A PRACTICAL APPROACH TO ELIMINATE DEFECTS IN GRAVITY DIE CAST AL-ALLOY CASTING USING SIMULATION SOFTWARE

S. Ferhathullah Hussainy[1], M. Viquar Mohiuddin[2], P. Laxminarayana[3], A. Krishnaiah[4], S. Sundarrajan[5]

[1]*Professor, M.E.D., MJCET, Telangana, India.*
[2]*Associate Professor, M.E.D., MJCET, Telangana, India.*
[3,4]*Professor, M.E.D., Osmania University, Telangana, India.*
[5]*Director, National Institute of Technology - Tiruchirappalli, India.*

Abstract

This paper deals with elimination of defects in aluminium alloy castings produced by gravity die casting process. The main intention of work is to investigate the defects and improve quality of a gravity die cast component using Computer Aided Casting Simulation Software. In this study an industrial gravity casting die is used which was producing defective components. The die and components produced by the die are studied to eliminate the defects using virtual simulations. The defects in the components are identified to be solidification shrinkage, cracks, unfilled riser and incomplete mould cavity. The reasons for the defects are analyzed as either improper selection of process parameters, or improper design of gating and risering system. SOLIDCast simulation software is used for simulating the solidification process of casting and visualizing outputs showing possible problematic areas or defects which may occur in the cast product. The work is carried out in two stages. In first stage, few test castings are produced by modifying the process parameters (pouring temperature, pouring time, pre heat and alloy type) and results are compared with simulation results produced using same parameters. The pouring and simulation results are observed to be in good accordance with each other. In second stage, number of virtual iterations of casting is performed by changing riser dimensions. It was found from the simulation results that riser with 35mm diameter is required to produce casting with zero defects. The die is modified accordingly with the simulation results and metal is poured. The castings produced are observed to be sound and contain no defects; and also it is verified that solidification simulation helps in locating the defects, eliminating them and ultimately improving the quality of castings without any shop-floor trails.

Keywords: *Aluminum-Alloys, Casting Defects, Gravity Die Casting, Material Density and SOLIDCast Simulation*

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1. INTRODUCTION

Casting is one of the most economical processes in manufacturing industry to produce metallic components. The process of producing a new casting in a foundry begins with receiving design from a customer, which includes dimensions, tolerances, type of material, surface finish, strength, etc. The foundry engineer designs the gating and risering system for the casting. The time spend in designing and re-designing the gating and risering system might take few days or up to several weeks, depending upon the complexity of the casting, before sound castings are made.

In the past, the foundry man has strived for ways to improve the casting process and eliminate the defects that occurred in the castings by trial-and-error, and his past experiences. Scientists throughout the years have studied the science of casting and metallurgy and developed theories and mathematical models to explain the properties of metals while going through the solidification process. Casting simulation programs are developed from these methods which are useful in predicting how the casting will come out. Defects and problems can be discovered before the actual product is cast avoiding costly trails to prevent the defects [3].

In the present scenario, the use of casting simulation software is increasing day by day in Indian foundry industry and essentially replacing or minimizing the shop floor trials to attain sound castings. The casting simulation technology has sufficiently matured and has become an essential tool for casting defect troubleshooting and method optimization. It enables quality assurance and high yield without shop-floor trails, and considerably reduces the lead time for the first good sample casting. Productivity is improved, higher value castings can be taken up, and internal knowledge can be preserved for future use and training new engineers [2].

In this work, an attempt has been made to investigate the reasons for the defects occurring in the gravity die cast components and resolve them using Computer Aided Casting Simulation Technique along with experimental validation.

2. LITERATURE REVIEW

Years after the development of casting simulation programs, virtual simulations of castings have now stepped into the maturity. Many new techniques have emerged and lot of work is going on to test the results of simulation experimentally. Some of the related works are acknowledged here. T. R. Vijayaram. et. al. [4], in their work discussed about the simulation process of casting solidification with the aid of an example, which will help the foundry engineers to optimize the design parameters, understand the temperature history of solidifying casting, and identify hot-spot region with the aid obtained from time-temperature contours. D. Kakas [5], observed a complex shape piston casting produced in foundry with a considerable scrap loss due to porosity. During production there are some solidification problems, due to the poor feeding of the thinnest part of the piston wall, where the copper chills are applied. The idea was to investigate the influence of variety casting parameters and casting design by computer simulation. A. P. Wadekar et. al. [6] in their research work have taken a Compressor Housing and performed casting simulation with the help of high end package. It is seen that designer can easily identify various defects of casting before actual production starts, this helps to reduce rework and finally produces good quality product in minimum time. Adnan S. Jabur [7] has given details of how to predict the shrinkage cavities of Al-Si castings by using the solidification simulation software. . S. G. R. Brown et. al. [8] detailed the use of visualization techniques for a complete design process for a generic automotive component. Their work was to redesign a generic automotive component considering both the stress related and solidification related design problems simultaneously. Filling and solidification of the designs were simulated using MAVISFLOW. D. R. Gunasegaram et. al. [9] in their paper have given details of vital process parameters affecting the size and location of a shrinkage pore defect in an aluminium alloy permanent mould casting of varying section thicknesses. The foundry achieved a reduction of more than 13% in its annual scrap rate for the casting involved. V. R. Maniar et. al. [10] in their paper have applied casting simulation software PROCAST to visualize complete solidification process which was not possible during real casting. Defects such as shrinkage, porosity, gas porosity, unfilled mould, cold shut etc. were graphically observed. T. Nandi et. al. [11] in their paper has optimized riser size of LM6 aluminum alloy by using conventional method and computer aided casting simulation software. They have considered plate casting with different riser sizes to study solidification behavior of the alloy used. N. A. Dukare et. al. [12] has optimized a gating system by using MOULDFLOW software. Objective of their work was to optimize gating/riser system design based on CAD and simulation technology with the goal of improving casting quality such as reducing incomplete filling area, decreasing large porosity and increasing yield.

