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Casting Defect Analysis and Optimization Using Auto Cast Simulation Software

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Abstract: Casting defects are corrected in a variety of ways in the casting industry. Casting rejections in significant numbers are a waste of both money and time. Single defects in casting can have single or multiple reasons, thus identifying what's causing the fault is important. Modern technology of simulation has minimized wastages while also reducing defect rates. It will be useful to take a more controlled approach to identify, detecting, and controlling the main causes of an issue. The primary goal of this investigation is to provide detailed information on the several Front Hub component failures. The examination of Front Hub is described in this document, along with possible preventative actions. This research will help in improving Front Wheel Hub's production and quality.

Keywords* — *Casting Defect, Casting Simulation, Optimization.

I. INTRODUCTION

Casting is a complex process that involves important metallurgical and mechanical components. It is one of the most cost-effective production techniques used in industry. The microstructure is mostly determined by the rate of solidification, which in turn impacts mechanical qualities like as strength, hardness, and machinability. The location, size, and shape of risers in a casting depends on the shape, mold design, and heat of the casting, properties of the metal and other factor process parameters. Improperly designed riser and gate systems will always result in defective molds with shrinkage cavities or poor experimental results, which are always better for mold design and development and to achieve optimal process parameters. However, this can be expensive, time-consuming, and in some cases impossible. Therefore, the casting simulation process is a convenient way to properly design a riser system and analyze the effect of various parameters. The number of foundry simulation programs in India is also increasing day by day, as it essentially replaces or minimizes shop floor testing to achieve the desired internal quality in the maximum possible time. It can greatly reduce iterations on the shop floor and is mainly used for proof-of-concept.

Simulation programs generally increase the confidence of foundries when creating more complex castings (complex, large) with higher margins. It also provides a scientific and documented basis for quality assurance and certification.

II. LITERATURE

Ravi [1] studied the benefits of casting simulation, bottlenecks and best practices for overcoming bottlenecks without burial testing, they provided quality assurance and significantly minimize lead times to cast the first good sample. Naveen [2] discussed steps, which were included in the simulation, the possible sources of error, and the care that has to be taken during the time of the casting simulation process. According to him, the designer should have confidence in the casting simulation tools that are going to be used. The confidence level will come by experience and usage of the tool to mimic the effect of various process parameters. Prabhakara et al. [3] have studied on the solidification mold filling simulation of green sand casting, ductile iron casting sand, and using casting simulation software such as PRO CAST, it was concluded that defects such as shrinkage, porosity, etc. could be eliminated. It can also improve yield of the casting, optimize the gating system design & mold filling. Maria et al. [4] have described how casting simulation application has been one of the most beneficial as it helps in avoiding shrinkage scrap, improving cast metal yield, optimizing the gating system design, optimizing mould filling, and finding the thermal fatigue life of impermeant moulds. Several case studies have been done to demonstrate the use of tools under industrial conditions. Dabade and Bhedasgaonkar [5] carried out design of experiments and computer assisted casting simulation technique both are combined to analyse the sand related and methoding related defects in green sand casting. In their first method Taguchi based L18 orthogonal array has been used for experimental purpose and analysis was carried out using Minitab software for analysis of variance (ANOVA) and analysis of mean (AOM) plot. To get the

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shrinkage porosity to optimize level in casting part there were number of iterations performed with the help of casting simulation software. Reduced shrinkage porosity and increased yield as a result of the new gate and feed system. Kant Havel et al. [6] investigated chill performance on steel casting for investigation of chill performance using DOE and response surface method. The parameters were taken are chill distance, chill thickness pouring temperature & pouring time. Nandi [7] carried out stepped component by considering the purpose to study solidification behavior OR LM6 at difference size of riser neck, with the help of FEM based casting simulation software. They have also found that whenever the size of riser remains constant. They understand that effect of size riser neck on the solidification behavior of the aluminum alloy castings and the position and size of shrinkage defect in the casting changes at difference riser neck. Simulated results have more or less size experimental result. Choudhary et al. [8] observed incomplete fill because of a sudden variation in thickness. It has been compulsory to redesign and redevelop the component geometry without affecting its functionality by giving the required number of drafts and radius at the junction. They have made an attempt to carry out the whole process with the help of simulation and optimization in Auto CAST software. Joshi et al. [9] investigated on 3D junctions in castings simulation based on DFM analysis and guidelines, they have also found that the location of shrinkage porosity by casting solidification simulation and corrected by minor modification to part the design with the help of Autocast simulation.

