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Rejection Analysis and Quality Control of Castings at Inducto Cast

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***Abstract*—Casting is a traditional process widely used in industries. Technological development has not yet been observed in this area. The process of casting generally leads to defects in the components produced. There are two ways to bring about improvement: either by applying quality control tools or by applying theoretical knowledge. Pareto Analysis is used to select the product which has maximum rejection and affects the revenue of the company. The defects in the product are analysed using Fish Bone diagram. Based on that, firstly, an optimum moulding sand composition is obtained by Taguchi method. Secondly an optimum gating system design for the product is achieved by Taguchi method. Various iterations are performed in E-foundry software. The optimum design is further simulated on AutoCast software to provide assurance**

Keywords—Casting,Taguchi,Pareto,E-foundry

I. INTRODUCTION

Inducto Cast is a sand casting industry that manufactures components made of either cast iron or spheroidal graphite cast iron. The objective is to identify the main problems incurred in the company during the manufacturing of various products. And then solving the problems by carrying out the rejection analysis and applying different quality improvement tools and techniques. The main target is to reduce the rejection of the product and to increases productivity by different productivity improvement tools and technique.

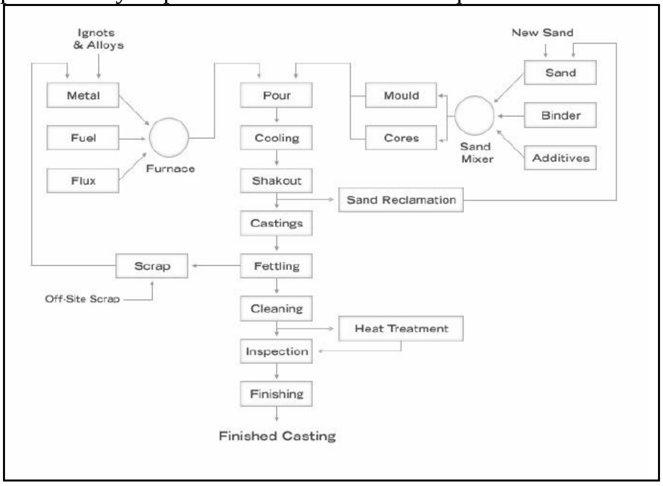

Fig. 1 Casting process flow chart

II. PRODUCT SELECTION

A. *Pareto Analysis*

Pareto Analysis is a statistical technique in decision making that is used for the selection of a limited number of tasks that produce significant overall effect. It uses the Pareto Principle (also known as the 80/20 rule) the idea that by doing 20% of the work we can generate 80% of benefit of doing the whole job. Or in terms of quality improvement, a large majority of problems (80%) are produced by a few key causes (20%). Out of various products, one product has been identified.

Table 1 Rejection Data for March-June 2017

Rejection data for March-June 2017							
Sr. No	Product Category	Product Name	Total Volume of Casting	Rejected Volume of Casting	Weight	Rejection Percentage	Cost price
1	Casing	KBV CT 280 TOP	40	1	122	2.50	7503
5	Helical gearbox casing	S2 K3 22 TOP	17	3	227	17.65	12777.65
7		S2 K3 19 TOP	20	2	91	10.00	5617
8		S2 K3 19 BTM	36	5	111	13.89	6894
13		S2 K3 18 TOP	15	1	66	6.67	4104
14		S2 K3 18 BTM	14	1	78	7.14	4811
18		S3 K4 22 BTM	11	1	190	9.09	17051
19	Lantern	LANTERN 2500	45	2	81	4.44	12976
22		LANTERN 1000	17	1	75	5.88	12233
25	Muff coupling	MUFF COUPLING 6300	69	5	26.5	7.25	2819.5
26		MUFF COUPLING 2500	37	5	19	13.51	1954.5
28	Fan	BRG HSG 250	18	2	10	11.11	1320
29		BRG HSG 6300	33	1	37	3.03	3907