3. CASTING SIMULATION

Casting simulation software can predict where and what defects might occur in a casting so the time and material used in the trial stage may be reduced. The casting process simulation is temperature and time dependent program. Freezing of castings is a non-linear transient phenomenon and involves modification of phase with liberation of latent heat from an affecting liquid-solid boundary. The casting process simulation programs consider the thermo physical data of the alloys and suitable boundary conditions data as an input and helps in predicting the defects by observing temperature distribution or hot spots in the castings. The casting simulation programs have different approaches in calculating and predicting the outcome of a casting. Each method hold advantages and disadvantages compared to other. Few casting simulation methods are mentioned below:

1) Numerical Approach.
   - Finite Element Method (FEM).
   - Finite Difference Method (FDM).
2) Geometrical Approach.
   - K-Contour Method.
3) Computer Wave Front Analysis.
   - Pour-out Method.
   - Cubic Spine Functions.
4) Mesh less Method.
5) Grid-based simulation system.

In this study SOLIDCast software is used to carryout casting process simulation. It is a program which simulates the solidification process of castings using Finite Difference Method. This software has been developed by Finite Solutions Inc., USA.

3.1 Steps in Casting Simulation

Steps involved in casting simulation using SOLIDCast software are as follows:

1) Select Materials: Casting Alloy, Mould Material and Boundary Conditions.
2) Create a 3D Model: Import STL files from CAD system or create 3D shapes within SOLIDcast.
3) Mesh the model.
4) Run a simulation:
   - SOLIDCast simulation.
   - FLOWCast simulation.
5) Plot simulation results.
6) Decide whether to redesign/rerun the simulation.

3.2 SOLIDCast Simulation

SOLIDCast is a casting simulation software program which can simulate thermal changes and heat transfer in the solidification process of a casting. It assists the user to visualize the solidification process of a particular casting. The program offers functions to help guide a user in producing gating and riser designs. It also has functions which produce visual outputs showing possible problem areas and defects which may occur in a casting. It can help shorten the lead time and reduce the loss in the trial casting stage.

3.3 FLOWCast Simulation

FLOWCast is the fluid flow modeling module for mold filling simulation, which works in conjunction with the SOLIDCast modeling system. It simulates the flow of liquid metal into a mold, along with the cooling of the metal and heating of the mold. It has two modes - Quick Simulation and Full Simulation. Quick simulation is a fast-filling algorithm, where as Full Simulation is a full CFD simulations of fluid flow. It uses the meshed SOLIDCast model to run its simulation and displays the temperature, velocity and pressure during the fill.

4. EXPERIMENTAL PROCEDURE

The following steps were performed during gravity casting process:

- Melting of aluminium
- Degassing
- Coating of die
- Clamping of die
- Preheating the die
- Pouring of metal
- Cooling and solidification
- Cleaning and inspection

4.1 Dimensional Details

Figure shows the dimensional details of 3D model of the product developed using SolidWorks modeling software and imported to SOLIDCast simulation software and assembled with gating and risering system.

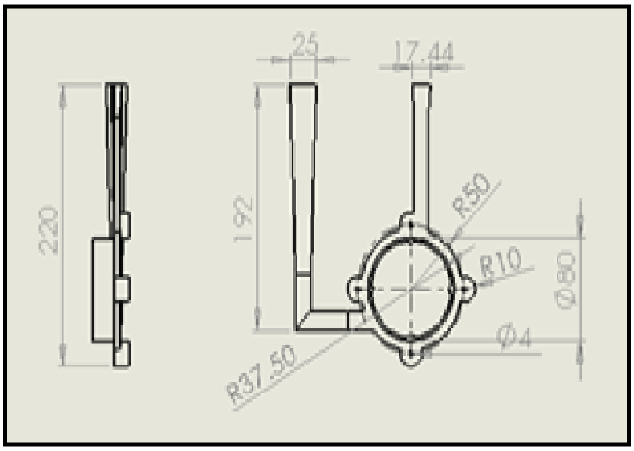

Fig-1: Dimensions of casting with gating and risering

4.2 Gravity Die Casting Mould

The mould for gravity die casting is of two plates with parting line in vertical plane having mould cavity with gating and risering system machined on it.

