2	2	1
6	2	3	2
7	3	1	2
8	3	2	3
9	3	3	1

Table 2: L9 array arrangement

The arrangement of the factors in arrays is represented in the table below. The software used for this purpose is the MINITAB statistical tool.

Worksheet 1 ***

↓	C1	C2	C3
	Moisture	Sand particle size	permeability
1	3.0	48	180
2	3.0	50	200
3	3.0	52	225
4	3.6	48	200
5	3.6	50	225
6	3.6	52	180
7	4.0	48	225
8	4.0	50	180
9	4.0	52	200

Table 3: Arrangement of the data in L9 orthogonal array

For the given arrangement of the percentage rejection of parts due to defects were taken into account. Here we have to minimize the number of rejections due to defects, so "smaller the better" approach is used here. The observed rejections are shown in table 4.

Worksheet 1 ***

↓	C1	C2	C3	C4	C5	C6
	Moisture	Sand particle size	permeability	Trial 1	Trial 2	Trial 3
1	3.0	48	180	3.0	3.20	3.60
2	3.0	50	200	4.8	5.00	4.80
3	3.0	52	225	5.3	5.23	4.30
4	3.6	48	200	6.5	7.20	6.90
5	3.6	50	225	5.8	6.10	6.20
6	3.6	52	180	7.1	6.80	6.70
7	4.0	48	225	6.6	5.25	6.33
8	4.0	50	180	7.2	7.60	7.60
9	4.0	52	200	6.4	6.80	7.10

Table 4: Experimentally observed defects

The S/N ratio found using the smaller the best approach is shown in table 5

Worksheet 1 ***

↓	C4	C5	C6	C7	C8	C9	C10
	Trial 1	Trial 2	Trial 3	Average	SSQ	SSQ/3	S/N
1	3.0	3.20	3.60	3.26667	32.200	10.7333	-10.3073
2	4.8	5.00	4.80	4.86667	71.080	23.6933	-13.7463
3	5.3	5.23	4.30	4.94333	73.933	24.6443	-13.9172
4	6.5	7.20	6.90	6.86667	141.700	47.2333	-16.7425
5	5.8	6.10	6.20	6.03333	109.290	36.4300	-15.6146
6	7.1	6.80	6.70	6.86667	141.540	47.1800	-16.7376
7	6.6	5.25	6.33	6.06000	111.191	37.0638	-15.6895
8	7.2	7.60	7.60	7.46667	167.360	55.7867	-17.4653
9	6.4	6.80	7.10	6.76667	137.610	45.8700	-16.6153

Table 5: S/N ratio

The effect of a factor level is defined as the deviation it causes from the overall mean. Hence as a first step, calculate the overall mean value of η for the experimental region defined by the factor levels. The overall mean *m* is given by

$$m = 1/9(\eta 1+\eta 2+\cdots+\eta 9) = -15.2039$$

Using the S/N ratio data available in Table 5 the average of each level of the three factors is calculated and listed in Table 6. These average values are shown in Figure 1. They are separate effect of each factor and are commonly called main effects.

Level	Moisture	Sand particle size	permeability
1	-12.66	-14.25	-14.84
2	-16.36	-15.61	-15.70
3	-16.59	-15.76	-15.07
Delta	3.93	1.51	0.86
Rank	1	2	3

Table 6: Average η for different factor levels

Once the average η for different factor levels are found the S/N vs. factor level was plotted.

After the experiments are conducted, the ANOVA is used to analyse the results of the experiments. The significant factors and/or their interactions are identified, for various trial conditions and the parameters which significantly influence the casting defects. However, some more information is required to conclude with an optimum setting of parameters. In applying ANOVA technique, certain assumptions must be checked through analysis of residuals before interpreting and concluding the results. It is highly recommended to examine these residuals for normality, independence, and constant variance, when using ANOVA. In this paper, F ratio test is employed to check constancy of residual variance. If the F ratio test statistic is equal to or less than its corresponding critical value, the residuals have constant variance. The F-ratio value can be found using the ratio of mean square of a factor to variance of error. It can be seen from the F-ratio value result that the significant factors are the control factors in the order of moisture, sand particle size and permeability. The expected amount of sum of squares (SS) for each factor is computed by using variance. The percentage contribution (P) for each factor is calculated by using expected amount of sum of squares (SS) in Table 7. The ANOVA table is shown in Table 7.

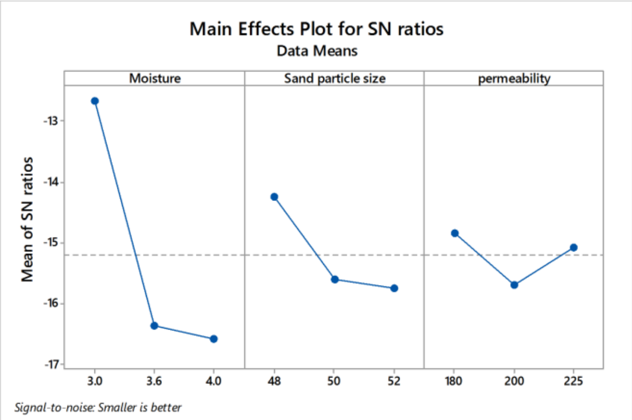

Fig. 1: S/N vs. factor level plot

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Moisture	2	29.269	14.6345	5.46	0.155
Sand particle size	2	4.158	2.0792	0.78	0.563
permeability	2	1.198	0.5988	0.22	0.817
Error	2	5.361	2.6807		
Total	8	39.986			

Table 8: ANOVA table

The major inferences from the ANOVA table are given in this section. Referring to the sum of squares in Table 8, the moisture makes the largest contribution to the total sum of squares [(29.269/39.986) x 100 = 73.2%]. Sand particle size makes the next largest contribution (10.4%) to the total sum of squares, whereas permeability makes only 2.99% contribution. The larger the contribution of a particular factor to the total sum of squares, the larger the ability is of that factor to influence η. Moreover, the larger the F-value, the larger will be the factor effect in comparison to the error mean square or the error variance.

The value of η under the optimum condition is predicted using the additive model as

$$\eta_{opt} = -11.3422$$

The mean square count at the optimum condition is calculated as

$$y = 10^{-\eta opt/10} = 13.62$$

The corresponding root-mean square rejection count is

$$\sqrt{y} = \sqrt{13.62} = 3.69$$

From the results it can be seen that by selecting the found out factor levels the rejection percentage can be kept at 3.69%.

IV. Conclusions

Blowholes were studied to find out the factors causing it. The reduction of blowholes was done by optimizing the control variables or factors affecting them. Taguchi method was the best available method to optimize the factors and together with the help of analysis of variance the optimum control factors were found out. Moisture content and sand particle size account for the main reason for controlling defects. The percentage occurrence of the blowholes can be reduced to 3.69 % which is a significant improvement in this case. Taguchi method is thus a cost effective method which can be used in industry to reduce the wastage of cast parts with the existing industry resources.

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