Optimization of Sand Casting Process Parameter Using Taguchi Method in Foundry

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Abstract

The purpose of this paper is to optimize the sand casting process parameters of the castings manufactured in iron foundry by maximizing the signal to noise ratios and minimizing the noise factors using Taguchi method. A Taguchi approach is used to capture the effects of signal to noise ratio of the experiments depending upon the orthogonal arrays used, an analysis of variance and optimum conditions are found. This paper demonstrates a robust method for formulating a strategy to find optimum factors of process and interactions with a small number of experiments. The process parameters considered are moisture, sand particle size, green compression strength, mould hardness, permeability, pouring temperature, pouring time and pressure test. The results indicated that the selected process parameters significantly affect the casting defects in the foundry. The improvement expected in reduction of casting defects is found to be 37.66 percent.

Keyword(s): Casting defects; Taguchi method; Iron foundry; Control factors; Sand casting

1. Introduction

Quality improvement in foundry industry have been carried over by researchers and foundry engineers for robust product at the customers end by applying various optimization methods to the sand casting process parameters: the gradient search method, the finite element method (FEM)- based neural network method and the Taguchi method [1, 2]**.** Taguchi [3, 4] has introduced several statistical tools and concepts of quality improvement that depend heavily on the statistical theory of experimental design. Some applications of

Taguchi's method in the foundry industry have shown that the variation in casting quality caused by uncontrollable process variables can be minimized [5, 6].
The concept of robust projects for the process and the product introduced by G. Taguchi [7, 8] seeks to make both the process and the product insensitive to disturbing factors that occasionally or systematically affect the variability of the process that may lead to imperfections in the products.

2. Literature Review

Sand casting is one of the most common production technique used for manufacturing ferrous castings. Cupolas are solely used by iron foundries for continuous production of molten iron. Der Ho Wu et al [9] applied the Taguchi method to optimize the process parameters for the die casting of thin-walled magnesium alloy parts in computer, communications and consumer electronics industries. The results confirmed the effectiveness of robust design methodology. Sushil Kumar et al [10] have carried out an optimization technique for process parameters of green sand casting of a cast iron differential housing cover based on

Taguchi parameter design which indicated in determining the best casting parameters for differential housing cover. Pradeep Kumar et al [2] applied the Taguchi's approach to the vacuum sealed process to obtain an optimal setting of the control factors that yielded the optimum surface roughness of the Al – 11 per cent Si alloy castings. Muzammil et al [11] made a study for optimization of Gear Blank Casting Process by Using Taguchi's Robust Design Technique. In this study they demonstrated that casting process involve a large number of parameters affecting the various casting quality features of the product. The reduction in the weight of the casting as compared to the target weight was taken to be proportional to the casting defects. B. H. Kim et al [12] in their study, the relationship between casting process parameters and mechanical properties in a 14.5% Si containing corrosion resistant cast iron was statistically investigated using Taguchi method. The effects of casting process parameters on mechanical properties and corrosion resistance were further confirmed by combined analysis of fractography, hydrogen content determination, microscopic test and acid resistance test. Ballal Yuvraj P. et al [13] describes that in order to produce any product with desired quality proper selection of process parameters is essential. This paper describes use and steps of Taguchi design of experiments and orthogonal array to find specific range and combinations of turning parameters. Quality achieved by means of process optimization is found to be cost effective in gaining and maintaining a competitive position in the world market. Dr. M. Arasu [14] the approach taken in this paper expects the foundries to use a standard classification system to describe undesirable casting artifacts for more effective failure analysis. It deals the various aspects of a systematic approach to understanding and development of quality cost system in cast iron foundries. A. Noorul Haq.et al [15] in their study demonstrates optimization of CO2 casting process parameters by using Taguchi's design of experiments method. The effect of the selected process parameters on casting defects and subsequent setting of the parameters are accomplished by using Taguchi's parameter design approach.