Fig-2(a): First plate of the mould

Fig-2(b): Second plate of the mould

4.3 Casting Materials

The chemical compositions of LM6 and LM25 aluminium alloys used are given in the Table-1. Finally the component has to be cast by any one of the two alloys; hence both the alloys are considered in the study for the purpose of simulation and experimentation.

Table-1: Chemical Composition.

%Wt.	LM-6	LM-25
%Si	12.72	6.29
%Mg	0.08	0.34
%Fe	0.72	0.70
%Mn	0.20	0.33
%Cr	0.02	0.01
%Cu	0.29	0.05
%Pb	0.03	0.02
%Zn	0.21	0.05
%Ni	0.03	0.01
%Al	85.6	92.1

Large quantities of sand and permanent mould castings are made from Al-Si alloys such as LM6, LM25 etc., in LM25 (Al-7Si-0.3Mg) small additions of magnesium induce significant age hardening through precipitation of Mg-Si in the aluminium matrix. Aluminium-Silicon alloys have high fluidity because of the presence of relatively large volumes of the Al-Si eutectic. The advantages of Al-Si alloy castings are high resistance to corrosion, good weldability and moreover, silicon reduces the coefficient of thermal expansion.

5. METHODOLOGY

The actual production is quite complicated as castings are associated with many defects. To produce good quality castings it is essential to identify the defects, understand the causes for the defects, find the remedies, and work on it to eliminate them. Defects in the produced components are identified as solidification shrinkage, cracks, unfilled riser and incomplete mould cavity. One of the reasons for solidification shrinkage is improper riser dimensions meaning that there is no available liquid metal in the riser to feed the casting when it is solidifying. Cracks are due to stresses developed during solidification as complete metal mould is acting as a chill. Unfilled riser and incomplete mould cavity occurs due to the loss of fluidity in the metal because of chilling effect of the mould and air entrapment. Molten metal is loosing heat while flowing through the gating system, mould cavity, risering system and solidifying in the way before completely filling the mould. Hence to eliminate these defects and produce quality castings, the experimental trails are to be performed either by varying the process parameters like pouring temperature, pouring time, alloy type and preheat temperature; or by redesign the gating and risering system; or maybe both.

The experimentation in this paper is explained in two stages. In the first stage experiments are conducted by varying the process parameters and practical experiments are compared with virtual trials. In the second stage virtual trials are carried to determine the correct riser dimensions suitable for the casting. The results of simulations are then compared with that of experimentation for the purpose of validation.

5.1 Stage-1

In first stage, few test castings are produced by changing the process parameters to check whether the defects are eliminated or getting minimized by change in process parameters. The Gravity die casting process parameters include: casting material, mould material, pouring temperature, pouring-time, preheat and die coating. Aluminium alloys LM6 and LM25 were used as casting materials; the material for the mould was Low Carbon Steel. The literature suggests that the optimum pouring temperature for gravity die casting is 720^{o}C, hence all the castings were poured at 720^{o}C (et. al. Zaid). Pouring time was approx. 3 seconds based upon shape and size of the casting. The mould was preheated at 200^{o}C and 250^{o}C. Sodium silicate + chalk powder is used as die coat as it was commonly used in industries. The practical experiments were conducted by varying parameters as given in the Table-2.

Table-2: Process Parameters & Expt. Results for Stage-1.

Trail	**Material (Al-alloy)**	**Preheat (^{o}C)**	**Expt. Results** (Sound/Defective)
1	LM6	200	Defective
2	LM6	250	Defective
3	LM25	200	Defective
4	LM25	250	Defective

5.1.1 Simulation Studies

After the experimental trial the virtual trial was conducted in SOLIDCast simulation software by using the same parameters as used in experimentation. Casting materials used are LM6 and LM25; the material for the mould was Low carbon steel. The Heat transfer coefficients (HTC) used for the alloy type LM 6 and LM25 in virtual trails are given in the Table-3:

Table-3: Heat Transfer Coefficients for virtual trials.

HTC Between	**LM 6** (W/m^2-k)	**LM 25** (W/m^2-k)
Casting - Riser	56784	41832
Casting - Ambient	8.5	6.4
Casting - Mould	1135.5	1777
Riser - Ambient	8.5	6.4
Riser - Mould	709.8	588
Ambient - Mould	45.4	45.4

3D models of the cast product, gating system, and risering system are created using SolidWorks CAD software and STL files from CAD system are imported in SOLIDcast program. If CAD files are not present, 3D shapes can also be created within SOLIDCast. After model is imported, it is meshed to run a simulation using SOLIDCast and FLOWCast. Moreover, the mold is created automatically around the casting when mesh is generated. Sample images of meshed casting, mould, SOLIDCast simulation and FLOWCast simulation are shown in the Figures 3-6.

