OPTIMIZATION OF GATING SYSTEM PARAMETERS OF CI CONVEYOR BRACKET USING TAGUCHI AND COMPUTER AIDED SIMULATION TECHNIQUES

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Abstract

In sand casting method, process of making casting depends upon various factors like mould, gating system, type of metal etc. For a sound casting, it is required to optimize the casting parameters for a given geometry of casting, to remove the defects and improve the quality in casted products. In this paper Taguchi technique along with design of experiments method (DOE) and Computer Aided Casting Simulation Technique are combined for optimization of gating system parameters of a CI Conveyor Bracket to improve the Product Yield (PY) and Hardness (HRD) of the casting. The gating system related parameters considered are, Runner Upper Diameter (mm), Runner Lower Diameter (mm), Runner Height (mm), Ingate Height (mm), Pouring Time (sec). In the First half part of the work, Taguchi based L18 Orthogonal Array was generated for experimental purpose and analysis of result was done using S/N ratio, Minitab 17 Software and Analysis of Variance (ANOVA) to analyze effect of gating system parameters on Product Yield and Hardness. In the second half part of work, AutoCast simulation software was used for validation of the result. Parameters are also validated by implementing it in foundry.

Key Words :

1. Introduction

As looking towards history traditional casting process is running since 6000 years long and is a basis of the entire mechanical industry. However, it still faces various problems such as difficulty in quality improvement, less production rate, to improve energy efficiency, to reduce material consumption and the question of environmental protection; one of the reasons behind it is complex casting process and lack of theoretical guidance (C.M. Choudhari et al., 2014). Sand casting is one of the most simplest type of casting process and highly used for centuries since it accounts for largest tonnage of production of different types of castings and because of its economical facts and flexibility in production (Manikanda Prasath K. et al., 2014). Casting process has many quality affecting casting process parameters some of which are controllable and some are noise factors. Therefore Taguchi Technique is the good choice for quality improvement in castings. Taguchi's contributions have made the practitioner's work simpler by advocating use of very less number of experimental designs and providing clear understanding of variation nature and economic consequences of quality engineering in the manufacturing sector (S. Guharaja et al., 2006). Dr. Taguchi has introduced several new statistical concepts in the field of quality improvement which have proven to be estimable. Many Japanese manufacturers have improved their product and process quality with a great success. Taguchi has calculate on W.E. Deming's observation that only 15% to the worker and more i.e. 85% of the poor quality is attribute to the

manufacturing process, out of which again many researchers has reported that 90% of the defects are due to incorrect design of Gating and risering system.

1.1 Process parameters of Green Sand castings

The process parameters can be listed in five categories as follows:

1. Mould-machine-related parameters
2. Cast-metal-related parameters
3. Green-sand-related parameters
4. Mould-related parameters
5. Shake-out-related parameters

An Ishikawa diagram (cause and effect diagram) was constructed as shown in Fig. 1 to identify the casting process parameters that may influence green sand casting defects (S. Guharaja et al. 2006).

Fig. 1 : Cause and effect diagram

2. Literature Review

Presently various research work and experiments have been done on several distinct casting parameters for all casting methods. In sand casting the process parameters are classified in following categories as: 1. Machine related parameters 2. Metal related parameters 3. Sand related parameters 4. Mould related parameters 5. Shake-out related parameters, etc. Most percentage of defects are improved by optimizing sand and gating system related parameters.

Zhizhong Sun et al. (2008) optimized the gating system parameters of cylindrical magnesium casting in iron foundry by maximizing signal to noise ratios and minimizing the noise factors using Taguchi method with multiple performance characteristics. They have selected four gating system parameters, namely ingate height, ingate width, runner height, runner width for optimization with consideration of multiple performance characteristics including filling velocity, shrinkage porosity and product yield. Although the product yield has decreased by 1.57%, the shrinkage porosity is decreased by 56.57% and the filling velocity is decreased by 58.05% and finally it is concluded that the multiple performance characteristics such as product yield, shrinkage porosity and filling velocity can be simultaneously considered and improved through this optimization technique. Uday A. Dabhade et al. (2013) applied Taguchi method to optimize the green sand casting parameters as Moisture content (%), green compression strength (gm/cm²), Permeability Number, Mould Hardness Number for improvement of casting quality by reducing casting defects like sand drop, bad mould, blow holes, cuts and washes for reducing % rejection in casting products.