III. METHODOLOGY ADOPTED BY AUTO CAST

To study the casting process of a hub and its casting defects, studied the casting process of hubs with their major casting defects. Then with the help of a 2D sketch, we can able to draw the 3D CAD model for the hub with the help of solidworks. Then convert that particular file into an STL file and then save it. Browse and upload the casting model file in the software and then as per the requirement for properties and composition should be provided. As per the mold, the box size should be provided 610 x 508 x 400. Then before providing the feeder, neck, and sleeve we should check the hotspot reason then only we can be able to design as per it. Hotspots are the last solidifying reason for the casting. After the identification of the hotspot then provided the neck and feeder in bor the reason for the hub. Identify hotspots then according to it start designing the design for the neck and feeder. Check whether the hotspots are shifted inside the neck and feeder if not then repeat it 4 to 6 times. After that provide an exothermic sleeve of the thickness of 10mm. Due to this, it helps to retain the heat for a longer time. It is effectively increasing the thermal modulus and there by solidification time. After that mold filling gets started from 1 to 100 percent, in which we can see how the filling is done. After that check, the solidification of temperature and how much amount of temperature is acted for a particular reason. Ravi [1] has suggested casting simulation and optimization methodology as shown in figure 1.

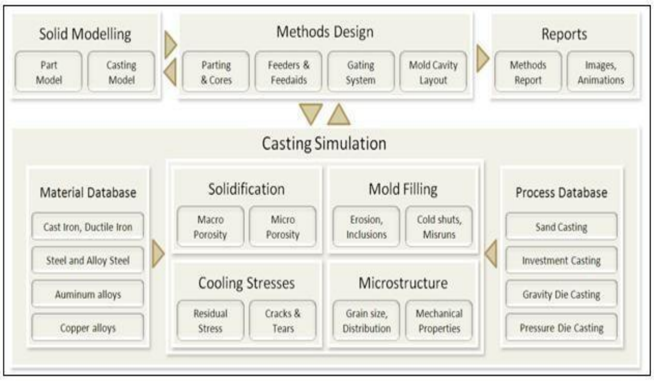

Fig-1: Flow chart of simulation formulation [1]

A. COMPONENT DETAILS: -

The Front Hub is selected for casting simulation as shown in figure 2. It is made up of material ductile iron. The pouring temperature is considered as 1550^0C for the same.

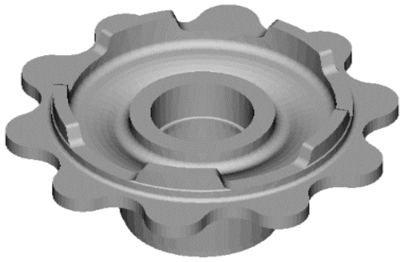

Fig -2: Front Wheel Hub

B. PRINCIPLE OF OPERATION: -

There are some phases in a casting simulation project:

1. Data collection: This is the most important step and accurate and complete data will lead to accurate modeling and conclusions. You must first define the problem and determine the need and type of modeling.
    a) Improving quality or productivity
    b) Rapid development of new casting designs
    c) Input data required for modeling
    d) CAD model of casting is cast part

2. Method design data including details of mold separation, feeder, gating system, cavity, and feeder. Design and Modeling Methods. Solid modeling of the design method is performed at this stage, converting the casting model into a three-dimensional model of the mold containing the feeder, gate, core, and feeder as well as cavities for the part.

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3. Numerical simulation: This step first requires some important data input as it is the creation of a proper mesh containing the entire model. Second, various boundary conditions such as heat transfer coefficient. The simulation run depends on the function module [2].

