Defect reduction in ring blank casting through design of experiments

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Defect Reduction in Ring Blank Casting Through Design of Experiments

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Abstract – *This research was carried out to optimize the pattern design parameters and to reduce the cold metal (CM) defect during piston ring blank casting made in high pressure green sand foundry. Design of experiments methodology was used to minimize the defect level in gating system of the pattern design. Multiple input factors are considered and controlled simultaneously to ensure that the effects on the output responses are causal and statistically significant. Metal feeding system parameters like runner diameter, choke thickness and pouring basin weight with different level were taken as input factors for this study. A full factorial design was used to design the experiment and the established variable relationships and studies on interaction effects were discussed in this study. Experimental data were statistically analyzed and optimized by using Yates method of computing factorial effects.* ***Copyright © 2015 Praise Worthy Prize S.r.l. - All rights reserved.***

Keywords*: Ring Blank Casting, Cold Metal Defect, Choke Thickness*

Nomenclature

A Choke thickness
B Runner diameter
C Pouring basin weight

I. Introduction

Quality improvement is an important goal in any type of business in order to compete the global market. Customer expectations on the product may vary from time to time due to advancements in information technology and supply chain management.

Hence, to sustain and make continuous growth in the business, there is always a need to focus on the primary areas like price reduction, achieving world class quality, inventory control and lead time reduction. Each manufacturing concern has potentials to improve the efficiency and effectiveness of its process by refinement activities. This is achieved by using Design of Experiments (DOE), which is the most effective break-through strategy ever devised. It helps the companies to make substantial improvements on their bottom-line by designing and monitoring day-to-day business activities which in turn minimizes all types of wastes and scrap level thus, increasing the customer satisfaction and profitability. Many organizations have implemented downsizing, outsourcing, activity based costing, business process re-engineering, just in time, kaizen and Total Quality Management (TQM) for improving their quality.

While all these tools are useful, they often fail to make break-through improvements on the bottom line and quality. Defective casting leads to huge losses in productivity.

Employing systematic approach to realize the nature of defect, method of defect formation and by controlling the key process factors, rejections could be reduced [1].

Timely implementation of advanced techniques based on the quality control research is necessary to avoid the defects on the product [2]. Defects take place during casting process due to several reasons. The Major defects are based on filling defects, shape related defects, thermal defects and appearance defects [3]. A study on the casting defects during casting process reported that the sand-to-binder ratio, permeability of the mold, molten metal temperature and amount of de-oxidant were the majorly influencing parameters for casting defects [4]. In another research, six-sigma approach was used to reduce the work rejections during casting of piston rings.

The study reported that, the use of quality tools like six sigma decreased the work rejection from 38.1 % to 13.2 % [5]. Though research works have been carried out in piston ring casting process, many process parameters have not yet been studied for process optimization and defects rejection. The present study deals with the optimization of process parameters to reduce the cold metal defects during piston ring blank casting process.

The major variable that influence the likelihood for formation of cold metal defects are pouring temperature, gating system design and chemistry of the molten metal.

Since pouring temperature and chemistry are controllable factors, other parameter like choke thickness, runner diameter and pouring head weight were taken as the input factors at different levels for the present research.

A full factorial design was used for analysis and study of estimated relationship between the variables and their interaction effects.

Finally, all the data were statistically analyzed by using Yates method of computing factorial effects. This research work was carried out with the following objectives:

1. Identification of influencing factors causing cold metal (CM) defect during ring blank casting.
2. Determination of optimum factor levels to minimize cold metal defect.
3. Estimation of percentage contributing of each factors and their interaction effects.
4. Conducting experimental runs by setting factor value at the optimal level for validation.

II. Experimental Details

A cold metal defect is an imperfection or deficiency in the cast part.

This is identified with respect to the specifications given by customers and technical experts. Quality is the absence of defect in the unit identified. In other words, it is the process of reducing the defects during casting process. CM defect mainly takes place due to non-uniform filling of molten metal during casting process.

The Fig. 1(a) shows the cold metal defect in S.G Iron ring blank. Fig. 1(b) shows the running system, which includes the runner diameter, choke thickness and in-gate sizes namely in-gate height and in-gate length.

Fig. 1(c) and Fig. 1(d) show the poring basin and pouring basin molten metal after pouring respectively.

III. Design of Experiments

Design of experiments (DOE) is a series of ordered tests in which purposeful modifications are made on the factors in order to investigate the change on the output responses. It is a statistical technique used to study the effect of inputs on the multiple output variables simultaneously [6].