Also, for reducing Methoding, Filling, and solidification defects such as shrinkage porosity, hot tears etc, Computer Aided casting simulation technique is used. Experimental result obtained using optimized parameters as; % rejection in castings due to sand related defects is reduced from 10% to a maximum up to 3.59%. Also concluded that; shrinkage porosity defect, quality and yield of casting can be efficiently improved by Computer assisted casting simulation technique in shortest possible time and without doing actual trials in foundry shop. C. M. Choudhary et al. (2014) discussed about the simulation method of sand casting design using AutoCast-X software for minimizing the casting defects to improve its quality. They mentioned that various casting defects occur because of improper design of feeding system. Hence instead of going for direct experimental way, the attempt is made to compute an optimum feeding system using simulation software. S. Guharaja et al. (2006) applied Taguchi method to optimize the process parameters of green sand casting. First of all the cause and effect diagram was constructed to identify the process parameters that may influence green sand casting defects. the most significant parameters with their optimized

values are found to be moisture content (2.6%), Green sand strength (950gm/cm²), permeability number (235), and mould hardness number (80). These optimized values were used in final experimentation and gave result as, improvement in casting yield and reduction in casting defect from 25% to a maximum of 3.25%. Manikanda Prasath K. et al. (2014) reduced the sand related casting defects and improved the effective yield of casting by optimizing the green sand process parameters using Taguchi method and by using Solid cast simulation Software for simulating gating system. The optimum conditions for the control factors of casting process parameters found to be moisture content (4.5%), Green sand strength (1300gm/cm²), permeability number (200), and mould hardness number (75), Pouring temperature (1400 °C), Sand particle size number (AFS) (53). As a result of optimization they have got reduction in casting defects i.e. from 8.10% to 2.71% and effective yield are improved to 64.30% from 58.5%. Dr. B. Ravi (1999) has discussed how computer system has brought revolution in manufacturing sector. A scene of Past-present-future of computer-Aided system is described in this paper and has shown that how this system helped industries to directly improve the profit of production by reducing lead time and cost of production. He has generated software named AutoCAST which has become a fine tool for casting industry. So instead of going to do shop floor experiments in making First Article Approval, the software found to be very helpful in generating step by step casting process and gives final result in which we can find out whether defects will be present or not and after final result we can apply it in shop floor. In this way the software was found to be very helpful in saving time, cost, material wastage, etc.

From all these literatures, Taguchi method is found to be the best method for optimization of parameters.

3. Experimental Work

3.1 Research Methodology

This research work is done at a small scale Industry where the methodology of work done is shown briefly in figure 3.1.

Fig. 2 : Flow chart of research methodology

3.1 Experimental Process

Experiments were performed at small scale foundry producing grey cast iron components.

3.2.1 DOE method for selection of orthogonal array

Process parameters of gating system that influences product yield and hardness are selected with their levels as shown in table 1.

Table 1
Process parameters and their levels

Sr. No.	Parameters	Levels		
		1	2	3
1	Pouring Time (sec)	8	16	-
2	Runner Upper Diameter (mm)	45	50	55
3	Runner Lower Diameter (mm)	30	35	40
4	Runner Height (mm)	90	95	100
5	In-gate Height (mm)	8	11	15

Out of five selected parameters, one parameter is at two levels and other five parameters are at three levels. Therefore using MINITAB 17 software from a mixed level design, L18 orthogonal array is selected for the experimentation. Various factors and their interactions are assigned in each column of the L18 orthogonal array as shown in table 2.

Table 2
L18 orthogonal array

Trial No.	PT	RUD	RLD	RH	IH
1	1	1	1	1	1
2	1	1	2	2	2
3	1	1	3	3	3
4	1	2	1	1	2
5	1	2	2	2	3
6	1	2	3	3	1
7	1	3	1	2	1
8	1	3	2	3	2
9	1	3	3	1	3
10	2	1	1	3	3
11	2	1	2	1	1
12	2	1	3	2	2
13	2	2	1	2	3
14	2	2	2	3	1
15	2	2	3	1	2
16	2	3	1	3	2
17	2	3	2	1	3
18	2	3	3	2	1

3.2.2 Conducting the experiments

After assigning the parameters and their interactions in the columns of selected orthogonal array, the factors are assigned for each trail as shown in experimental array table 3. As per L18 orthogonal array all the 18 experimental trials were performed sequentially.