3. Methodology

The objective of this paper is on optimizing the process parameters of sand casting process including optimum levels and the case study is done in a job foundry in central India. The Taguchi method can be applied by using eight experimental steps that can be grouped into three major categories as follows [8]**.** :
• Planning the experiment: (1) Identify the main function of casting process. (2) Identify the quality characteristic to be observed and the objective function to be optimized. (3) Identify the control factors and their alternate levels. (4) Identify noise factors and the testing conditions of the process. (5) Design the matrix experiment and define the data analysis procedure.
• Performing the experiment: (6) conduct the matrix experiment.
• Analyzing and verifying the experimental results: • (7) Analyzing the data, determining the
Optimum levels for the control factors, and predicting performance under these levels: • (8) Conducting the verification (also called confirmation) experiment and planning future actions.
The basic steps for achieving the above target are summarized below [16, 17]

1. To select the most significant parameters that causes variations in the quality characteristics.
2. Casting defects have been selected as the most representative quality characteristics in the green sand casting process, as it is related to many internal defects (sand blow holes, pinholes, scabs, metal penetration, mold shift, mold crack, sand drop.). The target of the green sand casting process is to achieve "lower casting defects" while minimizing the effect of uncontrollable parameters.
3. Make the green sand casting process under the experimental conditions dictated by the chosen orthogonal array and parameter levels. Based on the experimental conditions, collect the data.
4. An analysis of variance (ANOVA) table is generated to determine the statistical significance of the parameters. Response graphs are plotted to determine the preferred level for each parameter.
5. Beside the optimum settings of the control parameters and predict the results of each of the parameters at their new optimum levels.
6. 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 main causes of rejection in castings are due to improper pattern, improper gating system, improper control of sand parameters, improper molten metal composition. The process parameters of the sand casting can be listed as follows:

- Sand particle size
- Moisture percentage in sand
- Green compression strength
- Mould hardness
- Permeability
- Pouring temperature of molten metal
- Pouring time of molten metal in mold
- Pressure test

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 for engine castings and fittings. Significant interactions within control parameters are also considered. The parameters, along with their ranges are given in Table 1.

Table 1.Control factors of process parameters and their levels

Factor designation	Control factors	Range	Level 1	Level 2	Level 3
A	Moisture (%)	3.5 – 4	3.5	4	----
B	Sand particle size (AFS)	50 – 55	50	53	55
C	GCS (g/cm^2)	900 – 1200	900	1100	1200
D	Mould hardness (nu)	50 – 80	50	70	80
E	Permeability (nu)	150 – 220	150	185	220
F	Pouring temperature (deg c)	1300 – 1420	1300	1390	1420
G	Pouring time (sec)	20 – 28	20	24	28
H	Pressure test (MPa)	1.5 – 2.5	1.5	2	2.5

3.1 Quality Characteristics

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. Here the objective function to be maximized is:

$$\frac{S}{N} ratio\ (\eta') = -10\log(mean\ square\ surface\ defects)$$

$$S/N\ ratio\ (\eta') = -10\log(\Sigma yi\text{^}2)/n$$

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 the number of experiments orthogonal array, and *yi* the *ith* value measured.

3.2. Selection of Orthogonal Array

Selection of an orthogonal array depends upon the number of control factors and interaction of interest. It also depends upon number of levels for the control factors of interest. Therefore with one control factor moisture percentage of two levels and other control factors sand particle size, green compression strength (GCS), mould hardness number, permeability number, pouring temperature of molten metal, pouring time of molten metal in mould and pressure test for casting leakage with three levels are considered, L18 orthogonal array is selected with 18 experimental runs and eight columns. Taguchi has provided in the assignment of factors and interaction to arrays. The tools are: (1) the linear graph and (2) triangular tables. Linear graphs indicate various columns to which factors may be assigned and the columns subsequently evaluate the interactions of those factors. The assigned L18 orthogonal array is shown in Table 2 and the experimental orthogonal array having their levels are assigned to columns are shown in Table 3.

Table 2.Orthogonal array L18 (control factors assigned)

Trial no.	A	B	C	D	E	F	G	H
1	1	1	1	1	1	1	1	1
2	1	1	2	2	2	2	2	2
3	1	1	3	3	3	3	3	3
4	1	2	1	1	2	2	3	3
5	1	2	2	2	3	3	1	1
6	1	2	3	3	1	1	2	2
7	1	3	1	2	1	3	2	3
8	1	3	2	3	2	1	3	1
9	1	3	3	1	3	2	1	2
10	2	1	1	3	3	2	2	1
11	2	1	2	1	1	3	3	2
12	2	1	3	2	2	1	1	3
13	2	2	1	2	3	1	3	2
14	2	2	2	3	1	2	1	3
15	2	2	3	1	2	3	2	1
16	2	3	1	3	2	3	1	2
17	2	3	2	1	3	1	2	3
18	2	3	3	2	1	2	3	1

