OPEN ACCESS

International
Journal
Of Modern Engineering Research (IJMER)

Minimization of Shrinkage Porosity in A Sand Casting Process By Simulation In AUTOCAST-X Software with Experimental Validation by Destructive testing

A.K.Gajbhiye[1], C.M.Choudhari[2], D.N.Raut[3], B.E.Narkhede[4], B.M.Bhandarkar[5]

[1](Student, M. Tech., Department of Production Engineering, V.J.T.I. Mumbai, India.)
[2](Professor, Fr. C. Rodrigues Institute of Technology, Vashi, Navi Mumbai, India.)
[3](Professor and Dean Administration, Department of Production Engineering, V.J.T.I., Mumbai, India.)
[4](Professor and Head, Department of Production Engineering, V.J.T.I., Mumbai, India)
[5](Chairman, Indian Institution of Industrial Engineering {IIIE}, Navi Mumbai, India)

Abstract: *There is an increasing demand in manufacturing environment for the best quality of casting products at the right time and quantity. In order to survive in the competitive market and to achieve customer satisfaction trial-and-error method to produce defect free casting products from design to manufacturing is too costly and not effective [1]. Modernization is the only key to improve casting quality and productivity. This paper discusses the simulation process of casting solidification with the AutoCAST-X software of a intricate shape small size casting of LM6 (Al alloy) metal. With the help of simulation study hot spot in the casting has been identified. This has immensely helped in locating the optimum position and size of the feeder required. This paper also shows the application of feeding aids as exothermic sleeve. The simulation study has shown the improvement in feeding yield and quality of the casting.*

Keywords: *AutoCAST-X, Casting, Design, Feeding aid., Hotspot, LM6(Al Alloy), Shrinkage, Simulation Software.*

I. Introduction

Metal casting is one of the oldest manufacturing processes used to manufacture the complex shape objects. There is an increasing demand in manufacturing environment for the best quality of casting products at the right time and quantity. In order to survive in the competitive market and to achieve customer satisfaction trial-and-error method to produce defect free casting products from design to manufacturing is too costly and not effective[1]. Numerical simulation provides a powerful means of analyzing various physical phenomena occurring during casting processes. It gives an insight into the details of fluid flow, heat transfer and solidification. The goal of such simulations is to help shorten the design process and optimize casting parameters to reduce scrap, use less energy and, of course, make better castings. Shrinkage is a major defect in sand casting and often becomes a cause of casting rejections and rework in casting industry. Shrinkage is a phenomenon concerning the reduction in the size of a casting during its transition from a liquid to a solid state. The volume in both the liquid and solid phases changes under the influence of temperature. The difference in density of the liquid and solid phases, which causes a significant difference in the volume of these phases, should be taken into account. The phenomenon of metal shrinkage has a substantial impact on the quality of castings. The phenomenon of casting shrinkage cannot be avoided. It is however possible to minimize the occurrence of its negative effects on the casting. In order to achieve this computer simulation is inevitably necessary. Various simulation software's based on different numerical techniques such as Finite Element Method (FEM), Vector Element Method (VEM), Finite Difference Method (FDM), Finite Volume Method (FVM), Vector Gradient Method (VGM) etc. are available to find these defects and minimize them. AutoCAST which is based on VGM is providing easy computer interface to deal with these issues for entire method designing of casting. Hence it become customary for a foundry engineer or a product designer to anticipate all issues prevailing to the potential defects in the casting and take a suitable measure in advance to minimize them. Hence one best way is to use the casting solidification simulation practices. The simulations were compared with experimental trials to ensure that the simulation results are in good agreement with the experimental trials.