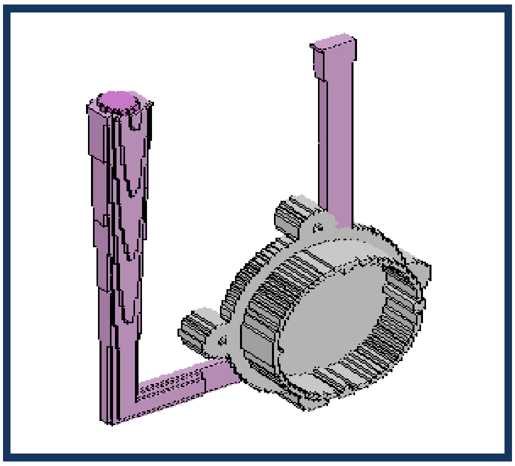

Fig-4: Meshing of Mould

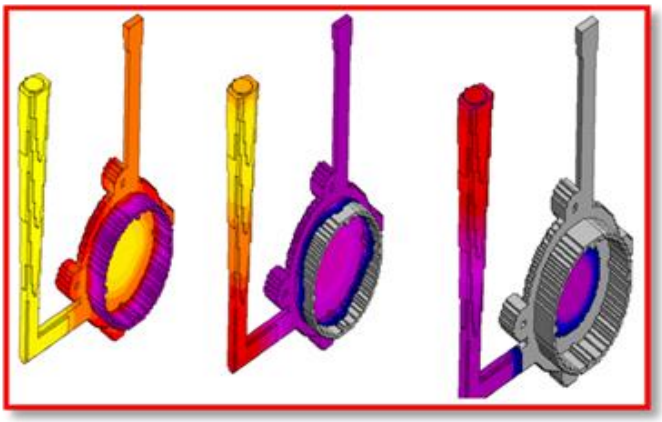

Fig-5: SOLIDCast Simulation

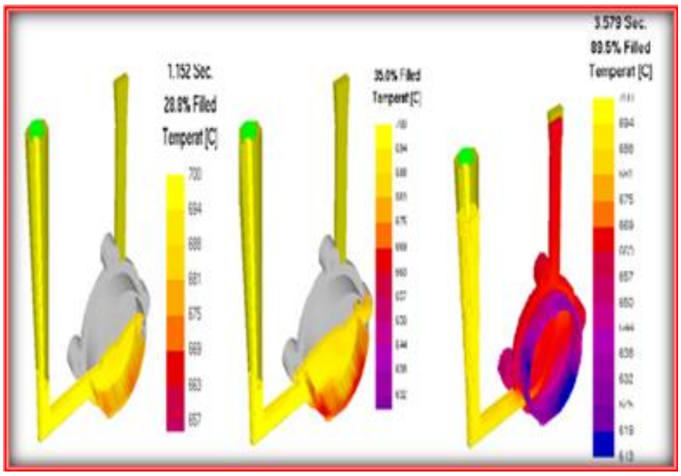

Fig-6: FLOWCast Simulation

After completion of the simulation, results are plotted using CastPic function. CastPic is a function that can create a detailed, three-dimensional image of the casting with result data plotted onto the image as a range of colors. This function can show the whole casting or section the image to show internal details in the casting. Sample plot using hotspot feature is shown in the Figure-7.

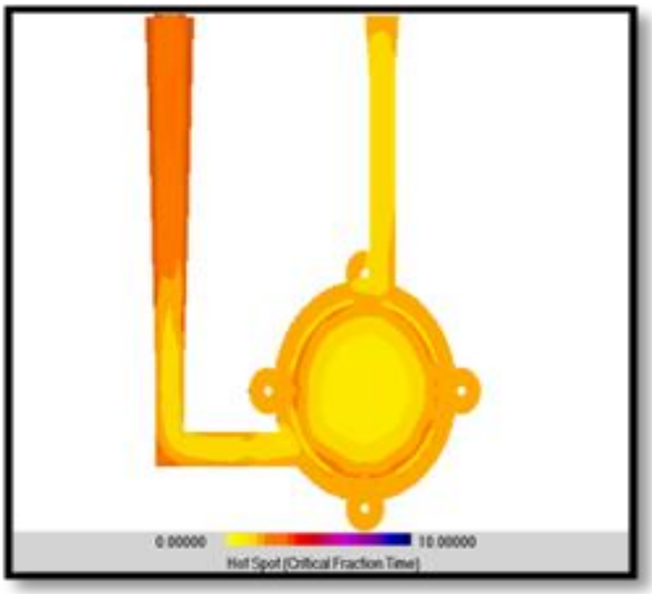

Fig-7: Plotting of results for Hotspot.

After the simulation, the results can be interpreted using following features:

- Solidification Time
- Critical Fraction Solid Time
- Material Density Function
- Temperature Gradient
- Cooling Rate
- The Niyama Criterion
- Hot Spots
- Custom Criterion

In this study Material Density Function is used to analyze the defects. ***Material Density*** criterion is a result of a calculation in which the contraction of the casting and resulting flow of liquid metal is taken into account during solidification. Areas having metal removed due to feeding liquid metal to other areas of the casting will have lower material density number. The material density function is a number varying between 0 and 1; 0 meaning that the metal has been completely drained from that part of the casting while 1 indicates completely sound metal. It is found that, in general, values in the range between 0.995 or 0.990 and below are areas of detectable shrinkage porosity in castings. Using the material density function results are plotted and compared with that of experimental castings in the Figures 8-11 shown below.