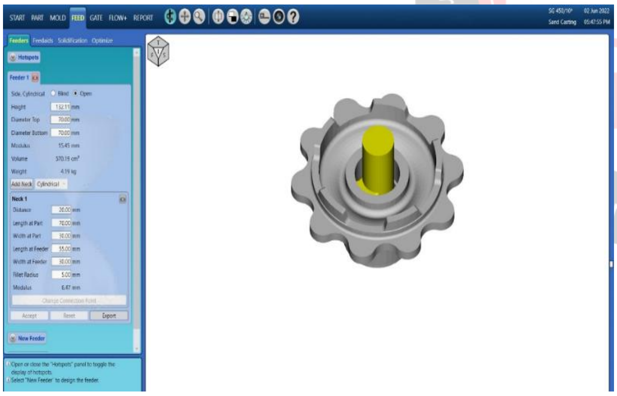
From the table 1, Process parameters has been mentioned which are used during the simulation.

Table 1: Process Parameters

Title	Details
Casting Material (Grade)	Ductile Iron (SG 450/10)
Pouring Temperature	1525-1550 °C
Pouring Time	12-15 sec
Riser Type	Open Type
Box Size	610 x 508 x 400

IV. METHODOLOGY

Simulation-based trials do not waste material, energy, or labour, and do not hold up regular production. Computer simulation gives a better understanding of the casting process, allowing for the detection of defects problems and the manufacture of defect-free castings. Thus, numerical simulation of casting can be considered as an important method to make casting technique change from experience test to science guidance. It necessitates the use of a standard. STL file for the methods layout. The use of correct boundary conditions, on the other side, leads to accurate simulation results.



Side, Cylindrical ○ Blind ● Open
Height 132.11 mm
Diameter Top 70.00 mm
Diameter Bottom 70.00 mm
Modulus 15.45 mm
Volume 570.15 cm³
Weight 4.19 kg

Neck 1
Distance 20.00 mm
Length at Part 70.00 mm
Width at Part 30.00 mm
Length at Feeder 55.00 mm
Width at Feeder 30.00 mm
Fillet Radius 5.00 mm
Modulus 6.47 mm

Open or close the "Hotspots" panel to toggle the display of hotspots.
Select "New Feeder" to design the feeder.

Fig-3: Existing Gating System in Industry

This is the gating system being used in industry, as shown in figure 3, although it is producing several defects. Shrinkage Porosity, which is seen in huge quantities, is one of the major Problem.

Fig- 4:(a) Front view **Fig-4: (b)Top view**

This is when shrinking porosity at the bore reason has been detected in figure 4. The current yield is approximately 88.23% as shown in table 2. So, using simulation techniques, we will try to adjust the location, size, and form of the existing gating system in order to optimize the result and improve the yield.

Table 2: Existing gating System

Criteria	Existing gating system
Feeder dimension	Feeder Diameter- (top and bottom) is 70mm, feeder height - 132.11mm.
Quality	Defect is plotted near bore reason.
Yield	88.23%
Remark	Not good

A. *TRIAL NUMBER 1*

Fig-5: Importing the Model of the front hub into Autocast simulation software

Import the 3D model into the software environment. Parts are modeled in Solid Works CAD software and converted to an STL format suitable for modeling. Import the casting model in STL format into the modeling environment as shown in figure 5. The parts change orientation depending on the layout. This will orient the part according to the layout position in the template.

Selection of casting with material and pouring temperature. The required composition of the metal matrix is added as per the foundry chart as shown in the table 3.

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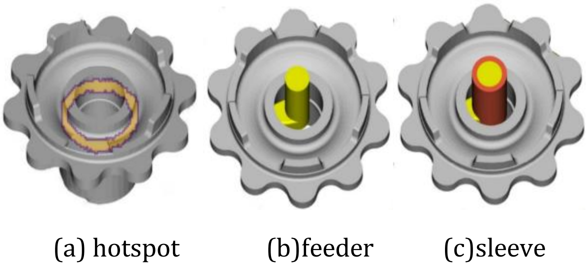
Table 3: Composition of material used by foundry

Carbon (C)	3.42 %
Chromium (Cr)	0.04 %
Iron (Fe)	93.48 %
Magnesium (Mg)	0.20 %
Manganese (Mn)	0.19 %
Molybdenum (Mo)	0.05 %
Nickel (Ni)	0.05 %
Phosphorus (P)	0.04 %