The objective of conducting an experiment is to optimize and determine the levels of critical variable which would result in the best process performance [7], [8]. DOE has been used by several researchers to analyze and optimize the output parameters for varying input factors [9], [10]. The first step in DOE is to identify the influencing factors and the factor settings are made to those influencing factors as presented in Table I.

Three input factors are selected with three levels and hence it forms $2^3 = 8$ runs as presented in Table II.

Running the experiment twice on each trial combination without changing the setting is called repetition. The present study has not done any repetition in experiments. Running the experiment twice on each trial combination, with a change of setting is called as replication and this study was conducted with two replication on two different dates.

If the runs are made in random order as opposed to a standard, it is called randomization and the present work does not deals with randomization.

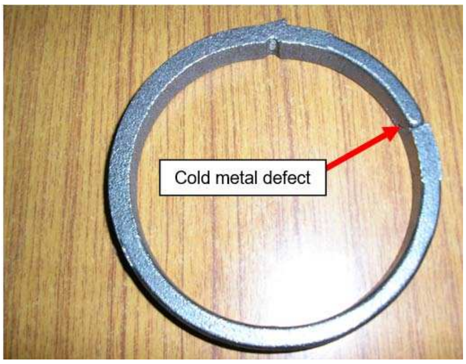

Fig. 1(a). CM defect in Iron ring blank

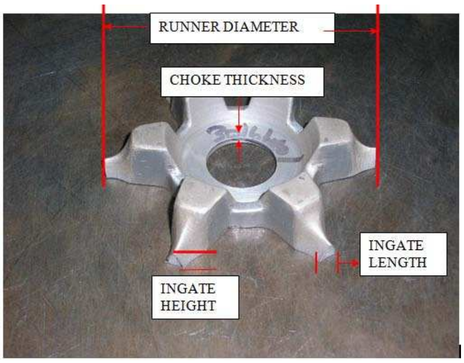

Fig. 1(b). Running system

Fig. 1(c). Pouring basin

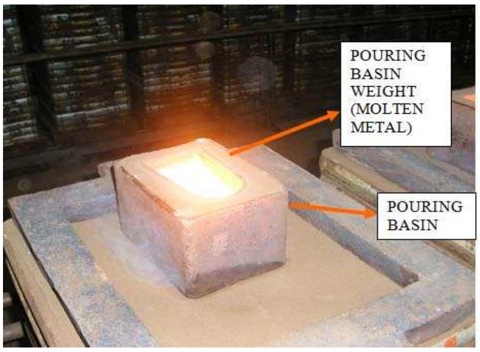

Fig. 1(d). Weight of pouring basin

The trial runs and measured responses for each trial were presented in Table III. The individual effects of all input factors and their interaction effects were calculated and presented in Table IV. The influence of each factor on the CM defect was presented in Figs. 2.

TABLE I
FACTORS AND LEVELS

Factor	Unit	Signal leval-1	Signal leval-2
Choke thickness (A)	mm	3.00	3.50
Runner diameter (B)	mm	132.00	116.00
Pouring basin weight (C)	kg	3.00	3.30

TABLE II
DESIGN TABLE

Trial	Choke thickness (A)	Runner diameter (B)	Pouring basin weight (C)
1	3.00	132	3.00
2	3.5	132	3.00
3	3.0	116	3.00
4	3.5	116	3.00
5	3.0	132	3.30
6	3.5	132	3.30
7	3.0	116	3.30
8	3.5	116	3.30