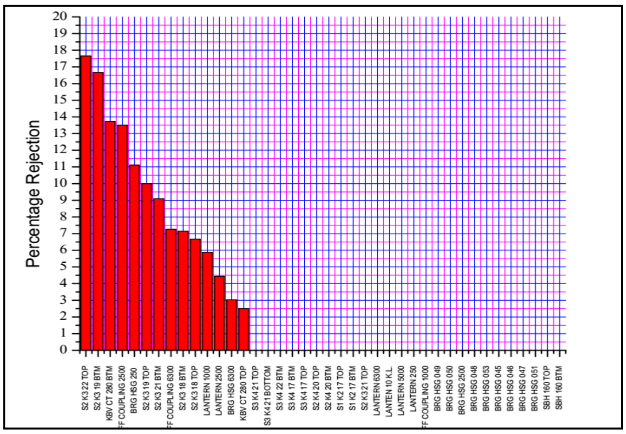

Fig. 2 Graph of Percentage Rejection vs Part Name

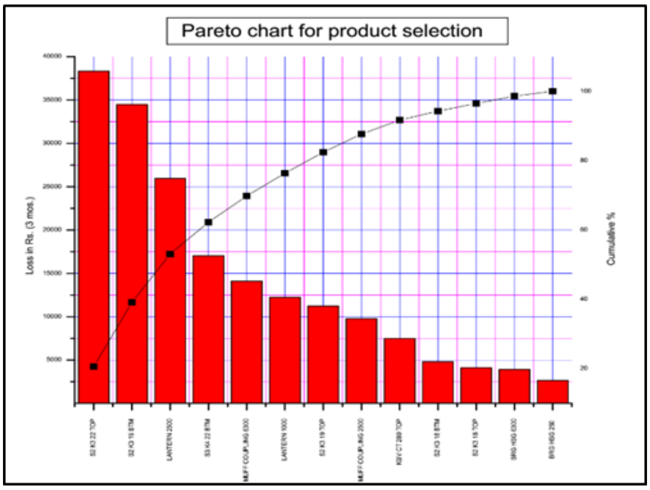

Fig. 3 Pareto chart for product selection

From pareto chart S2K3-22 is selected for further analysis.

B. Fish Bone Diagram

Fish-Bone diagram is a tool that is useful for identifying and organising the known or possible causes of quality, or lack of it. One of the important benefits of contracting it is it helps to determine the root causes of a problem or quality characteristic using a structured approach. Fish-Bone diagram can be used to figure out various causes related to defects incurred in casting. The causes can be further segregated into four different categories:

- Man
- Material
- Method
- Machine

. Various Defects commonly incurred during the process for which the Fish-Bone diagram is formulated are as follows:

- Blow hole
- Cold Shut
- Sand Inclusion

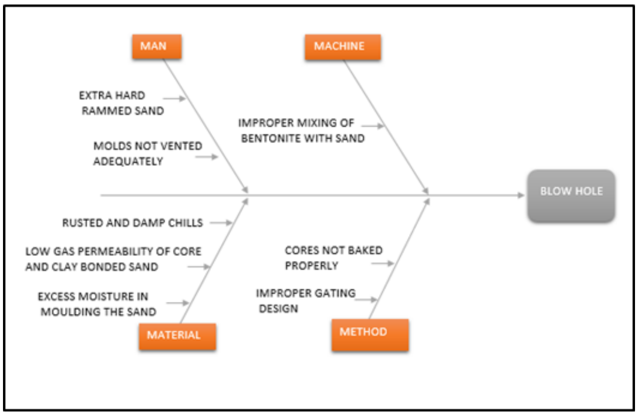

Fig. 2 Fish bone diagram for blow holes

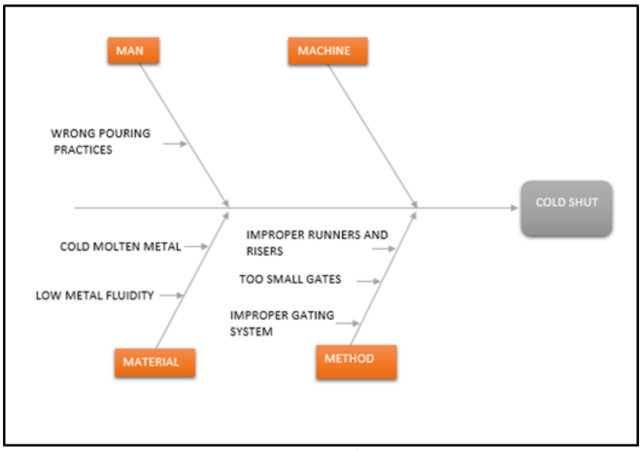

Fig. 3 Fish bone diagram for cold shut

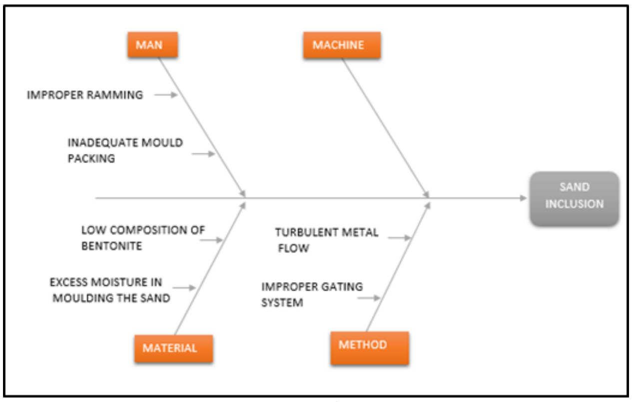

Fig. 6 Fish bone diagram for sand inclusion

As observed from the Fish-Bone Diagram for various defects, the significant causes for defects incurred in casting are Improper Sand Composition and Improper Gating design. So, bringing about a variation in the sand composition and preparing a new gating system design would be the main motive to reduce the defects.

