

# Optimization & Experimental Validation of Feeding System for Steel Casting Using Traditional and Simulation Technique- A Case Study

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## Abstract -

In metal casting there is always a compromise between the cost involved in the production of cast component and the quality required. Besides, it is always desired that the yield of casting is maximized against the volume of feeder/riser accommodated to meet the solidification shrinkage requirement. In this article an optimization framework is presented based on CAD and simulation. During metallurgical process, it induces casting defects like shrinkage, porosity and hot tears. To eradicate and eliminate these problems, appropriate design of casting and methoding is necessary. The problems can be predicted and prevented by means of computer simulation of casting solidification [7]. With practical approach oversized feeders have normally been designed and tested on shop floor. This consumes lot of time and resources. Thus, there is a need for computer aided optimal feeder design coupled with solidification simulation so as to reduce the no. of the shop-floor trials and obtain enhanced yield and high quality, in minimal possible time. The simulated results are more or less similar with experimental results [1]. The combined program enables foundry engineers to seamlessly carry out 3-D methods design, advanced coupled simulation, defects prediction, and casting optimization within an extremely user-friendly environment [3]

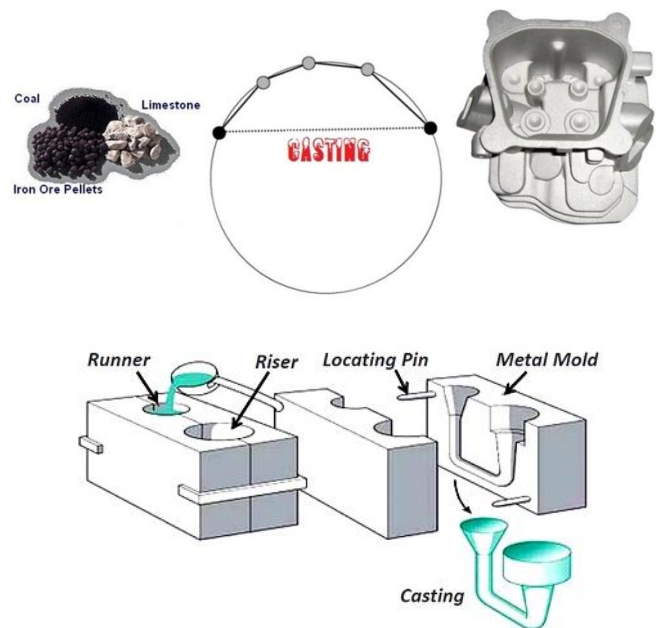
In this article experimentally it is observed that shrinkage cavity has shifted towards the feeder whereas it remained at the center of non-feeder part. Hence use of simulation helped in locating the optimum position and size of the feeder required [9]. It is concluded that the selection of proper feeder affects the quality of casting and from casting simulation casting products can be developed very fast and time required in development of cast parts will be less.

**Key Words:** Volumetric shrinkage; Casting simulation; Feeding system design; Hot Spot, Casting yield; and Optimum design.

## 1. INTRODUCTION

Traditional casting trade has a long history and until now it has been the basis of the entire mechanical industry [9]. Metal casting is one of the primary methods of producing bulk shapes. Very complex shapes can be cast from nearly every metal, making casting an extremely versatile

process. In short words it is the shortest distance between raw material and finished good. Castings are made in sizes that range from fractions of an ounce to hundreds of tons. Casting process is one of the earliest metal shaping techniques known to human being. It means pouring molten metal into a refractory mold cavity and allows it to solidify. The solidified object is taken out from the mold either by breaking or taking the mold apart. The solidified object is called casting and the technique followed in method is known as casting process. For making highly intricate jobs, a lot of time in making the perfect mold to the last detail so hardly any finishing work was required on the casting made from the molds.