Density	7100.00 kg/m³
Density Liq	6900.00 kg/m³
Solidus Temp	1140 °C
Liquidus Temp	1161 °C
Pouring Temp	1550 °C
Liq-Sol Shrinkage	3.50 %
Latent Heat	272.00 kJ/kg



(a) hotspot (b)feeder (c)sleeve

Fig-6: (a), (b), (c). Identification of hotspot and providing sleeve

i) Hotspots Before Gating System and Creation of Riser Inside the Software-

The possible hotspot is predicted from the casting geometry based on thickness at different sections. The feeder or riser is attached according to the hotspot areas suggested in the software. The sleeve is attached to the feeder as it reduces the heat transfer and improves the efficiency of the feeder. The sleeve is 10 mm in thickness and exothermic as shown in the figure 6.

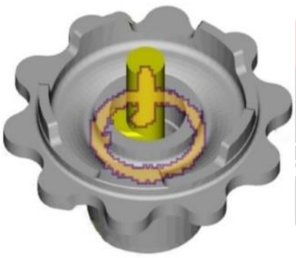


Fig- 7: Migration of Hotspots in the feeder

The hotspot is again checked after adding the feeder and sleeve. Now the hotspot is shifted into the feeder as shown in figure 7. The mold is created in the simulation environment automatically based on the overall geometrical sizes of the casting layout.

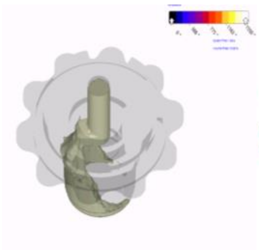


Fig- 8: Mould Filling

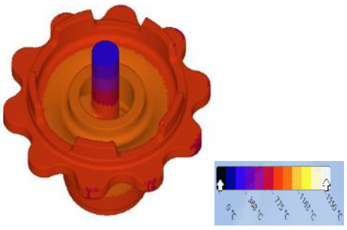


Fig- 9: Mould Solidification

ii)Filling of Casting Layout and Flow Simulation and Solidification of Casting -

The filling point is given and then the filling in the simulation environment starts for given boundary conditions as shown in the figure 8. After completion of the filling and solidification, the solidified view of the layout is visible with a color code for temperature distribution shown in figure 9. The liquid fraction criteria are used for identifying the last solidifying regions in the layout.

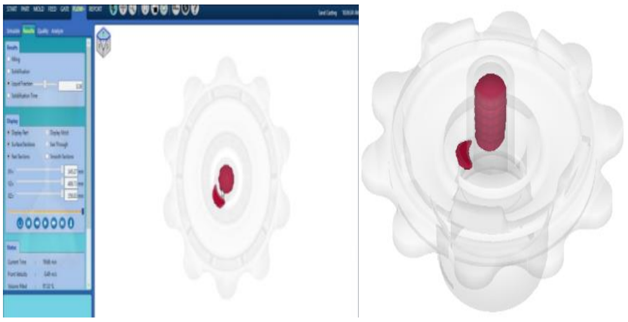


Fig- 10: Shrinkage Porosity Defect

The results are plotted after the completion of the simulation. The figure 10 shows the liquid fraction criteria in the layout. The red color identifies the location of shrinkage in the layout. As per the results, shrinkage is observed in the ingate and feeder. The shrinkage is eliminated from the casting. But the shrinkage is observed near the ingate so there might be chances of occurring defect nearby it.

B. TRIAL NUMBER 2-

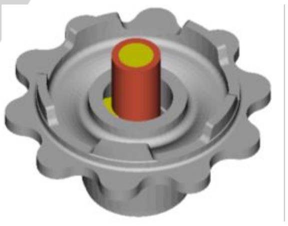


Fig- 11: Modified gating system

As shown in the figure 11 is modified from the existing and the feeder and sleeve are provided at the central location. The yellow portion indicates the feeder and the red portion indicates the sleeve. The chemical composition as per the requirement can be given in the simulation. The composition with carbon, phosphorous, manganese, etc. is kept constant.