III. SAND TESTING

A. Grain Size Test

The grain size and distribution influence many sand properties such as permeability, Flowability, refractoriness, surface fineness and strength. The finer the sand grains, the finer is the molding sand as whole. Fine grain sands give good surface finish but possess low permeability. For same clay content, the green strength is higher in case of fine sands as compared to coarse sands. Coarse and uniformly graded sand imparts high permeability, good refractoriness and high flowability. Normally the foundry sand possesses the grain size between 0.1 to 1.0 mm. The fine-grained sands are used to make intricate and small size castings. Coarse grained sands are used to make large castings. (Refer Appendix 2). 100 grams of sand is taken for the test.

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Sieve No .	Sand retained on each sieve, g	Percentage of sand retained, (A)	Multi plier (B)	Product (A*B)
270	46	30.67	200	6134
200	74	49.33	140	6906.2
Pan	26	17.33	300	5199
TOTAL	146	97.33	-	18239.2

Table 2 Multiplying Factor for Mesh opening

AFS Grain Fineness number = (Total Product) / (Total Percent of Sand Retained)

$$= \frac{18239.2}{97.33}$$

$$= 187.40$$

The achieved GFN being comparatively higher is suitable for smaller castings with good surface finish and high flowability. However smaller sizes are not permeable enough. Molds made of very fine-grained sands will be closely packed and have little space between the sand grains that wouldn't allow entrapped air and gases to escape – leading to porosity defects. Hence, to obtain sound casting without porosity defect GFN value should lie between certain ranges.

B. Permeablity Test

The permeability number of the sand sample can be calculated from the following equation:

Calculation

$$P = \frac{Vh}{Atp}$$

Where,

P=AFS standard permeability number

V=Volume of air in cm^3 =2000 cm^3

H=Height of specimen in cm=5.08(or, 2 inches)

A=Cross-sectional area of specimen in cm^2= 20.268 cm^2

p=Air pressure in g/cm^2 = 10 g/cm^2

t=Time in minutes

The above equation can be simplified as

$$P = \frac{3007.2}{t}$$

Where, t = time in seconds=35 seconds

$$P = \frac{3007.2}{35}$$

$$P = 85.92$$

For the given composition of sand, permeability lies in the range for heavy grey iron. As such it will allow entrapped air and generated gases to escape through mould. And hence it is not the governing cause for defects such as blow holes.

C. Sand Hardness Test

Sample	Hardness	Average Hardness
1.	65	76.5
2.	72	
3.	79	
4.	90	

Table 3 Observation Table for Hardness number

A hard rammed mold generally reads 90, while a soft mold reads 50 to 60. The average value for the sample obtained is 76.5 which is above 50 and sufficient to retain the sand in normal pouring conditions. Hence hardness is not the affecting parameter for severe penetration by the liquid metal and washing of the sand.

D. Optimum Sand Composition using Taguchi Analysis

The following factors were used to perform sand testing to find out the optimal composition:

- Bentonite content
- Moisture content

Factors	Level 1	Level 2	Level 3	Level 4
Moisture content	2%	3%	4%	5%
Bentonite content	2%	3%	4%	5%

Table 4 Factor table for optimum sand composition

Based on the Taguchi method applied for the sand testing, we found out the optimum composition of Sand mixture.

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Moisture Content	Bentonite content	Dry Compressive strength(psi)	Green Compressive strength (psi)	SNRA1	Mean
2%	2%	65	2.8	11.94	33.9
2%	3%	71	4.5	16.05	37.75
2%	4%	75	6.5	19.23	40.75
2%	5%	68	8.4	21.43	38.2
3%	2%	86	2.5	10.96	44.25
3%	3%	92	3.9	14.82	47.95
3%	4%	96	5.4	17.64	50.7
3%	5%	101	7.2	20.13	54.1
4%	2%	99	2	9.029	50.5
4%	3%	106	3.5	13.88	54.75
4%	4%	113	5.1	17.15	59.05
4%	5%	120	6.5	19.25	63.25
5%	2%	105	2	9.02	53.5
5%	3%	119	3.3	13.37	61.15
5%	4%	146	4.2	15.47	75.1
5%	5%	152	5.5	17.81	78.75

The plots generated by Minitab software is as follows:

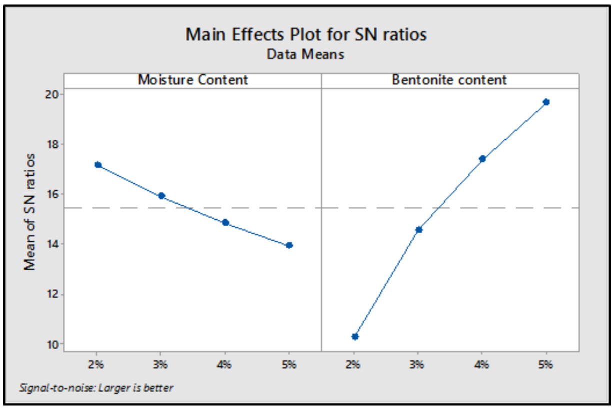

Fig. 7 Main effects plot for SN ratio

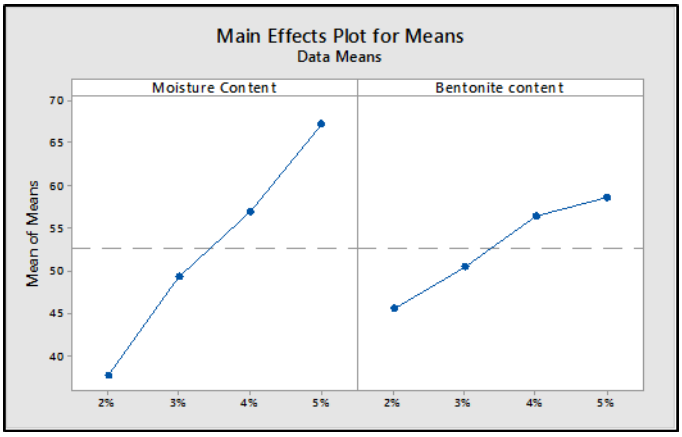

Fig. 4 Main effects plot for mean

IV. GATING SYSTEM DESIGN

A. Feeder Design

Calculation of pouring time based on experimental rules:-

$t = S\sqrt{W}$ seconds

where W : weight of metal poured = 932.55 pound

S : 2.20 for thickness more than 15mm

$T = (2.20) \times \sqrt{(932.55)}$

$= 67.1$seconds

1. Calculation of Pouring rate:-

Assume initial pouring rate = (1.5)*(average pouring rate)

To calculate the optimum pouring rate for different metals, following method can be used:

For ferrous metals:-

$$R = \frac{W^p}{(1.34 + \frac{t}{13.77})}$$

W : weight of casting = 423kg

t : critical casting thickness = 10mm

P = 0.5 for weight [0,500]

$$R = \frac{423^{0.5}}{(1.34+\frac{10}{13.77})} = 9.953 kg/s$$

Here R is obtained without consideration of fluidity and friction. Hence, flow rate has to be corrected for metal fluidity and the effect of friction in the gating system. The adjusted pouring rate can be calculated as:-

$$R_a = \frac{R}{k.f}$$

For liquid cast iron, take coefficient of friction (f) = 0.15

$$R_a = \frac{9.953}{13*0.15} = 5.104 kg/s$$

2. Average filling rate:-

$$\text{Average filling rate} = \frac{weight\ of\ casting}{filling\ time}$$

$$= \frac{423}{67.1} = 6.30 kg/s$$

3. Velocity of flow: -

For Fe based alloy, taking velocity as 500mm/s

4. Effective metal head of casting: -

h_p : effective metal head of casting

H : height of sprue = 230mm

h_1 : height of casting in cope = 290mm
h_2 : height of casting = 590mm

$$h_p = H - 0.5\left(\frac{h_1^2}{h_2}\right)$$

$$h_p = 230 - 0.5\left(\frac{(290)^2}{590}\right)$$

= 158.728mm

5. Choke Area:-

A_1 : choke area
W : casting weight
ρ : density of molten metal = 7000kg/m^3
h_p : effective height of metal head
c : discharge co-efficient
g : gravitational acceleration = 9.8m/s^2
t : pouring time

$$A_1 = \frac{w}{\rho t C\sqrt{2gh_p}}$$

$$A_1 = \frac{423}{7000 * 67.1 * 0.8 * \sqrt{2 * 9.81 * 0.158}}$$

= 6.3936 x 10^{-4} m^2

$$A_1 = \frac{\pi}{4}{d_1}^2$$

$$d_1 = 0.02853m$$

= 28.53mm

6. Sprue exit area:-

$$Q = \rho A_1 V_1$$

5.104 = 7000 * (6.3936 x 10^{-4}) * V_1
V_1 = 1.140m/s = 1140mm/s
Also, V_2 = 500mm/s
Using continuity equation. $A_1V_1 = A_2V_2$
(6.3936 x 10^{-4}) * 1140 = A_2 * 500
A_2 = 1.45 x 10^{-3}m^2

$$A_2 = \frac{\pi}{4}{d_2}^2$$

$$d_2 = 0.043m$$

7. Gate Thickness

To avoid hot junction,
Gate Modulus = $\frac{1}{2}$ (local casting modulus)
= $\frac{1}{2}$ (wall thickness)
= $\frac{1}{2}$ (70)
= 35mm

Riser Design

Riser is design by Caine's Method as follows:

1. Caine's Method

V_c = 0.02443 x 10^6 cm^3
A_c = 2.6394 x 10^4 cm^2

$$\left(\frac{A}{v}\right)_c = 1.08 \text{ cm}^{-1}$$

Assuming height of riser to be equal to height of sprue:-
h_s : height of sprue = 230mm
h_r : height of riser = 230mm
Volume of riser :

$V_r = \pi r_r^2 h$
$= \pi r_r^2 (230)$
$= 72.22\ r_r^2$ cm^3

Area of riser :

$A_r = 2\pi r_r^2 + 2\pi r_r h$
$= 6.28\ r_r^2 + 144 r_r$

$$\frac{Ar}{Vr} = \frac{6.28\ rr2\ +\ 144rr}{72.22\ rr2}$$

$$x = \frac{\left(\frac{A}{v}\right)_c}{\left(\frac{A}{v}\right)_r} = \frac{1.08}{\frac{6.28\ rr2\ +\ 144rr}{72.22\ rr2}}$$

Now,

$$x = \frac{a}{y-b} + c$$

Let a = 0.33
b = 0.030
c = 1.00

$$\frac{1.08}{\frac{(6.28\ rr2\ +\ 144rr)}{(72.22\ rr2)}} = \frac{0.33}{\left(\frac{72.22\ rr2}{0.02443\ x\ 106} - 0.03\right)} + 1$$

r_r = 7.955 cm

V_r = 72.22 (7.955)^2 = 4570 cm^3

Taking number of risers = 4

Volume of each riser :

$$V = \frac{Vr}{4}$$

= 1142.5 cm^3

$V = \pi r_1^2 h$
$= \pi r_1^2$ (23)
r_1 = 3.98cm
Diameter of riser = 79.5mm

2. Modulus Method

V_c = 0.02443 x 10^6 cm^3
A_c = 2.6394 x 10^4 cm^2

$$\left(\frac{A}{v}\right)_c = 1.08 \text{ cm}^{-1}$$

Assuming height of riser to be equal to height of sprue: -
M_c : modulus of casting
M_r : modulus of riser
D : diameter of riser (cm)

$$M_c = \frac{1}{\left(\frac{A}{v}\right)_c}$$

$$= \frac{1}{1.08}$$

= 0.926

Now,

M_r = 0.2D

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but

$$M_r = 0.2\ M_c$$
$$D = 6\ M_c$$
$$= (6 * 0.926)$$
$$= 5.55\text{cm}$$

The diameter of riser obtained from various methods is as follows:
From Caine's method:79.5mm
From Modulus mehod:55.5mm
Current riser diameter:102mm

V. ANALYSIS AND SIMULATION

Casting simulation is a powerful tool which can be used to visualize progressive solidification of molten metal inside a mold cavity. It helps to identify the defects like hot spots, cold shut, and shrinkage cavity. The defect is generally eliminated by connecting a feeder which is designed to solidify later than the hot spot. The defect can also be eliminated by changing the design of the gating system.

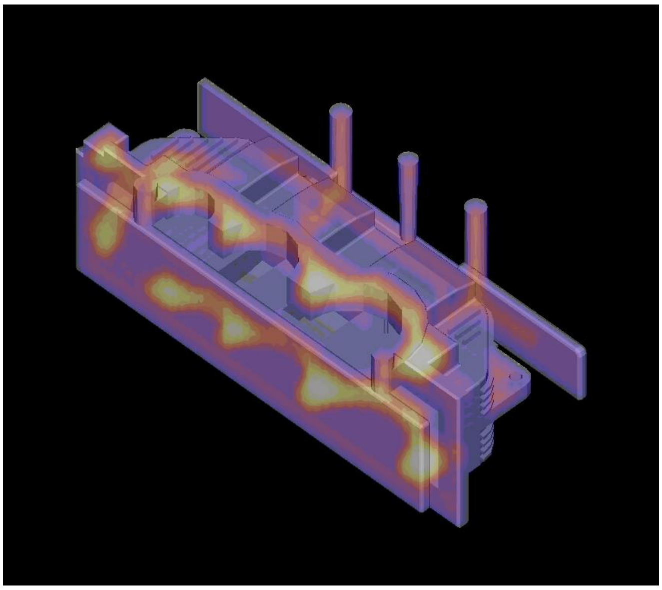

Fig. 5 Thermal analysis of current gating system

Simulation with Current Gating System

Total feeder volume = 5.495 x 10^6 mm^3
Sprue upper diameter D = 45 mm
Sprue lower diameter D = 35 mm
Height of sprue = 230 mm
Number of risers = 4
Diameter of risers = 50 mm
Casting Yield = 81.63%

A. Analysis using Taguchi Method

Taguchi Method is a systematic process which uses orthogonal array to choose the optimum iteration. As such it eliminates the chances of missing out the most optimal solution. The following factors were used to find the parameters for optimum gating system design:

- Number of Risers
- Diameter of Riser
- Pouring Temperature
- The factor table is given below:

Factors	**Level 1**	**Level 2**	**Level 3**
Number of risers	3	4	6
Diameter of riser (mm)	55.6	79.5	102
Pouring temperature (ºC)	1250	1350	1450

Table 7 Factor table for casting simulation

Number of risers	**Diameter of risers (mm)**	**Pouring temperature (ºC)**
3	55.6	1250
3	79.5	1350
3	102	1450
4	55.6	1350
4	79.5	1450
4	102	1250
6	55.6	1450
6	79.5	1250
6	102	1350

Table 8 Different combinations posssibe using three parameters (L9 matrix)

Number of risers	**Diameter of risers (mm)**	**Pouring temp (ºC)**	**Casting yield (%)**	**Sound casting**	**Snra 1**	**Mean**
3	55.6	1250	81.07	57.5	36.43	69.29
3	79.5	1350	78.87	63.4	36.89	71.14
3	102	1450	75.12	100	38.58	87.56
4	55.6	1350	89.12	64.6	37.38	76.86
4	**79.5**	**1450**	**88.23**	**100**	**39.42**	**94.12**
4	102	1250	82.56	72.9	37.76	77.73
6	55.6	1450	80.05	64.8	37.05	72.43
6	79.5	1250	77.40	69.4	37.28	73.40
6	102	1350	72.93	74.8	37.37	73.87

Table 9 Finalized iteration specification of gating system

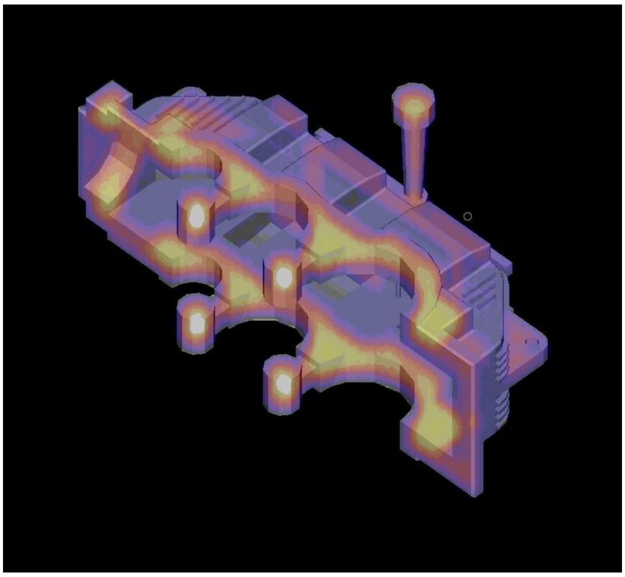

Fig. 10 Thermal analysis of proposed gating system iteration

The output parameter which were considered to find the optimum gating design are:

Casting Yield: It should be as high as possible because a higher value would indicate a significant material savings which would further result into cost savings.

Sound Casting: Sound casting indicates the tendency to generate the hotspots. Higher the value lower is the tendency to generate the hotspot. The simulation was carried out on E-foundry software where the hotspots generated were observed using a thermal plot.

Mean of both the parameters was taken into account for carrying out the Taguchi analysis. Based on the observations made, the iteration having the maximum Signal to noise ratio was selected as optimum iteration.