Table 3.Experimental orthogonal array

Trial no.	A Moisture content (%)	B Sand particle Size (AFS)	C Green Strength (g/cm^2)	D Mould hardness (nu)	E Permeability (nu)	F Pouring temperature (deg c)	G Pouring time (sec)	H Pressure test (MPa)
1	3.5	50	900	50	150	1300	20	1.5
2	3.5	50	1100	70	185	1390	24	2
3	3.5	50	1200	80	220	1420	28	2.5
4	3.5	53	900	50	185	1390	28	2.5
5	3.5	53	1100	70	220	1420	20	1.5
6	3.5	53	1200	80	150	1300	24	2
7	3.5	55	900	70	150	1420	24	2.5
8	3.5	55	1100	80	185	1300	28	1.5
9	3.5	55	1200	50	220	1390	20	2
10	4	50	900	80	220	1390	24	1.5
11	4	50	1100	50	150	1420	28	2
12	4	50	1200	70	185	1300	20	2.5
13	4	53	900	70	220	1300	28	2
14	4	53	1100	80	150	1390	20	2.5
15	4	53	1200	50	185	1420	24	1.5
16	4	55	900	80	185	1420	20	2
17	4	55	1100	80	220	1300	24	2.5
18	4	55	1200	70	150	1390	28	1.5

3.3. Experiment Results and S/N Ratios

The experiments were conducted thrice for the same set of parameters using a single-repetition randomization technique [18]. The casting defects that occur in each trial conditions were found and recorded. The average of the casting defects was determined for each trial condition as shown in Table 4. The casting defects are the “lower the better” type of quality characteristics. Lower the better S/N ratios were computed for each of the 18 trials and the values are given in Table 4:

Lower is better: S/N = -10 log [(Σy^2i) / n]

For example the S/N ratio for trial number 1 is:

η = -10 log [(Σy^2i)/3]

S/N ratio = -10 log [(5.25^2 + 5.7^2 + 4.21^2)/3]
= -10 log [(27.5625 + 32.49 + 17.7241)/3]
= -10 log [(77.7766)/3]
= -10 log [25.925]
= -14.138

3.4. Main effects of Factors and Analysis of Variance

The average effect of factors is shown in Table 5. After the experiments are conducted, the ANOVA is used to analyze 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 [19]. 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 [16]. 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 seen from the *F*-ratio value result that the significant factors are the control factors in the order of C (green compression strength), A (moisture), F (pouring temperature) and E (permeability). The other control factors are pooled due to less significance and percent contribution. The expected amount of sum of squares (SS) for each factor is computed by using variance. The percent contribution (P) for each factor is calculated by using expected amount of sum of squares (SS) in Table 6. The ANOVA table after pooling until the DOF of the error term is approximately half the total DOF of the experiment is shown in Table 6.

Table 4.Casting defects values and signal-to-noise ratio against experimental trial numbers

Trial no.	Percentage defects in experiment				Average	S/N ratio
	1	2	3	Total		
1	5.25	5.7	4.21	15.16	5.053	-14.138
2	4.48	5.58	5.56	15.62	5.206	-14.374
3	6.47	7.13	5.12	18.72	6.24	-15.982
4	3.93	4.16	5.04	13.13	4.376	-12.875
5	6.24	6.68	4.68	17.6	5.866	-15.46
6	7.29	7.17	6.79	21.25	7.083	-17.009
7	2.64	3.05	3.87	9.56	3.186	-10.178
8	3.75	5.54	5.13	14.42	4.806	-13.746
9	7.26	8.15	6.34	21.75	7.25	-17.252
10	6.34	4.83	7.24	18.41	6.136	-15.872
11	5.67	7.1	7.53	20.3	6.766	-16.668
12	9.1	9.53	9.29	27.92	9.306	-19.378
13	7.34	7.76	6.75	21.85	7.283	-17.261
14	6.67	5.2	6.33	18.2	6.066	-15.706
15	7.17	6.87	5.54	19.58	6.526	-16.345
16	3.09	5.89	4.78	13.76	4.586	-13.496
17	7.16	6.74	6.17	20.07	6.69	-16.525
18	7.29	7.64	7.64	22.57	7.523	-17.531

Average casting defects = 6.108 Standard deviation= 1.548

Table 5 Main effects

Columns	Factors	Level 1	Level 2	Level 3	L2 – L1
1	Moisture (%)	-14.557	-16.531	0	-1.974
2	Sand particle size	-16.068	-15.776	-14.788	.292
3	GCS	-13.97	-15.413	-17.249	-1.443
4	Mould hardness	-15.634	-15.697	-15.302	-.063
5	Permeability	-15.205	-15.036	-16.392	.169
6	Pouring temp.	-16.343	-15.602	-14.688	.74
7	Pouring time	-15.905	-15.05	-15.677	.854
8	Pressure test	-15.515	-16.01	-15.107	-.496