**Fig-1.** Basic casting process elaborating a mold and casted component

## 2. LITERATURE REVIEW

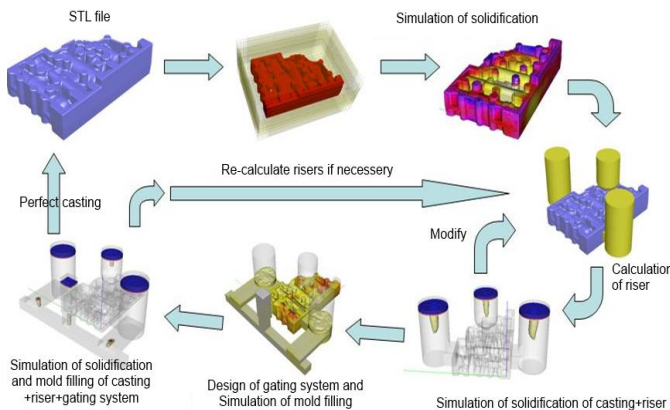
From the various literatures, it is found that numerical simulations of solidification have received considerable attention from researchers in the past.

Dr. B. Ravi presented various works related to casting simulation in the previous years some of which are:

Location of feeder and its shape selection, Framework of feeder design and optimization in order to maximize the yield and productivity against high rejection rate, Feeder neck proportions and a taper section so that modulus of the neck increases as it moves away from the casting. Moreover D Joshi, B Ravi in 2009, presented the classification and simulation based design of 3D junctions in casting wherein VEM was employed to predict the extent of shrinkage porosity defect and it was validated experiments. A benchmark part with 3D junction was also presented to show how simulation can be used to predict and prevent the defect by modifying the junction design.

Chvorinov in 1996 gave one of the earliest geometric based optimization efforts which was proposed on the modulus method and related it directly to solidification time of a casting. Wlodawer used Chvorinov's rule to design the feeders in such a way that the modulus (M) of the feeder is greater than that of the casting and must increase by 10% from the casting across the ingate to the feeder for ensuring adequate feeding. He proposed a relationship between casting, neck and feeder modulus as 1 : 1.1 : 1.2. Then Dr, Ravi & Srinivasan in 1996, proposed the Vector Element Method (VEM) which determines the feed path and location of hot spot inside the casting, using the direction of the largest thermal gradient at any point inside a casting to move along a path which leads to a hot spot (a local maxima of temperature with gradients tending to zero).

**3. METHADODOLOGY:**



**Fig - 2:** Web based Simulation methodology

A free ware web resource provided by E-foundry IIT Bombay is used for carrying out simulation on website <http://efoundry.iitb.ac.in>. Following steps are carried out for simulation and feedability analysis as shown in fig.2..

1. Preparation of 3D Solid model of cast part using CATIA R16 and saving it as a .STL file format.
2. Browsing and uploading the casting 3D model .stl file on [www.efoundry.iitb.ac.in](http://www.efoundry.iitb.ac.in)

3. Selection of proper cast metal and method of casting as sand/Die casting.
4. After waiting till the simulation results are displayed this will identify hot spots location.
5. Hence as per hot spot location riser/feeder size and location is decided.
- 6.3 D Modelling the part with feeder and saving as a .STL file.
7. Revise Simulation again and checking the location of hot spots.
8. If hot spots are not shifted inside feeders, repeated steps 4-6, till hotspot shifts to feeder and an optimized feeder size and location is decided which improves the casting yield.

**3. CASE STUDY:**



**Fig.3** Shrinkage defect over pulley

Above fig. 3 shows a pulley highlighting a shrinkage defect. The casting has, Volume of casting,  $V_c = 3.17 \times 10^9 \text{ mm}^3$ , Surface area of casting,  $S_{Ac} = 61000 \text{ mm}^2$ . A wooden pattern for the selected component is prepared. The various allowances so provided on the pattern for Steel casting are as follows:

**Table No.1**

Allowance type	Theoretical Allowance	Actual Allowance
Shrinkage	0.015 mm /mm	0.01 mm /mm

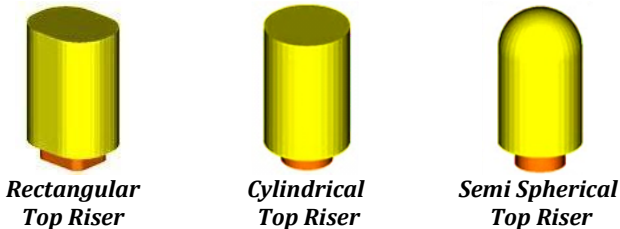
Initially design calculations were carried theoretically to find the various dimensions. Design calculations begin with calculation for pattern allowances followed by gating system and finally design of the feeder. Feeder design has been carried out using three different methods such as Caine's method,