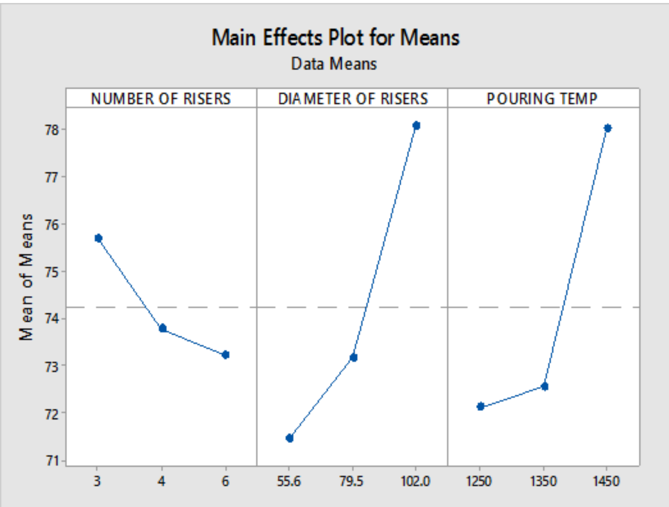

Fig. 11 Main effects plot for SN ratio

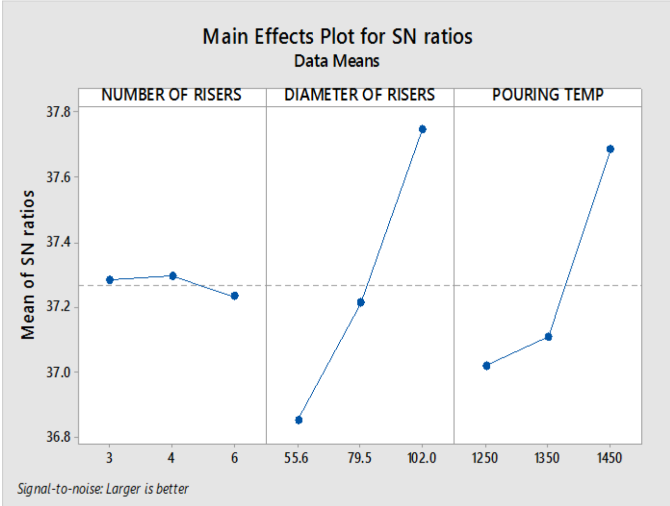

Fig. 12 Main effect plot for mean

Based on Taguchi Method, the optimum parameters for riser design are:

Factor	Optimum value
Number of risers	4
Diameter of risers	79.5mm
Pouring temperature	1450ºC

B. Validation of selected casting parameter using Auto cast software

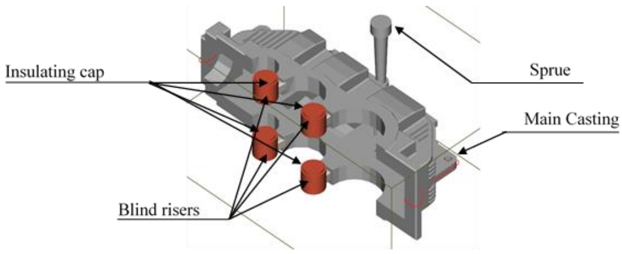

Fig. 13 Schematic diagram of proposed casting system

Iteration with 4 number of risers, diameter of riser 79.5 mm, and pouring temperature 1450ºc is selected and validated in AutoCast. To have low heat rejection in the riser we have introduced blind risers with insulating cap on top of each. That will lessen the amount of metal needed in riser compared to through risers. Proposed gating system and components are as shown below.

Defects observed in proposed casting

• Shrinkage Porosity:	Captured in Gating system
• Hard Zones:	Occurred in Gating system
• Unfilling (Misrun):	Inherently absent
• Cold Shut:	Inherently absent

•

From the detailed simulation of major casting defects present, it is found that misrun or unfilling and cold shut is inherently absent.The hard zone formed due to quenching effect because

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of convective heat transfer in surrounding air is trapped in the gating system.As shown in the figure given below no traces of hardzones were found in actual casting. Shrinkage porosity is not present as the all the hot spots were trapped in mainly three location. i.e. top two risers and gating system as shown in figure.

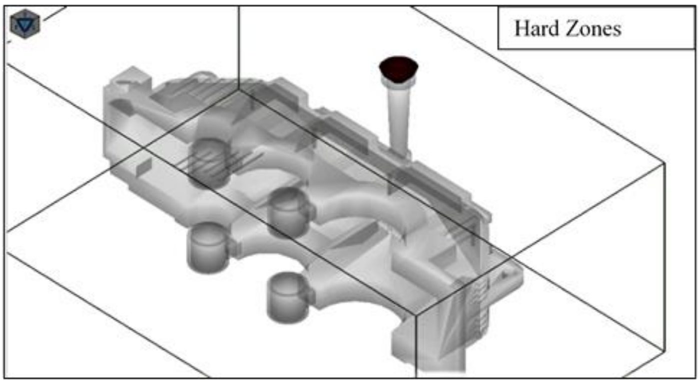


Fig. 14 Hard zones in proposed casting

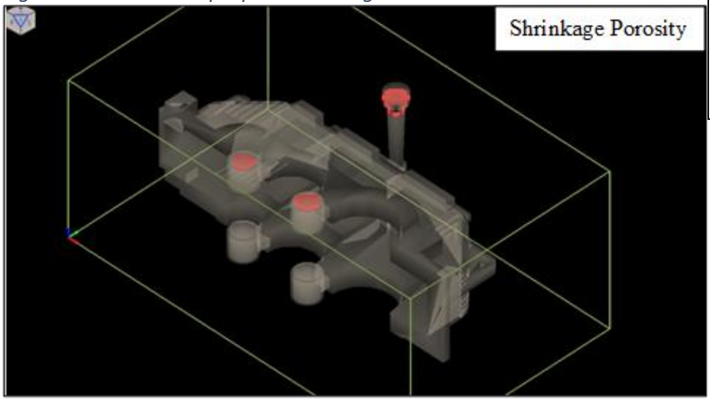


Fig. 15 Shrinkage porosity in proposed casting

C. Solidification time and temperature gradient

Solidification starts from the region having higher surface area to volume ratio and ends where the ratio is minimum. Hence as it is observed from the pictures at different time frame, solidification will start from gating system, will progress to the main body and ultimately last solidification will takes place at the risers where shrinksges will be trapped. The solidification time as per the software is 24.62 min.