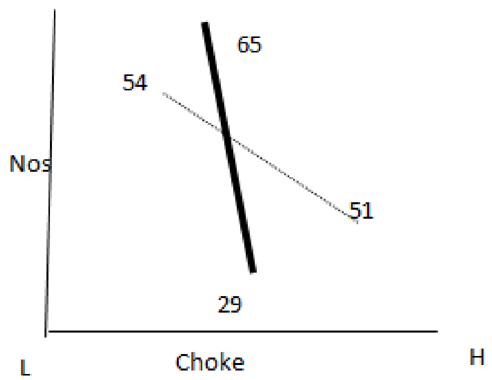

Fig. 2(a). Choke thickness versus CM defect

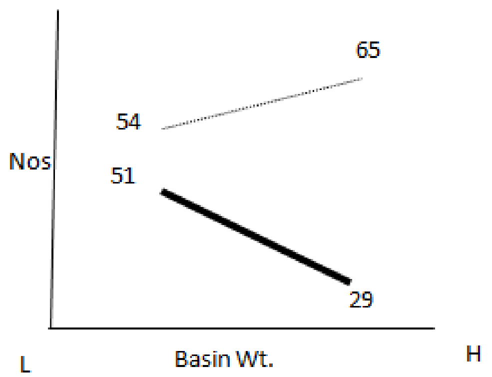

Fig. 2(b). Basin weight versus CM defect

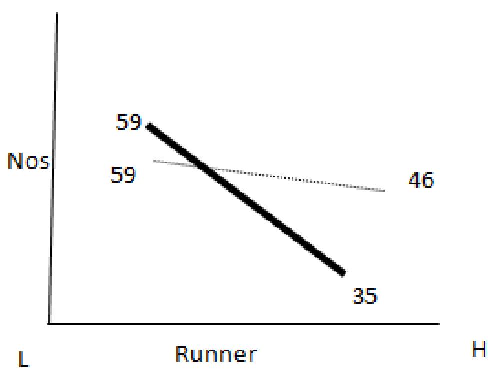

Fig. 2(c). Runner diameter versus CM defect

TABLE III
TRIAL RUNS AND RESPONSES

Trial	A	B	C	Cold metal defect (Rep-1)	Cold metal defect (Rep-2)	Total
1	3.00	132	3.00	26	28	54
2	3.5	132	3.00	31	33	64
3	3.5	116	3.00	27	26	53
4	3.5	116	3.00	18	20	38
5	3.0	132	3.30	42	42	84
6	3.5	132	3.30	16	18	34
7	3.0	116	3.30	23	23	46
8	3.5	116	3.30	12	11	23

TABLE IV
EFFECTS OF INPUT FACTORS

Effect of choke thickness		
	High level-3.5 mm	Low level 3.0mm
1	64	54
2	38	53
3	34	84
4	23	46
Total	159	237
X Bar	39.75	59.25
Effect	**-19.50**	
Effect of Runner diameter		
	High level- 116 mm	Low level- 132 mm
1	53	54
2	38	64
3	46	84
4	23	34
Total	160	236
X Bar	40.00	59.00
	-19.00	
Effect of Pouring basin weight.		
	High level 3.3 kg	Low level 3.0 kg
1	84	54
2	34	64
3	46	53
4	23	38
Total	187	209
X Bar	46.75	52.25
Effect	**-5.50**	
Interaction between Choke thickness and Runner diameter		
	High level-Choke	Low level-Runner
1	64	54
2	38	64
3	34	84
4	23	34
Total	159	236
X Bar	39.75	59
Effect	**-19.25**	
Interaction between Choke thickness and Pouring basin weight		
	High level-choke	Low level-basin
1	64	54
2	38	64
3	34	53
4	23	38
Total	159	209
X Bar	39.75	52.25
Effect	**-12.5**	
Interaction between Runner diameter and pouring basin weight.		
	High level-runner	Low level-basin
1	53	54
2	38	64
3	46	53
4	23	38
Total	160	209
X Bar	40	52.25
Effect	**-12.25**	

Each plot contains a thick line and a thin line, the thick line representing the high factor level and thin line representing the low factor level.

It was observed that the CM defect drastically reduces with increase in choke thickness at high level whereas at low level, there is only a slight decrease in the CM defect. Investigations of pouring basin weight on CM defect shows that, the defects decreases with increase in basin weight at high level but increases with increase in basin weight at low level [11]. It was observed that, the CM defect drastically reduces for increase in runner diameter at high level and the CM defect moderately decreases for increase in runner diameter at low level.

IV. Yates Analysis and Discussions

IV.1. Yates Method

Yates developed a systematic method which is more accurate when there are three or more factors as presented in Table V.

TABLE V
YATES TABLE

Treatment combination	Replicate-1	Replicate-2	Total	Effect (1)	Effect (2)	Effects total-3
1	26	28	54	118	209	396
A	31	33	64	91	187	-78
B	27	26	53	118	-5	-76
Ab	18	20	38	69	-73	2
			Total	**396**	**318**	**244**
C	42	42	84	10	-27	-22
Ac	16	18	34	-15	-49	-68
Bc	23	23	46	-50	-25	-22
Abc	12	11	23	-23	27	52
Odds			237	196	152	276
Evens			159	122	92	-92
Total			**396**	**318**	**244**	**184**

This method is used to yield a quantitative estimate of a dependent variable with different levels [12]. The various entities in Table V are calculated as follows:

1. Arrange the treatment combination in the standard order as shown in the table.
2. Place the corresponding treatment totals in total column.
3. Drive the column (1) by adding the CM defects. For instance, the first entry 118 is the sum of first two treatment total namely (54+64). The second entry is the sum of the second pair of CM defects (53+38) and so on.
4. Get the total for the top half of the Effect (1) column. (118+91+118+69)=396.
5. Obtain the lower half of the Effect (1) column by taking the differences of the same pairs taken in step number 3. The first number of each pair from the second number in every case. Thus 10 = (64 - 54), -15 = (38 - 53), -50 = (34 - 84), -23 = (23 - 46).
6. After having obtained effect (1) column, enter two more entries namely odds and evens.