II. LITERATURE REVIEW

From the existing and recent literature citations it is found that the currently available casting solidification simulation software's have a lot of capabilities to analyse the defects and have received considerable attention from researchers in the past. Various research and their finding related to improvement in casting quality and minimization of shrinkage defects using simulation software has been mentioned in this section. Yeh-Liang Hsu et. al. [2] carried the casting simulation using ProCAST software for aluminium wheels. Here, shrinkage index was used to predict the casting quality of aluminum wheels to find the optimal parameters affecting the casting process. Thoguluva R. V. et. al. [3] studied the role, prospects, and application of computers in foundries to improve casting quality and productivity. Author has mentioned about the different casting simulation softwares available. Prabhakara Rao et. al. [4] has discussed about the simulation process of casting solidification with the aid of an example, which will help the foundry industries to optimize the design parameters, better understand the mould filling and temperature history of the solidifying castings to identify the defects with the aid of obtained time-temperature contours using ProCAST softwares. Author has also mentioned the limitation of the conventional sand casting and gating design. T. Ramu et. al. [5] has developed a solid model of flywheel by using PRO-E and exported it to MAGAMA-5 software to simulate the model and to develop the pattern so as to avoid the foundry defects which will help in reducing the manufacturing cost. A. Kermanpur et. al. [6] studied the metal flow and solidification behaviors in a multi-cavity casting mould of two automotive cast parts using FLOW-3D simulation software and validated the simulation model against the experimental observations showing that the four-cavity mould is more suitable than the three-cavity one, in getting a more uniform casting quality for all cast parts. The simulation model was also able to study the effects of several casting parameters including the melt superheat, pouring time (velocity), mould surface roughness, gating design, and the mould configuration for the quality and soundness of automotive cast parts. T.Nandi et. al. [7] studied plate castings to investigate the solidification behavior of aluminum alloy (LM6) with different sizes of feeders based on conventional methods and computer simulation technique. Author has concluded that the application of casting simulation software in the foundries not only minimizes the wastages of resources but also enhances the quality and yield of castings, which implies higher value addition and lower production cost. In the present work intricate shape small size casting of LM6 (Al alloy) is taken for study. Design calculations using conventional methods has been done. designed calculation has been verified by performing solidification simulation using AutoCAST software.

III. PROBLEM DEFINITION

Fig. 1. below shows the different views of casting pattern with various allowances. The component shown in Fig. 1. has, Volume of casting, Vc = 201800 mm3, Surface area of casting, SAc = 29000mm2 and Casting modulus Mc = 6.9586 mm. Here, non-pressurized gating ratio as 1:2:2 is used.

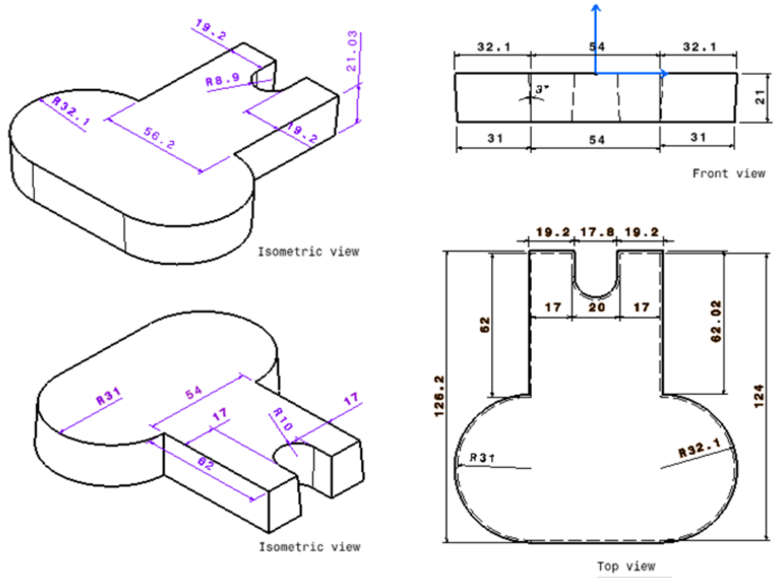

Fig.1. wooden pattern with allowances for casting

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, Modulus method and Naval Research Laboratory (NRL) method and the highest value obtained by Caine's method is taken for analysis. here, Feeder has been design in such a way that it should solidify last. A few important calculation result are mentioned in the Table 1 as given below.

Table 1. Design parameters and their calculated values.

Sr. No.	**Designed Part**	**Values**
1.	Mass of the casting (in Kg)	0.547
2.	Pouring Time (in Seconds)	5.472
3.	Diameter of Sprue at Top, Bottom and Sprue Length (in mm)	18, 15, 30
4.	Sprue well: Diameter and Height (in mm)	30, 30
5.	Runner dimensions: Width, Height and Length (in mm)	9, 18
6.	Ingate dimensions: Width, Height and Length (in mm)	9, 18, 44
7.	Feeder dimension based on Caine's method: Diameter of Feeder at Top, Bottom & Height (in mm)	50, 48, 50
8.	Neck: Diameter and height (in mm)	22, 10
9.	Pouring basin: Diameter at Top, Bottom and Height (in mm)	60, 40, 30

IV. SOLIDIFICATION SIMULATION USING AUTOCAST-X SOFTWARE

The software simulates the way casting engineers decide the casting process, parting line, cores, mold box, feeders, gating system and mold layout, and analyzes each decision to suggest how the design could be modified to improve quality as well as reduce tooling and manufacturing costs.