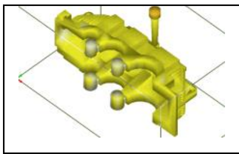
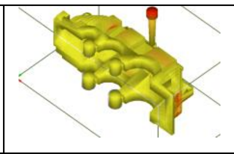
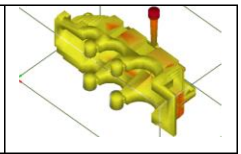
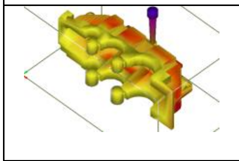
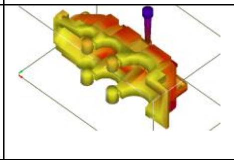
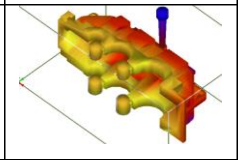
		
Current Time = 57.31s	Current Time = 151.74s	Current Time = 225.21s
Volume Solidified= 5.30%	Volume Solidified= 30.20%	Volume Solidified= 45.04%
		
Current Time = 429.09s	Current Time = 560.02s	Current Time = 852.5s
Volume Solidified= 70.07%	Volume Solidified= 80.01%	Volume Solidified= 95.01%

Fig. 16 Volume solidification at different interval of time

D. Advantage of proposed riser placement over current riser riser placementt

When riser placed as per current system:
TC_2: Riser solidifies at the time of pouring
When blind risers placed as proposed system:
TC_1: Risers solidifies at last

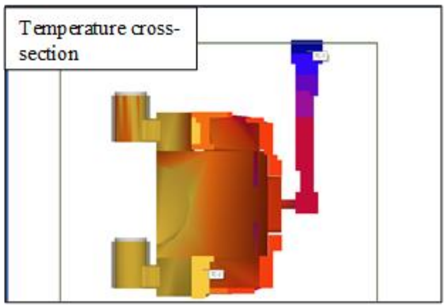


Fig. 17 Temperature cross section in proposed casting

As shown in temperature profile cross-section it is evident that higher most temperature (yellow and orange) is at opposite to the sprue while lower temperature is nearer to the sprue. Hence from theoratical knowledge of placement of riser, the best possible location of placing riser is at the opposite to the location of sprue. While the current location of riser is nearer to sprue where it tends to solidify earliest.

The graph plotted of temperature vs time depicts the difference between temperature of riser placed at location 1 (Proposed location) and location 2 (Current location) with the time of solidification

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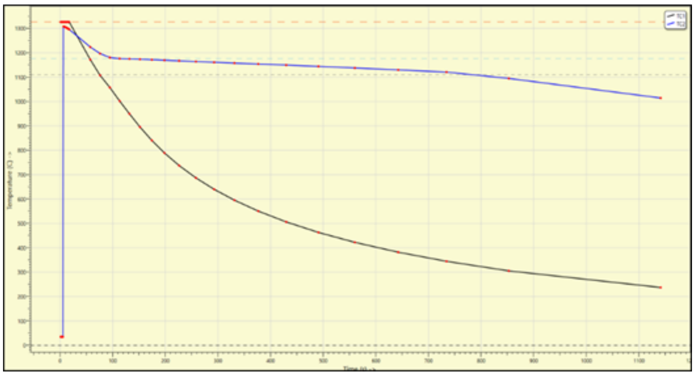

Fig. 18 Solidification time vs. Temperature plot at two location of riser placement

E. Total savings per annum using the proposed design

Tangible benefits in terms of cost incurred:
a) Material saved in terms of yield:

Parameters	Current Casting	Proposed Casting
Yield(%)	81.63	88.23
Weight of the component(kg)	227	227
Weight of the gating system(kg)	51.08	31.28
Total Weight (kg)	278.08	258.28
Material cost(Rs.30/kg for CI)	8342.40	7748.40
Processing cost(Rs.24/kg for CI)	6673.92	6193.92
Total cost(Rs.)	15016.32	13942.32
Number of components produced annually	51	51
Cost incurred annually(Rs.)	7,65,832.32	7,11,058.32

b) Rejection reduction due to removal of the defects:-

Parameters	**Current Casting**
Number of rejected components produced annually	51
Weight of the component(kg)	227
Material cost(Rs.30/kg of CI)	6810
Processing cost(Rs.24/kg for CI)	5448
Total cost(Rs.)	12258
Number of components rejected per annum	9
Cost incurred annually due to rejected component(Rs)	1,10,322

Total Savings Per Annum = (Savings due to improving Yield) + (Savings by removing the defects)
= 54,774 + 1,10,322
= Rs.1,65,096

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