Table 3
Experimental L18 Orthogonal Array

Trial No.	PT	RUD	RLD	RH	IH
1	8	45	30	90	8
2	8	45	35	95	11
3	8	45	40	100	15
4	8	50	30	90	11
5	8	50	35	95	15
6	8	50	40	100	8
7	8	55	30	95	8
8	8	55	35	100	11
9	8	55	40	90	15
10	16	45	30	100	15
11	16	45	35	90	8
12	16	45	40	95	11
13	16	50	30	95	15
14	16	50	35	100	8
15	16	50	40	90	11
16	16	55	30	100	11
17	16	55	35	90	15
18	16	55	40	95	8

4. Experimental Analysis

4.1 Analysis of experimental result

The castings of Conveyor Bracket were made against the trial conditions. After getting the castings first they are taken to the process of sand removing throughout the surface of casting along with gating system. Then the weight of casting with gating system was measured and noted down with trial sequence. Then all the castings were sent to remove the gating system and for finishing process. Again the weight measurement was done for all finished castings and was noted down in the same sequence. The Product Yield (PY) of casting was then calculated by using following formula

$$\text{Product yield (PY)} = \frac{\text{Total Casting Weight (Tw)}}{\text{Casted Part Weight (Cw)}}$$

And the Hardness (HRD) measurement test was done for all castings using Brinell Hardness Testing machine. In Brinell Hardness Testing machine the weight of 3000 kg was applied using 10 mm diameter ball point and then the

diameter of circular impression generated on casting was measured using microscope. Then from the BHN chart hardness number for respective diameter was found out.

The values of product yield and hardness for respective trials are recorded in table 4.

Table 4
Product Yield and Hardness Values

Trial No.	PT	RUD	RLD	RH	IH	PY (%)	HRD (BHN)
1	8	45	30	90	8	90.32	217
2	8	45	35	95	11	87.71	207
3	8	45	40	100	15	85.71	187
4	8	50	30	90	11	88.52	197
5	8	50	35	95	15	87.71	178
6	8	50	40	100	8	85.25	178
7	8	55	30	95	8	87.09	207
8	8	55	35	100	11	85.25	169
9	8	55	40	90	15	84.84	170
10	16	45	30	100	15	84.37	177
11	16	45	35	90	8	87.71	197
12	16	45	40	95	11	85.25	178
13	16	50	30	95	15	84.84	178
14	16	50	35	100	8	83.58	185
15	16	50	40	90	11	83.07	175
16	16	55	30	100	11	83.87	170
17	16	55	35	90	15	83.07	169
18	16	55	40	95	8	84.37	163

4.2 Signal-to-noise ratio and ANOVA Analysis

4.2.1 For Product Yield

The casting Product Yield is the “Larger the better” type of quality characteristics. Larger the better S/N ratios were computed for each of the 18 trials and the values are recorded in table 5.

Table 5
Product Yield values and Signal-to-noise Ratio values against Trial Numbers

Trial No.	PT	RUD	RLD	RH	IH	PY (%)	S/N Ratio
1	8	45	30	90	8	90.32	39.1157
2	8	45	35	95	11	87.71	38.8610
3	8	45	40	100	15	85.71	38.6606
4	8	50	30	90	11	88.52	38.9408
5	8	50	35	95	15	87.71	38.8610
6	8	50	40	100	8	85.25	38.6139
7	8	55	30	95	8	87.09	38.7994

8	8	55	35	100	11	85.25	38.6139
9	8	55	40	90	15	84.84	38.5720
10	16	45	30	100	15	84.37	38.5238
11	16	45	35	90	8	87.71	38.8610
12	16	45	40	95	11	85.25	38.6139
13	16	50	30	95	15	84.84	38.5720
14	16	50	35	100	8	83.58	38.4420
15	16	50	40	90	11	83.07	38.3889
16	16	55	30	100	11	83.87	38.4721
17	16	55	35	90	15	83.07	38.3889
18	16	55	40	95	8	84.37	38.5238