Solidification Simulation has been performed in AutoCAST-X environment according to the design dimensions obtained for Pattern with allowances, gating system and feeder. Simulation study of castings aims at identifying the hot spot locations, solidification time and thereby minimizing the shrinkage porosity etc. Step wise procedure for method design, internal quality assessment and obtaining the yield of the casting using AutoCAST-X software is outlined below:

The START module allows creating or opening a casting project, importing a part model, setting the materials and process, selecting the mold size, and saving a layout. These inputs are required for all other modules.

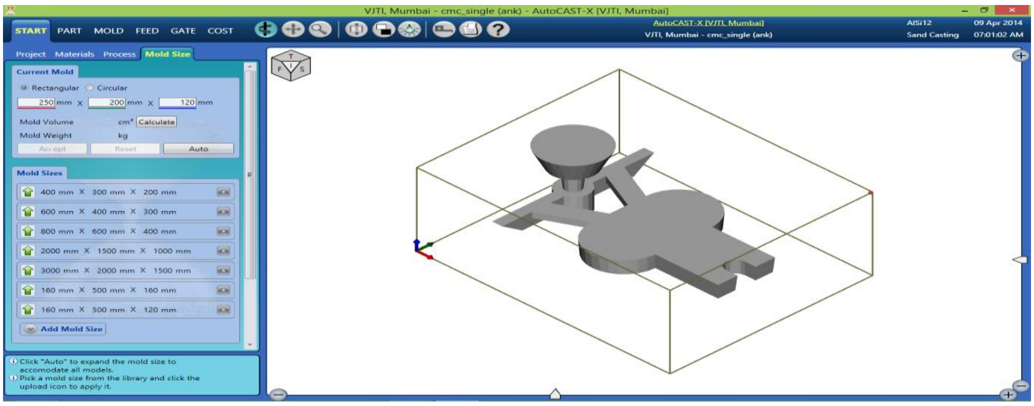

Fig. 2. imported part model of casting with mould shape and size

- Imported a 3D part model created in any CAD software as standard .STL file as shown in Fig. 2. A fitting mould will be automatically created and displayed.
- The rectangular mould box was chosen and dimensions have been taken as 250×200×120 mm.

- The entire mould containing the casting was automatically sub-divided into cubic elements for internal computations such as thickness, solidification and mould filling. The element size was defined as 2.01 mm
- Material selected was LM6 Grade Al alloy and sand casting was used as process.

The PART module is meant for computing the geometric and mass properties, analyzing the thickness (including reference radiograph), and identifying cored holes if any. These results are needed for methods design as well as for checking part-process compatibility. Part process compatibility has been checked using the optimize function. Here three parameters are checked for part-process compatibility viz. part weight, part size and minimum thickness as shown in Fig. 3.

Compatibility index = Σi importance of parameter i × compatibility of parameter i = 100%. A high compatibility index indicates an optimal process-friendly part design. The index is zero if even one parameter is incompatible (located in red zone).