Odds being the total of odd entries in effect column one and evens being the total of even entries. Thus Odds is = 118 + 118 + 10 + (-50) = 196

Total evens = 91 + 69 + (-15) + (-23) = 122

7. By following step 3 to 6, effect column (2) was obtained from effect column (1).
8. By following step 3 to 6, effect column (3) was obtained from effect column (2).
9. The effect column (3) contains the factorial effects total. The first number effect column (3) is the Grand total (G) = 396. The number of summing and differencing computation process is continued until Grand total equals to sum of Odds and evens of replication total column.
10. Contribution to the sum of squares due to treatment of the factorial effect (main and interaction effect) are obtained by dividing the squares of factorial effect totals by 16. When there are k factors and replicates, the divisor for the squared factorial effect total is $2^k r$. Where k = number of factor = 3, r = number of replicate = 2. Thus (2*2*2)*2 = 16.
11. The sum of squares due to treatments has 7 = (8 - 1) degree of freedom and is calculated independently from the totals of 8 treatment combinations. Grand total (GT) = Total sum of Odds and Evens; (237 + 159) = 396. Correction factor (CF) = ((GT)*(GT))/N = (396*396)/16 = 9801. Where N= $2^k r$

Total sum of Odds = 54 + 53 + 84 + 46 = 237

Total sum of Evens = 64 + 38 + 34 + 23 = 159

Treatment Sum of Squares =
$(54^2+64^2+53^2+38^2+84^2+34^2+46^2+23^2)/ 2 - CF$

12. Treatment Sum of Squares = 1260.

Total Sum of squares
$= (26^2+31^2+27^2+18^2+42^2+16^2+23^2+12^2+28^2+33^2+26^2+ 20^2+42^2+18^2+23^2+11^2) - CF$

13. Total Sum of squares = 1269.

The Sum of squares due to replicate is
$= ((\text{total sum of replicate } 1)^2$
$= (\text{total sum of replicate } 2)^2)/8 - CF$

Total sum of replicate 1=26+31+27+18+42+16+23+12=195

Total sum of replicate 2=28+33+26+20+42+18+23+11=201

14. The Sum of squares due to replicate is = $(195^2+201^2)/8-9801=2.25$

Error Sum of squares = Total sum of squares - Treatment Sum of squares - Sum of Squares due to replicate.

15. Error Sum of squares = (1269-1260) - 2.25 = 6.75

IV.2. ANOVA Analysis

The ANOVA table for all the factors and its combinations was presented in Table VI. The ANOVA analysis helps the researchers to know the significance of each input factor on the output response and its contribution on the responses [13], [14]. It was observed from Table VI that, all the three factors namely, choke thickness (A), runner diameter (B) and pouring basin weight (C) have significant influence on the CM defect. As far as the interaction effects was concerned, except choke thickness – runner diameter (AB) combination, all the other combinations namely choke thickness – basin weight (AC) and runner diameter – basin weight (BC) have significant influence on the CM defect. The three factor combination namely choke thickness – runner diameter – basin weight (ABC) have also has significant influence on the CM defect.

TABLE VI
ANOVA TABLE

Treatment combination	Mean effects	Sum of squares	F Calculated value	F table value	Significant
A	-9.75	380.25	394.3	3.79	Yes
B	-9.5	361	374.4	3.79	Yes
AB	0.25	0.25	0.3	3.79	No
C	-2.75	30.25	31.4	3.79	Yes
AC	-8.5	289	299.7	3.79	Yes
BC	-2.75	30.25	31.4	3.79	Yes
ABC	6.5	169	175.3	3.79	Yes

V. Conclusion

This research studied the pattern design parameters that affect the cold metal defect in the ring blank casting made in high pressure green sand foundry and the conclusions drawn are as under:

1. Except for the combination of choke thickness and runner diameter, all other factors and their interactions have significant influence on the CM defect.
2. Even though choke thickness, runner diameter and pouring basin weight are significant for reducing CM defect, they could not be used at high levels due to three reasons. First reason being that, increasing the choke thickness would lead to sand inclusion defect. Second reason being that, reduction in runner diameter makes mismatch of pattern in match plate. Third reason being that, if pouring basin weight is increased then the yield percentage would be reduced.
3. Taking the optimum levels of input factors in to consideration, it was able to reduce the CM defect from 55000 ppm to 18791 ppm.

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