Larger is better: $\frac{S}{N} = -10 \log_{10} \left(\frac{1}{n} \sum \frac{1}{y_i^2} \right)$

For example,

For trial no. 1, the S/N ratio is:

$$\frac{S}{N} = -10 \log_{10} \left[\frac{1}{1} \left(\frac{1}{90.32^2} \right) \right] = 39.115678$$

Similarly S/N ratio for all other trials is calculated and also S/N ratio is calculated by using MINITAB 17 software which is found to be the same.

Fig. 3 : Main effects plot for S/N ratios for PY

From the S/N ratio values of table 5, MINITAB 17 estimates the Main effect plot for S/N ratio as shown in figure 3. As the required product yield is 'Larger the better' type, so from the chart in figure 3; we can select the best set of parameters that can be determined by selecting the levels with highest value of each factor. So we get the optimum values of parameters as:

PT = 8 sec, RUD = 45 mm, RLD = 30 mm, RH = 90 mm, IH = 8 mm respectively.

Table 6
ANOVA for Product Yield at 95% confidence limit

Parameter	DoF	SS	Variance	F-ratio	P-value
PT	1	0.28173	0.28173	39.48	0.000
RUD	2	0.1373	0.1373	9.62	0.007
RLD	2	0.0939	0.0939	6.58	0.020
RH	2	0.0947	0.0947	6.64	0.020
IH	2	0.0510	0.0510	3.57	0.078
Error	8	0.05709	0.05709		
Total	17	0.71573			

S = 0.08448 R-Sq = 92.0% R-Sq(adj) = 83.0%
Rank: 1 = PT, 2 = RUD, 3 = RLD, 4 = RH, 5 = IH

ANOVA in table 6 indicates that Pouring temperature has most impact on Product Yield followed by Runner Upper Diameter, Runner Lower Diameter and Runner Height. But Ingate Height does not influence much.

4.2.2 For Hardness

Similarly as S/N analysis of Product Yield done above, the casting Hardness is the "Larger the better" type of quality characteristics. Larger the better S/N ratios were computed for each of the 18 trials and the values are recorded in table 7.

Table 7
Hardness values and Signal-to-noise Ratio values against Trial Numbers

Trial No.	PT	RUD	RLD	RH	IH	HRD	S/N Ratio
1	8	45	30	90	8	217	46.7292
2	8	45	35	95	11	207	46.3194
3	8	45	40	100	15	187	45.4368
4	8	50	30	90	11	197	45.8893
5	8	50	35	95	15	178	45.0084
6	8	50	40	100	8	178	45.0084
7	8	55	30	95	8	207	46.3194
8	8	55	35	100	11	169	44.5577
9	8	55	40	90	15	170	44.6090
10	16	45	30	100	15	177	44.9595
11	16	45	35	90	8	197	45.8893
12	16	45	40	95	11	178	45.0084
13	16	50	30	95	15	178	45.0084
14	16	50	35	100	8	185	45.3434
15	16	50	40	90	11	175	44.8608
16	16	55	30	100	11	170	44.6090
17	16	55	35	90	15	169	44.5577
18	16	55	40	95	8	163	44.2438

$$\text{Larger is better: } \frac{S}{N} = -10 \log_{10} \left(\frac{1}{n} \sum \frac{1}{y_i^2} \right)$$

For example,

For trial no. 1, the S/N ratio is:

$$\frac{S}{N} = -10 \log_{10} \left(\frac{1}{1} \sum \frac{1}{217^2} \right) = 46.729194$$

Similarly S/N ratio for all other trials is calculated and also S/N ratio is calculated by using MINITAB 17 software which is found to be the same.

From the S/N ratio values of table 7, MINITAB 17 estimates the Main effect plot for S/N ratio as shown in figure 3. As the required product yield is 'Larger the better' type, so from the chart in figure 3; we can select the best set of parameters that can be determined by selecting the levels with highest value of each factor. So we get the optimum values of parameters as:

PT = 8 sec, RUD = 45 mm, RLD = 30 mm, RH = 90 mm, IH = 8 mm respectively.