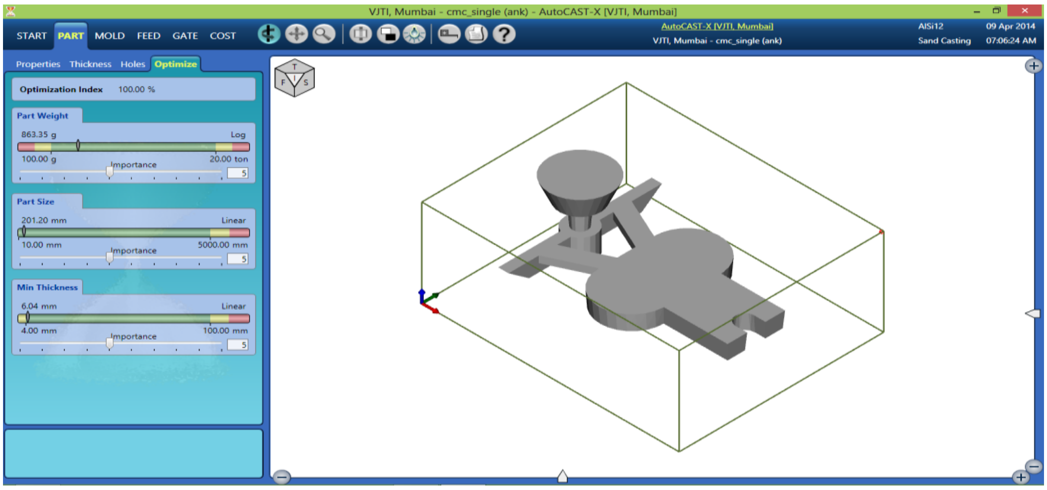

Fig. 3. part-process compatibility evaluation

The MOLD module contains functions for orienting the part in mold, setting the parting line (flat or stepped), designing cores (prints), deciding the number of cavities and their layout in mold. The mold size and cavities can be optimized considering the ratio of cast metal to mold material. Part orientation as well as parting plane placement is done in mold module as shown in Fig. 4.

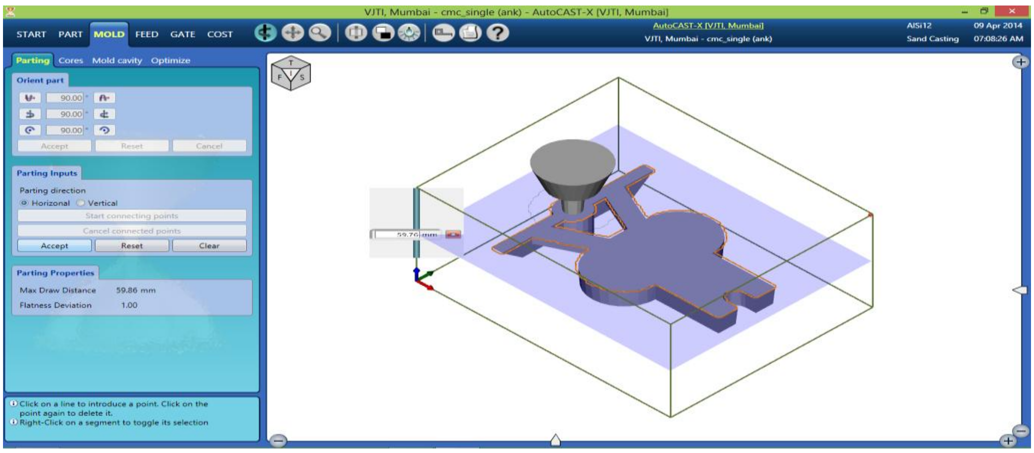

Fig. 4. placement of horizontal parting plane

The parting line is created using the volumetric mesh elements. Parting direction is selected as horizontal. Moldability index is 100% which is computed on the basis of metal to mold volume ratio, and number of mold elements as shown in Fig. 5.

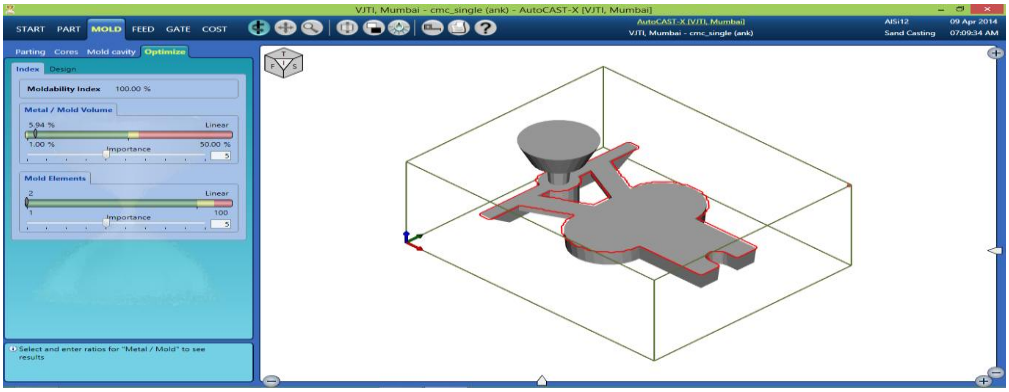

Fig. 5. moldability index

The FEED module enables designing and optimizing the feeders (feeders) with or without the feedaids to obtain the desired quality with high yield. Casting solidification is simulated and the results are shown as cooling animation and feed metal paths. The feeder design can be automatically optimized, driven by user constraints. Here, the last solidifying region of the casting has been identified as shown in Fig. 6. Green colored dot in the Fig. 8. indicates the location of the feeder.