5.1.2. Stage-1 results

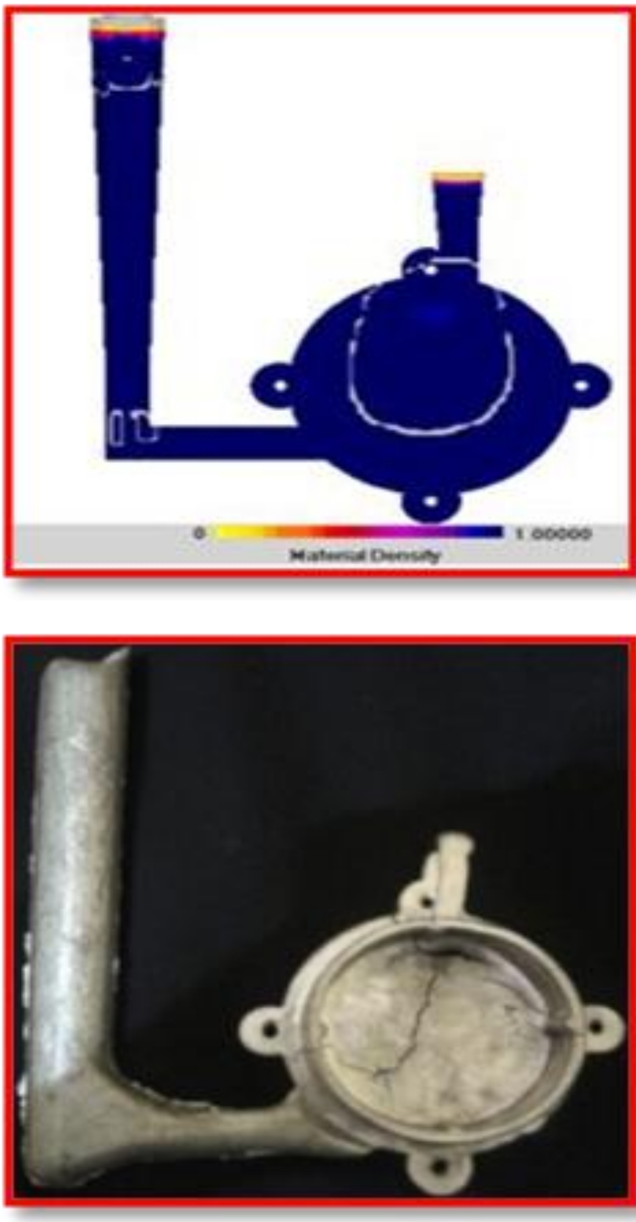

Fig-8a, 8b: Trial-1, Material LM6, Preheat 200°C

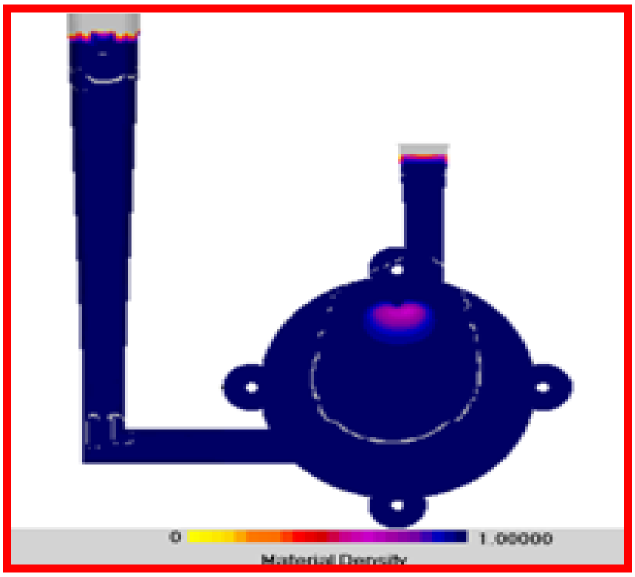

Fig-9a, 9b: Trial-2, Material LM6, Preheat 250°C

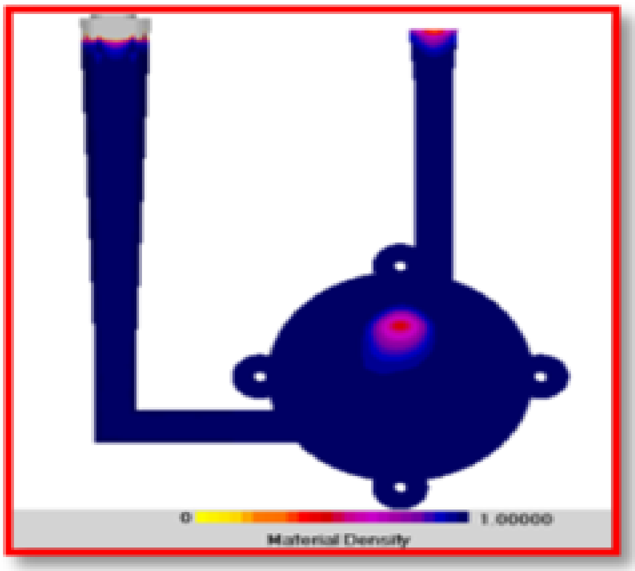

Fig-10a, 10b: Trial-3, Material LM25, Preheat 200°C

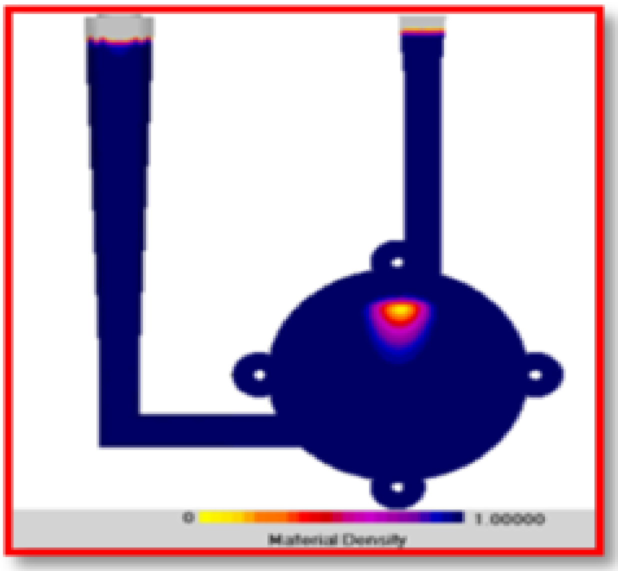

Fig-11a, 11b: Trial-4, Material LM25, Preheat 250°C

From the above Figures 8-11, it is apparent that LM25 is showing good results when compared to LM6. By preheating the die, in LM25, cracks are completely eliminated, riser is getting completely filled, there is no air entrapment or incomplete mould cavity, but the solidification shrinkage still exists exactly at the bottom of the riser. Hence it is confirmed, that in this case, change in parameters alone is not successful to eliminate all the defects completely. But it can be concluded that the software results are in validation with experimental results, as both experimental and simulation results are in good agreement with each other.

5.2. Stage-2

Process parameters were varied in the first stage in order to minimize the defects but it was not successful as all the components produced are defective. Therefore, in the second stage gating / risering system is to be varied and simulated for elimination of defects. From stage-1 simulations it is apparent that the metal is flowing smoothly in the gating channels and the defects are happening near the riser. Hence the design for risering system with LM25 alloy is only considered for further study.

The preliminary design of die was having rectangular riser. The rectangular risering system is leading to a quick solidification pattern and insufficient central flow, which prematurely closing the edges and was leaving the last filled areas fall into the inner portion of the casting. This resulted in a high probability of air entrapment in the casting and the risering system design was considered not proper for the part. Hence the existing riser shape was considered to change from rectangular to cylindrical. The cylindrical riser is modeled in SolidWorks and imported in SOLIDCast to run the simulation and observe the results. Likewise the numbers of virtual trials are performed by varying riser dimensions in SolidWorks and importing and simulating the results in SOLIDcast. The simulation results are plotted for varying riser dimensions and are shown in Figures 12-17.