**3.1 Feeder Design Using Caine's Method:**

Keeping in mind the various laid out rules for feeder design in the previous section and using Caine's method, the design of feeder is as follows:

The 'freezing ratio', of a mould is defined as the ratio of cooling characteristics of the casting to the riser.

$$X = \frac{\left(\frac{SA}{V}\right)_{\text{casting}}}{\left(\frac{SA}{V}\right)_{\text{riser}}}$$



In order to be able to feed the casting, the riser should solidify last and hence its freezing ratio should be greater than unity. It may be argued that the sphere has the lowest surface-area-to volume ratio and hence that it should be used as a riser. But in a sphere, the hottest metal being at the centre, it is difficult to use it for feeding the casting.

The next best is the cylindrical type which is most commonly used for its ease in moulding. Based on the Chvorinov's rule, Caine had developed a relationship empirically for the freezing ratio as follows:

$$X = \frac{a}{Y-b} + C \quad \dots \dots \dots \quad \text{Where, } Y = \frac{\text{Riser Volume}}{\text{Casting Volume}}$$

a, b and c are constants whose values for Steel are

0.10, 0.06 and 1.08 respectively.

- Volume of casting  $V_c = 3.17 \times 10^9 \text{ mm}^3$
- Surface area of casting  $A_c = 61000 \text{ mm}^2$
- Considering a cylindrical riser with  $H/D = 1$ ,

$$\text{Riser Volume} = \frac{\pi D^3}{4}$$

$$SA_{\text{riser}} = \text{Surface area of riser} = \pi D^2 + \frac{\pi D^2}{4}$$

Freezing ratio,

$$X = \frac{\frac{61000}{3.17 \times 10^9}}{1.25 \pi + \frac{0.25 \pi D^3}{3.17 \times 10^9}} = 3.84 \times 10^{-3} * D$$

$$Y = \frac{0.25 \pi * D^3}{3.17 \times 10^9} = 0.2477 D^3$$

Substituting the values of X & Y in Caine's relation, we get

$$3.84 \times 10^{-3} * D = \frac{0.1}{0.2477 D^3 - 0.06} + 1.08$$

By rearranging the terms and solving the above equation we get,  $D = 50.12 \text{ mm}$

Feeder neck dimensions due to geometry restrictions gives neck diameter,  $D_n = 35 \text{ mm}$

The empirical relations for top riser neck dimensions are:

- Length of neck,  $L_n = 15 \text{ mm}$

Modified surface area of casting due to neck placement .

$$SA_{\text{casting}} = 61000 - 0.785 * 35^2 * 35 = 60038.375 \text{ mm}^2$$

- New casting modulus is  $= \frac{3.17 \times 10^9}{60038.375} = 5.2799 \text{ mm}$

- Modulus of feeder,  $\frac{D}{6} = \frac{50}{6} = 8.33 \text{ mm}$

Here,  $M_f \geq M_c$ . Hence, design is safe.

Also,

$$V_f + V_n = 0.785 * 50^3 + 0.785 * 35^2 * 15 = 98537.12 \text{ mm}^3$$

$$\therefore \text{Casting Yield} = \frac{V_c}{V_f + V_n + V_c} * 100 = 60.12\%$$

Simulating the above results in E-foundry and optimizing the hotspots we have the final feeder dimensions as:

$$D = 50 \text{ mm}, D_n = 35 \text{ mm}, L_n = 15 \text{ mm}$$

Although modulus of feeder neck is less than modulus of casting, its effective modulus is always higher than the casting due to high heat transfer zone in the surrounding region of the neck.

### 3.2 Design of gating system components:

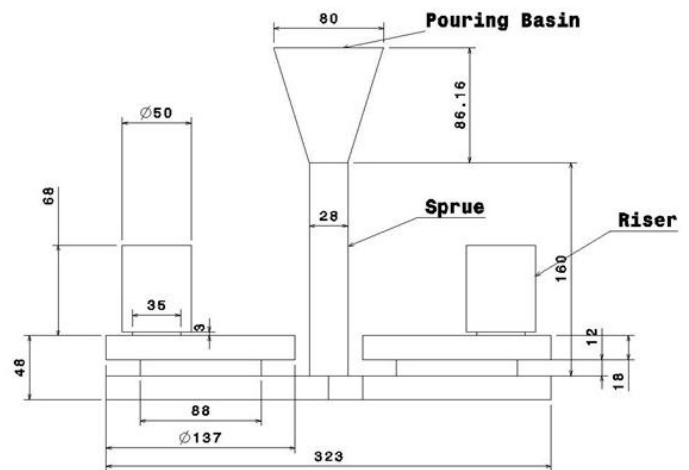


Fig. 4: Casting with designed gating and risering system as per Caine's method with riser of  $\phi 50 \text{ mm}$