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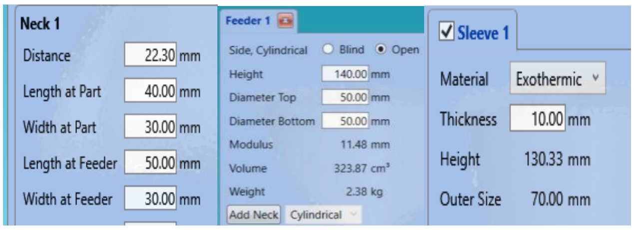
Table 4: Details of the neck, feeder, and sleeve



Neck 1

Distance	22.30 mm
Length at Part	40.00 mm
Width at Part	30.00 mm
Length at Feeder	50.00 mm
Width at Feeder	30.00 mm

Feeder 1

Side, Cylindrical ○ Blind ● Open

Height	140.00 mm
Diameter Top	50.00 mm
Diameter Bottom	50.00 mm
Modulus	11.48 mm
Volume	323.87 cm³
Weight	2.38 kg

Add Neck Cylindrical

☑ **Sleeve 1**

Material	Exothermic
Thickness	10.00 mm
Height	130.33 mm
Outer Size	70.00 mm

After importing the CAD model and applying boundary conditions the feeder is attached to the neck at the central location as shown in the figure 11. The exothermic sleeve with 10 mm thickness is provided on the feeder. In actual condition, only a sleeve is provided on the ingate area in the mold. The details of the neck, feeder, and sleeve are shown in table 4.

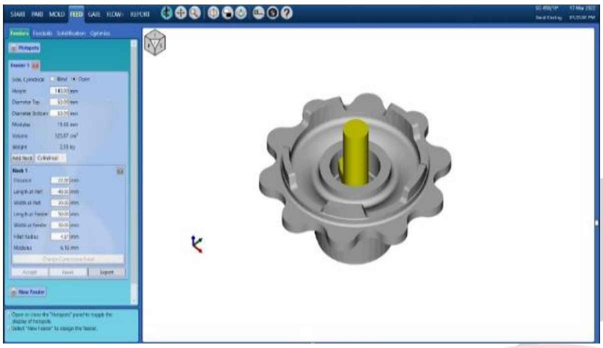


Fig-12: Changes made in height of the feeder

As we tried to change the height and decided to increase it up to 140mm. To check that we can get a better result, as compared to that of the first trial so we tried to increase the height of the feeder. The yellow color portion is the feeder where its height is 140 mm and its top and bottom diameter is 50 mm as shown in figure 12.

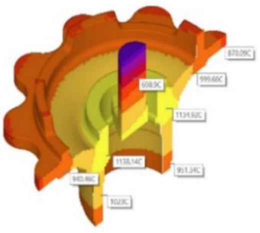


Fig-13: Mould Solidification

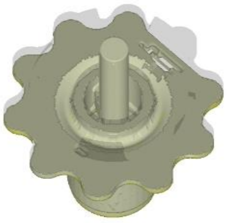


Fig- 14: Mould Filling

i) Filling of Casting Layout and Flow Simulation and Solidification of Casting-

The figure 13, indicates the solidification temperature behavior, various color indicates how much amount temperature has been acting for a particular reason. In the figure 14, shows the filling point is given and then the filling in the simulation environment starts for given boundary conditions.

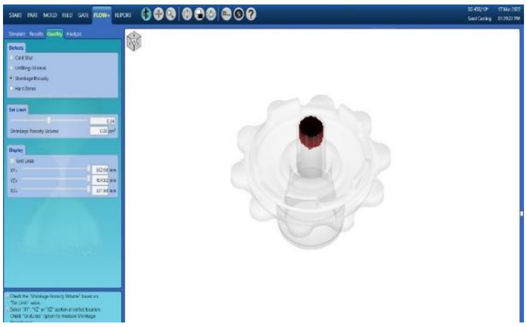


Fig-15: Defect location of Shrinkage Porosity

The figure 15, it shows the liquid fraction criteria in the layout, as we can see that shrinkage porosity has been observed in the feeder topmost part. Also, the defect reason shows at the sleeves and feeder reason. Where we can say that the defects get eliminated from the casting. Also, the better result as compared to that of the first trial. But the problem is that due to the increase in the height of the feeder, the feeder gets out of the box (cope and drag) otherwise they have to do change in the parting line, and also the cost gets increased.

ii) Problem in Trials 1 And 2-

1) In the first trial, the last solidifying region was found in a location other than the casting area. The red colour indicates where shrinkage has occurred in the layout. Shrinkage is seen in the ingate and feeder, according to the findings. The shrinkage in the casting is eliminated. However, there is a potential of shrinking at the bore.