Table 6.Analysis of Variance Results

	Factors	DOF	Sums of Squares	Variance	F-Ratio	Pure Sum	Percent
1	Moisture %	1	17.537	17.537	33.563	17.015	22.226
2	Sand particle size	(2)	(5.403)		POOLED	(CL = 84.14%)	0.000
3	GCS	2	32.422	16.211	31.024	31.377	40.987
4	Mould Hardness nu	(2)	(.541)		POOLED	(CL = *NC*)	0.000
5	Permeability	2	6.555	3.277	6.273	5.510	7.198
6	Pouring temperature	2	8.245	4.122	7.890	7.200	9.405
7	Pouring time	(2)	(2.349)		POOLED (CL = 81.71%)		0.000
8	Pressure test	(2)	(2.453)		POLLED (CL = 84.58%)		0.000
	Other/ Error	10	11.790	1.179			20.184
	Total	17	76.553				100.000%

3.5 Expected Cost Savings at Optimum Conditions

The performance of the expected optimum conditions is estimated considering the factors and interactions. The significant contributions made by factors A1, C1, E2 and F3 have a total contribution of 3.924 decibels. As the current grand average of performance is -15.544 decibels, the expected result at the optimum condition is computed at -11.619 decibels. Therefore the improvement expected in reduction of defects is 37.66 per cent. Estimating the performance of all factors at an arbitrary condition the expected result at optimum condition of S/N ratio is -9.689. In order to calculate the expected cost savings, Taguchi's loss function has been used **[20]** using equation.

$$L = \left(1 \times \frac{10^{\left[\left(\frac{S}{N}\right)1 \times \left(\frac{S}{N}\right)2\right]}}{10}\right) \times 100\% \text{ of L1}$$

= 73.42 percent/$ loss

Here (S/N) 1 = -15.444 and (S/N) 2 = -9.689

Table 7 Estimate of performance at any arbitrary condition

Column & Factor	Level description	Level	Contribution
1. Moisture	3.5	1	.987
2. Sand particle size	55	3	.756
3. GCS	900	1	1.574
4. Mould hardness	80	3	.242
5. Permeability	185	2	.508
6. Pouring temp.	1420	3	.856
7. Pouring time	24	2	.493
8. Pressure test	2.5	3	.436
Total contribution from all factors			5.855
Current grand average of performance			-15.444
Expected result at optimum condition S/N ratio			-9.689

3.6 Variation Reduction Data and Savings

The objective of the paper is to reduce the variation and getting closer to the target. After implementation of Taguchi method in the foundry a reduction of 37.66 % was observed. This was due to the improved signal to noise ratio from -15.544 to -9.689. The improved standard deviation was 0.788 from the current standard deviation 1.547.The optimum condition and performance factors are shown in Table 8, moisture percentage 3.5, GCS 900 g/cm^2, permeability number 185 and pouring temperature 1420 Celsius. The total contribution of all the factors is 3.924.

Table 8.Optimum condition and performance

	Factors	Level description	Level	Contribution
1	Moisture %	3.5	1	0.987
2	GCS g/cm^2	900	1	1.574
3	Permeability	185	2	0.508
4	Pouring temperature	1420	3	0.856
	Total contribution from all factors			3.924
	Current grand average of performance			-15.544
	Expected result at optimum condition			-11.619
	Improvement expected			37.66%

4 Conclusions

The optimum conditions for the factors computed are:
Moisture (%) – Level 1 – Minimum 3.5
Green compression strength (g/cm^2) – Level 1 – Minimum 900
Permeability – Level 2 – Minimum 185
Pouring temperature (deg. Celsius) – Level 3 – Maximum 1420
The improvement expected in minimizing the variation is 37.66 percent which means reduction of casting defects from present 6.16 percent to 3.84 percent of the total castings produced in the foundry. This also reflects that by

using Taguchi method the factor levels when optimized will result in reduction of casting defects and increase the yield percentage of the accepted castings without any additional investments. A usage of quality tools like Pareto chart is useful for finding the major defects in the daily operations of foundry. Quality of castings can be improved by aesthetic look, dimensional accuracy, better understanding of noise factors and the interaction between variables, quality cost system based on individual product, scrap reduction, reworking of castings and process control.

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