Fig. 4 : Main effects plot for S/N ratios for HRD

Table 8
ANOVA for Hardness at 95% confidence limit

Parameter	DoF	SS	Variance	F-ratio	P-value
PT	1	1.6185	1.6185	13.57	0.006
RUD	2	2.4995	2.4995	10.48	0.006
RLD	2	1.5876	1.5876	6.65	0.020
RH	2	0.6240	0.6240	2.62	0.134
IH	2	1.3135	1.3135	5.50	0.031
Error	8	0.9544	0.9544		
Total	17	8.5975			

S = 0.3454 R-Sq = 88.9% R-Sq(adj) = 76.4%
Rank: 1 = RUD, 2 = RLD, 3 = IH, 4 = PT, 5 = RH

ANOVA in table 8 indicates that Runner Upper Diameter has most impact on Hardness followed by Runner Lower Diameter, Ingate Height and Pouring Temperature. But Runner Height does not influence much.

4.3. Validation by Autocast Software

AutoCAST-X software is a fine tool for casting industry in which simulation of casting product can be done; which in result gives the report of Casting Yield, optimized value of gating system and the quality affecting defects like shrinkage porosity, blow holes formation, cold shut, Hard zone etc.

A solid model in STL format is imported in AutoCAST software. All the values of process parameters are entered in initial stage. Then gating system is designed by giving the dimensional input as the optimum values we get by experimentation i.e. PT = 8 sec, RUD = 45 mm, RLD = 30 mm, RH = 90 mm, IH = 8 mm. By feeding these values the casting model with gating system gets generated as shown in figure 5.

Fig. 5 : Gating system generated in AutoCAST software

The next stage of software work is, it checks the gating system for its effectiveness in complete filling of mould cavity. And which is done in this case as can be seen in red colored view of a completely filled model in figure 6.

Fig. 6 : Mould filling Process in AutoCAST software

After confirmation of mould filling process, simulation work starts. It is divided in two levels as: Simulation 'Till the End of complete filling' and 'Till the end of solidification'. Both the processes are shown in following figure 7.

Fig. 7 : Simulation process of mould complete filling and solidification in AutoCAST software

After completion of simulation process, software generates simulation report. From this report we get that, Product Yield value is found to be 90.91% and which is very near to the experimental value of 90.32% we get. So we can say that our optimal value of all parameters is valid. Report of software is shown in figure 8.

Fig. 8 : Simulation report of AutoCAST software

5. Result and Discussion

Experiment was carried out to increase Product Yield and Hardness of CI Conveyor Bracket at industry. Optimization of Product Yield and Hardness was done by using Taguchi technique and by the analysis we get the value as 90.32% and 217 BHN respectively. From the Taguchi analysis optimal values of parameters for both Product Yield and Hardness are tabulated in table 9.

Table 9
Optimal values of parameters for Product Yield and Hardness improvement

Sr. No.	Parameters	Optimal Values
1	Pouring Time	8 sec
2	Runner Upper Diameter	45 mm
3	Runner Lower Diameter	30 mm
4	Runner Height	90 mm
5	Ingate Height	8 mm

Also the simulation report of AutoCAST software gives the value of Product Yield to be 90.91% which is very close to the experimental value of 90.32%. Hence the optimal values are validated.

6. Conclusion

- A methodology for optimization of Gating design for sand casting process to maximize the Product Yield and Hardness for Conveyor Bracket has been described in this paper.
- The optimized levels of selected gating system parameters obtained by Taguchi method are: Pouring Time = 8 sec, Runner Upper Diameter = 45 mm, Runner Lower Diameter = 30 mm, Runner Height = 90 mm and Ingate Height = 8 mm.
- With Taguchi optimization method and experimental analysis we can conclude that for the Product yield to be more than 90% and Hardness to be more than 175 BHN can be obtained.
- Computer aided casting simulation technique is found to be the most effective and accurate tool to design the gating system and to find out the quality and yield of casting in very less time, without doing actual trials in foundry.

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