The route path which molten metal follows to enter into the mould cavity is pouring basin to sprue to base well to runner to in-gates to mould cavity. The design of such path is as follows:

- Weight of casting,  $W = 5.448 \text{ kg}$
- Pouring time,  $t = \sqrt{W} = 2.17 \text{ s}$

Considering  $t = 10 \text{ s}$  .....approximately

Mass density of the molten metal,  $\rho_m = 7850 \text{ kg/m}^3$

Assuming top gating system with the entire sprue to be located in the cope itself,

Effective metal head (sprue height),  $H = 160 \text{ mm}$

Using Bernoulli's equation and considering  $10 \text{ mm}$  height for the pouring basin from the top of the cope,

$$\therefore \text{Sprue diameter} = 28 \text{ mm}$$

### 3.3 Virtual simulation using E-Foundry web tool:

By following steps enlisted in fig.2 and its description, Initially, the geometry was prepared in .catpart and was imported to '.stl' (stereolithography) format. The '.stl' file is then imported to 'Sim Lab' in E-foundry and then several iterations are simulated. The simulation is done with the following parameters:

- Metal=Steel
- Type of casting= Sand casting
- Sand Mesh= Fine

The simulation results with riser and without riser are shown as follows.

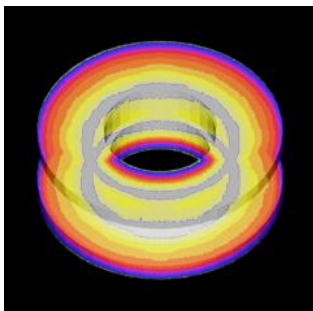


Fig. 3.3.1 Virtual simulation

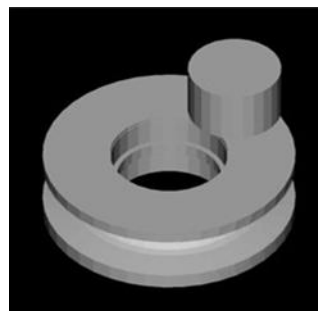


Fig. 3.3.2

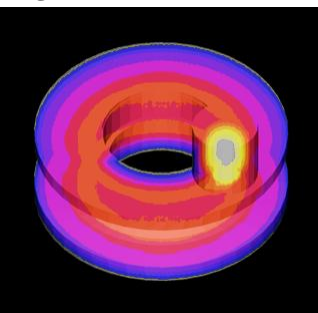


Fig. 3.3.3 Virtual simulation with D=40 mm

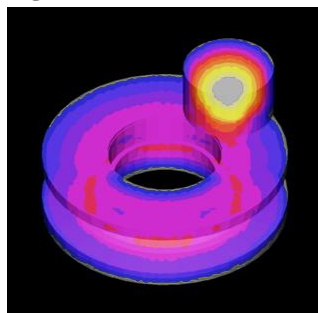


Fig. 3.3.4 Virtual simulation with D=50 mm

The temperature contours obtained from E-foundry for the selected area are shown in fig.3.3.1. These contours locate the hotspot region in the given geometry. Blue colour indicates early freezing regions in casting, and white yellow indicates hot spot. Different iterations of simulation are carried with different feeder diameters. [10]

### 3.3 Discussions on results of Virtual simulation:

Fig.3.3.1 indicates the solidification zone in casted component without feeder. It is seen that at the circumference of pulley a local hotspot formation (white colour) leads to unavailability of feed metal during solidification leads to shrinkage cavity of large volume.

Fig.3.3.3 indicates the solidification zone in casted component with the feeder of diameter D = 40 mm. It is seen that the hotspot is not completely removed from the

casting and has some hotspot zone left inside the casting. Indicated by dark yellow regions.