2) As per the second trial, we can see that shrinkage porosity has been observed in the feeder topmost part. Also, the defect reason visible at the sleeves and feeder reason. Where we can state that the defects get eliminated from the casting. Also, the better outcome of the result as compared to that of the first trial. Because of the increasing in height, we should adjustments in the box and the parting line must be made, which increases the cost.

iii) Suggestion –

The result of the first two trials was not much satisfying, so we tried to take another trial with a change in diameter of the feeder at the top and bottom. Also, some changes were made in the ingate that is located near the neck reason. The result will be compared to the new dimension.

iv) Final Trial –

Fig-16: Modified gating system

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In the third trial, we increased the diameter of the feeder as shown in figure 16, rather than increasing the height of the feeder, so there did not have any difficulty in adjusting the parting line or changing the cope and drag.

Table 5: Modified dimensions

Feeder 1
Side, Cylindrical ● Blind ○ Open
Height 132.11 mm
Diameter Top 60.00 mm
Diameter Bottom 60.00 mm
Modulus 13.47 mm
Volume 442.99 cm³
Weight 3.25 kg
Add Neck Cylindrical

Neck 1
Distance 22.00 mm
Length at Part 40.00 mm
Width at Part 35.00 mm
Length at Feeder 50.00 mm
Width at Feeder 35.00 mm

☑ **Sleeve 1**
Material Exothermic
Thickness 10.00 mm
Height 97.11 mm
Outer Size 80.00 mm

As we can see in the table 5, the diameter for the feeder at the top and bottom is provided at 60mm as in the previous two trials it was about 50 mm. Also, some changes were made at the neck reason.

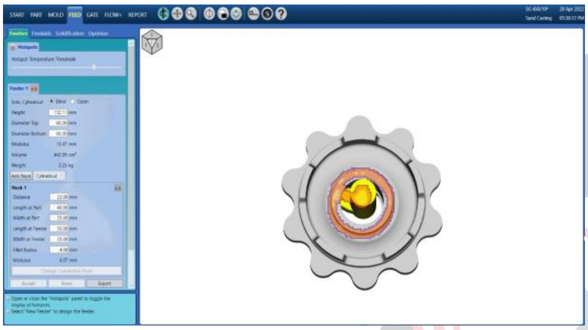

Fig-17: Shifted position of hotspot during solidification

Before providing the feeder and sleeve we should check the location of casting defects, which will help us to locate the feeder and ingate close to the hotspot's areas. After that, we have to check whether the hotspot is shifted in the neck and feeder reason so that simulation is correct. So, check it before providing a sleeve to it. As shown in the figure 17, our hotspot is shifted to neck and feeder reason.

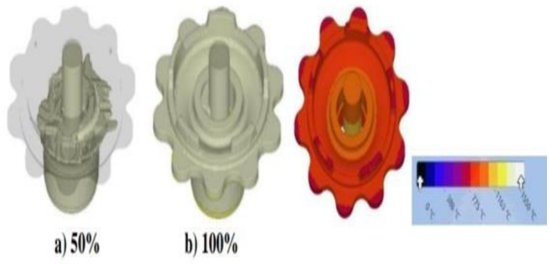

Fig-18: Shows the mold filling at different stages

The layout is then simulated with given boundary conditions such as pouring temperature, pouring time, material composition, etc. After completion of filling and solidification, the solidified view of the layout is visible with a color code for temperature distribution as we can see in figure 18. When we simulate the layout, it shows how solidification is done in actual and at various sections shown the temperature colors code. When we see the temperature at the hollow section there will be a lower temperature.