5.2.1. Stage2 results

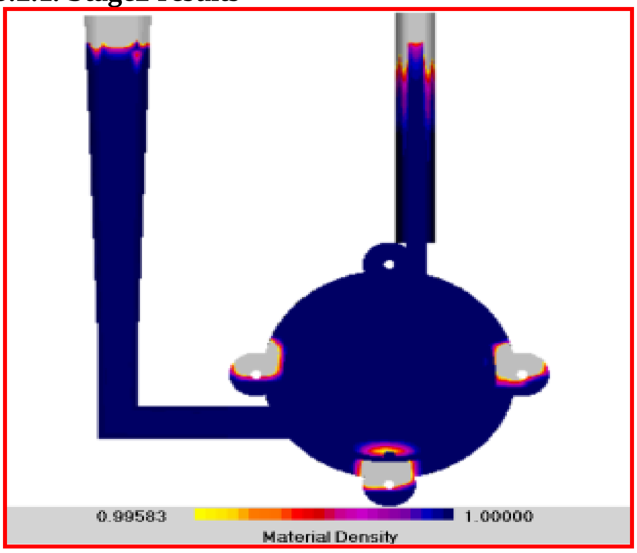

Fig-12: Riser Diameter 12mm

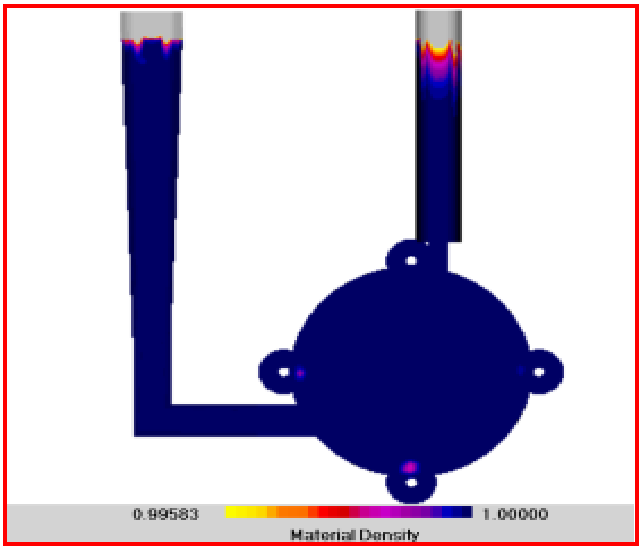

Fig-13: Riser Diameter 15mm

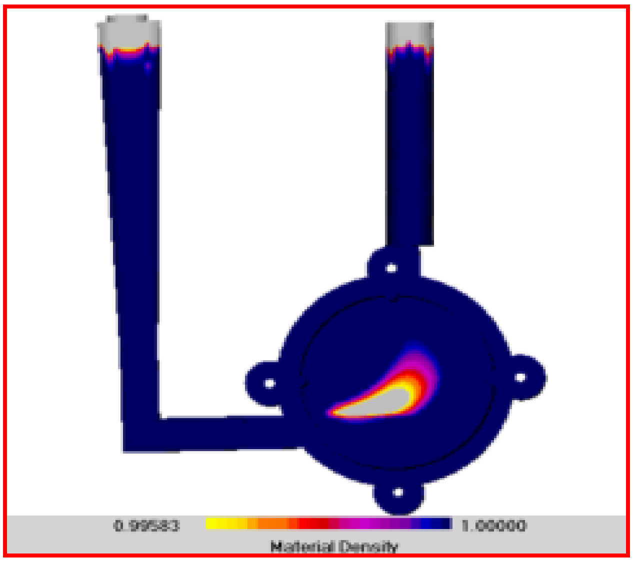

Fig-14: Riser Diameter 20mm

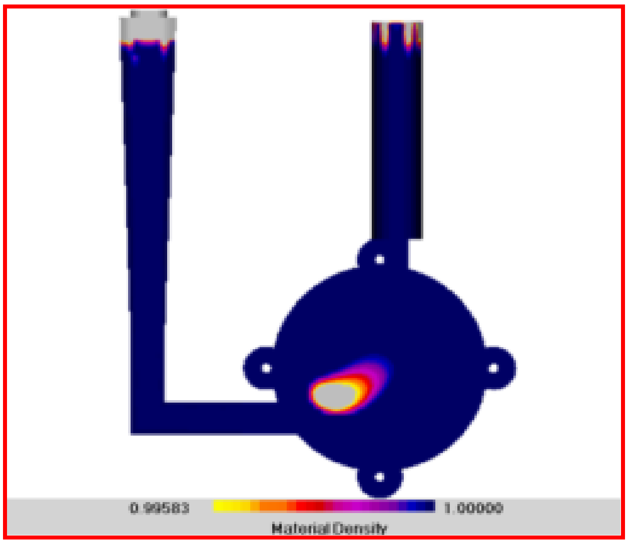

Fig-15: Riser Diameter 25mm

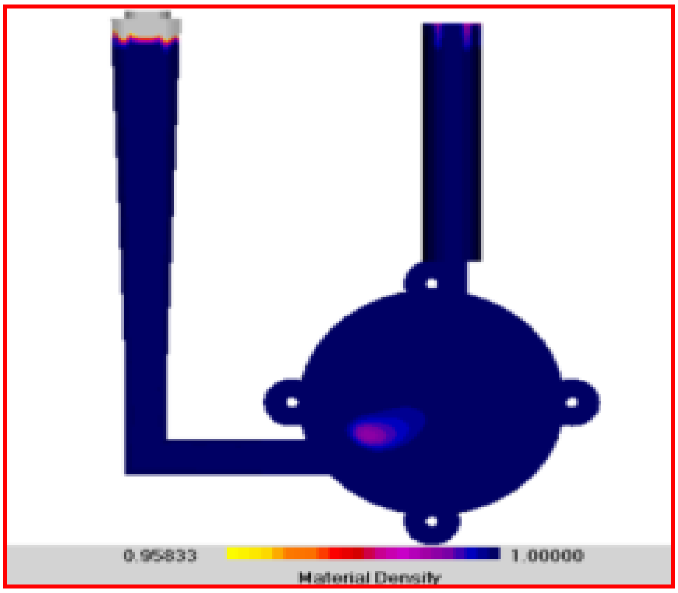

Fig-16: Riser Diameter 30mm

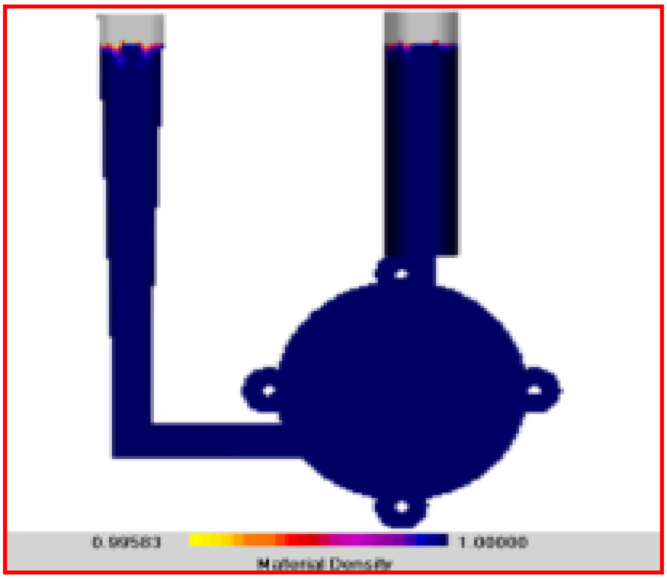

Fig-17: Riser Diameter 35mm

From the simulation results it is apparent that the riser with diameter 35mm is not producing any defects and is suitable for the casting. Hence die is machined accordingly with the simulation result to check the quality of the produced castings.

5.3. Experimental Validation

The gravity die casting mould is machined on milling machine using 35mm diameter milling tool (Figure-18). After machining the riser dimension of 35mm (Figure-19), the mould is taken to the foundry shop for testing by melting and pouring the molten metal into the modified die. It is observed that produced castings are sound and have no defects (Figure-21). Hence Zero defect casting has become a reality owing to Computer Aided Design of Casting.

Fig-18: Die during machining

Fig-19: Die after machining

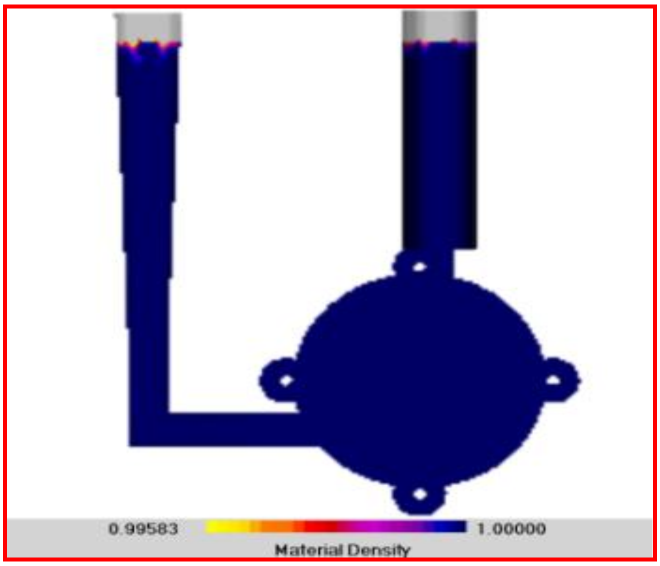

Fig-20: Final simulation result

Fig-21: Finally **s**ound casting

6. CONCLUSIONS

It can be concluded that the casting simulation has become a powerful tool to predict the location of defects and eliminate them by visualizing mould filling, solidification and cooling. It can be used to trouble shoot the existing castings or to develop a new castings without shop-floor trails by using fewer resources which reduces cost and time to market.