Fig.3.3.4 indicates the solidification zone in casted component with the feeder of diameter D = 50 mm. It is seen that the hotspot is completely removed from the casting and it is completely shifted to feeder.

## 4. EXPERIMENTAL VALIDATION OF RESULTS:

As per design steps based on the Chvorinov's rule, Caines method, feeder with diameter D =50 mm, diameter of neck Dn=35mm, and length of neck Ln =15 mm was selected and its effect on formation of hotspot was simulated as shown in fig.3.3.4.

This result and design of feeder is experimentally validated by carrying out traditional metal casting process sequence as shown in fig.5. These are discussed step by step as follows.

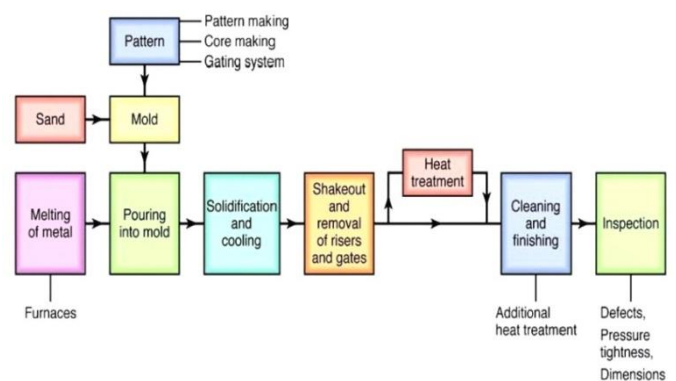


Fig.5 Basic sand casting process sequence

### 4.1 Pattern Making:

Pattern is a replica tool to create a cavity in sand after ramming sand around pattern. The mould cavity so designed and prepared is shown in the fig.6 below.

The casting is symmetrical about its horizontal axis hence a split pattern(cope and drag patterns) are prepared from wood .



Fig.6 Cope portion of wooden pattern

#### 4.2 Green sand preparation and Molding:



**Fig.7** Green Sand Preparation

**Table No.2**

Description of additives	Range
Grain Size	AFS 50 to 80
Green Compressive Strength	550 to 900 gm/cm <sup>3</sup>
Permeability	80-100
Moisture	2.5-6.5 %
Active Clay	6-12%

Green sand is mixture of sand and additives to impart green strength to mold as shown in fig.8. Molding consists of all operations necessary to prepare a mold for receiving molten metal. Molding usually involves placing a molding aggregate around a pattern held within a support frame, withdrawing the pattern to leave the mold cavity, and closing the mold. Green sand is prepared by adding following ingredients as shown in table no.2



**Fig.8**Cope and drag molding box assembly

#### 4.3 Melting and pouring:



**Fig.9**Melting and pouring using shank ladle

The preparation of molten metal for casting is referred to as melting. Melting is usually done in Induction furnace and the molten metal is poured in prepared molds by means of transfer ladle manually as shown in fig.9

#### 4.6 Shakeout, fettling and cleaning:



**Fig.10** Castings after Shakeout operation

The casting is separated from the molding sand referred as shakeout. Cleaning refers to all operations necessary to the removal of sand, scale, and excess metal from the casting. Defective castings are salvaged. Inspection of casting for defects and general quality follows.

#### 4.6 Inspections by destructive testing:



**Fig.11** Casting sliced mechanically to locate internal void

It is seen from the above cut-plane sections that casting is free from internal void. This indicates clearly that if appropriate amount of metal is available for the casting during solidification then shrinkage cavity can be eliminated.

This was predicted by the simulation and experimentally validated also.

### 3. CONCLUSIONS:

In this study, it was observed that a free of cost online virtual simulation tool available enables visualization of the progress of freezing inside a casting and identification of the last freezing regions or hot spots by identifying color coding. The application of casting simulation software in the foundries not only minimizes the wastages of resources like labor, material and energy but also enhances the quality and yield of castings, *Casting*

simulation is a powerful tool to visualize progressive solidification of molten metal inside a mold cavity.

It helps in locating the riser at proper location to achieve directional solidification. By carrying out casting virtual simulation, material, time and money can be saved which are required in Foundry shop floor trials. From casting simulation casting products can be develop very fast and time required in development of cast parts will be less.

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