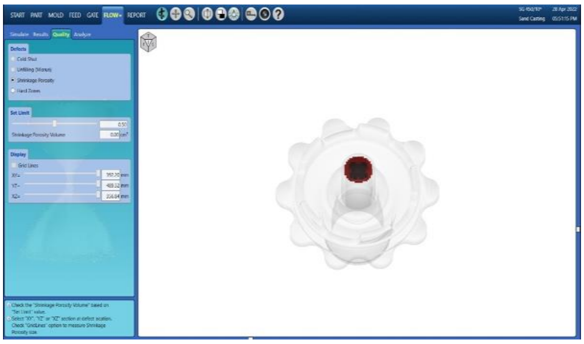

Fig-19: Defect eliminated of Shrinkage Porosity

The figure 19, shows the liquid fraction criteria in the layout, as we can see that shrinkage porosity has been observed in the feeder reason. We can say that the defects get eliminated from the casting and it is an ok part now.

v) Improved Result-

Trial 3 shows an improvement over the prior two trials, as evidenced by the fact that the result is better. This also means there are no shrinkage defect in the casting. As a result, this is the best compromise between the other two options.

V. RESULT AND DISCUSSION

a. As per the first trial, the last solidifying region is observed in the region other than casting. The red colour identifies the location of shrinkage in the layout. As per the results, shrinkage is observed in the ingate and feeder. There may be chances of shrinkage near bore.

b. As per the second trial, we can see that shrinkage porosity has been observed in the feeder topmost part. Also, the defect reason shows at the sleeves and feeder reason. Where we can say that the defects get eliminated from the casting. Due to the increase in height changes has to be done in the box and also in the parting line should be changed, where cost gets high.

c. As per the third trial, liquid fraction criteria in the layout, as we can see that shrinkage porosity has been observed in the feeder reason. We can say that the defects get eliminated from the casting and it is an ok part now. The results obtained at various trials are as shown in table 6.

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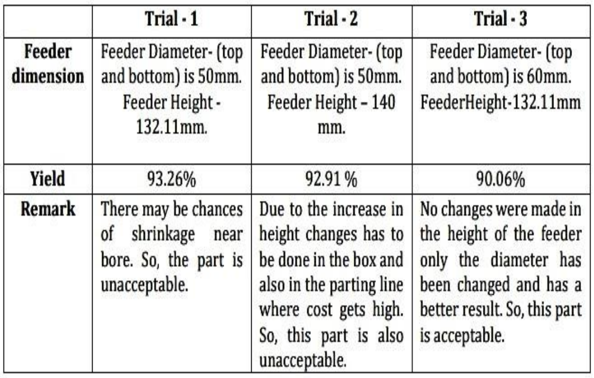
Table- 6: Details of Trials



	Trial - 1	Trial - 2	Trial - 3
Feeder dimension	Feeder Diameter- (top and bottom) is 50mm. Feeder Height - 132.11mm.	Feeder Diameter- (top and bottom) is 50mm. Feeder Height – 140 mm.	Feeder Diameter- (top and bottom) is 60mm. FeederHeight-132.11mm
Yield	93.26%	92.91 %	90.06%
Remark	There may be chances of shrinkage near bore. So, the part is unacceptable.	Due to the increase in height changes has to be done in the box and also in the parting line where cost gets high. So, this part is also unacceptable.	No changes were made in the height of the feeder only the diameter has been changed and has a better result. So, this part is acceptable.

VI. CONCLUSIONS

- In this study, solidification simulation provides for observation of the progress inside a casting as well as identification of the last hotspots' reason. The use of a well-designed gating system has greatly helped in obtaining directional solidification.
- By using the AutoCAST-X software, gating was applied in the final solidifying region. This method has helped to reduce solidification-related faults, resulting in a defect-free casting. The result is better for trial 3 as compared to that of the existing gating system, and the defect is eliminated. There is also an improvement in yield.
- Minor changes to existing large-scale castings can significantly reduce the amount of materials, energy, equipment, and labour used. Inspection and repair of massive, heavy castings throughout development can be costly, thus modeling is important.

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