Modification in risering system design by changing riser dimensions eliminates the defects from the cast part. Simulation showed that the new design provides a homogeneous mold filling pattern and the last filled area was transferred from part to the riser. The results of simulation are in good accordance with that of experimentation. The defects like solidification shrinkage, cracks, unfilled riser and incomplete mould cavity are completely eliminated from the casting. So, zero defect casting has become a reality owing to computer aided design of casting, by using which it is possible produce casting right first time and every time.

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BIOGRAPHIES

Mr. Syed Ferhathullah Hussainy received his B.E. in Mech. Engg. (1992), and M.E. in Prodn. Engg. (1997) from O.U., India. He has total of 21 years of Teaching experience and presently working as Prof. and Dean in M.J.C.E.T., India.

Mr. M. Viquar Mohiuddin received his B.E. in Mech.-Prodn. Engg., from O.U., India (1999), and M.S. in Adv. Mfg. Engg., from SHU, U.K. (2002). He has total 12 years of Industrial and Teaching experience.

Dr. P. Laxminarayana received his B.E. in Mech. Engg. (1989), M.E. in Prodn. Engg. (1995), and Ph.D. in Mech. Engg. (2003) from O.U., India. He has total 23 years of Teaching experience. Presently working as Prof. in M.E.D., O.U., India.

Dr. A Krishnaiah, received his B.E. in Mech. Engg. (1994), M.E. in Prodn. Engg. (1998) from O.U., India. He did his Ph.D. from IIT Madras (2006), Post Doctoral Research from South Korea (2008). He has total 17 years of Teaching experience, 37 publications, & Presently working as Prof. in M.E.D., O.U., India.

Dr. S. Sundarrajan, done his graduation in Mech. Engg. from TCE, India, P.G. and Ph.D. in Industrial Metallurgy from IITM. He edited 2 Engg. Hand books, published over 80 Tech. papers and guided 7 PhD’s. Prior to joining NIT-T, he was with missile programme of DRDO for over 30 years and received mentoring by Dr. A. P. J. Abdul Kalam.