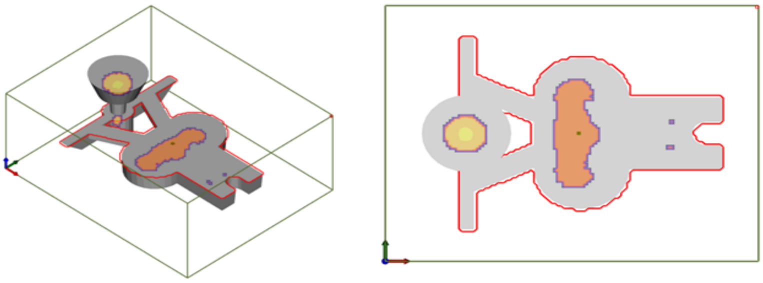

Fig. 6. hotspot indicating the last solidifying region

Now the feeder has been model according to the design dimensions and has been placed exactly on the top of the hotspot as shown in Fig. 7. to allow feed metal transfer during volumetric contraction that accompanies solidification shrinkage.

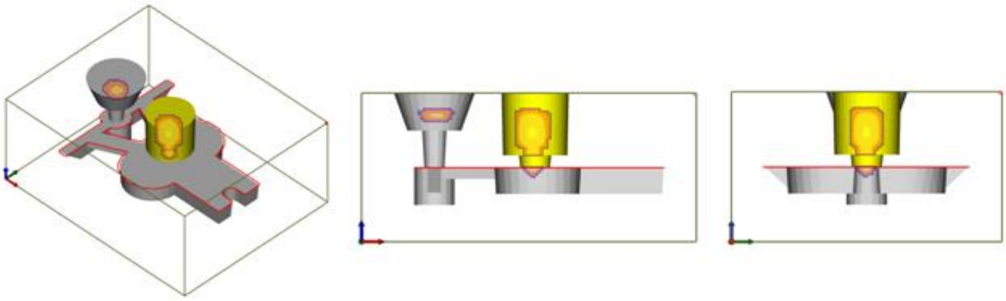

Fig. 7. partial shifted position of hotspot with the application of feeder

When insulating sleeve (exothermic) of 10mm thickness was incorporated and simulation was run. The hotspot got completely shifted in the feeder as shown in Fig. 8.

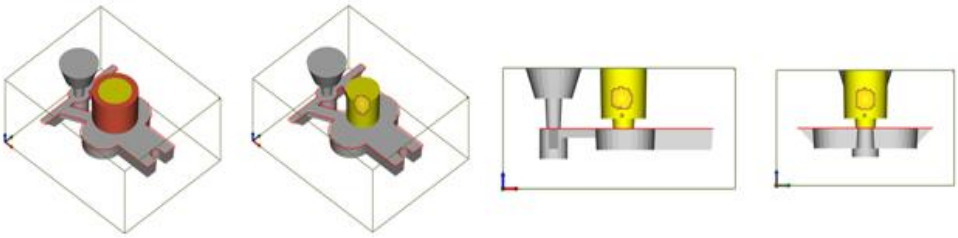

Fig. 8. completely shifted position of hotspot with the application of feeder along with sleeve

Two main results are produced in Solidification function:

- Cooling animation: progressive solidification as shown in Fig. 9.
- Feed metal paths: directional solidification as shown in Fig. 10.

Shrinkage porosity can be predicted by interpreting the above two results. This is expected in regions of high temperature and low gradient. Ideally, feedpaths should end inside a feeder. Long and hot feedpaths converging inside the casting imply a local hotspot that can result in a shrinkage porosity defect. Short and cold feedpaths are usually harmless. Good (directional) feeding is characterized by:

- Absence of isolated hot spots inside the casting
- Feedpaths converging and leading inside the feeders

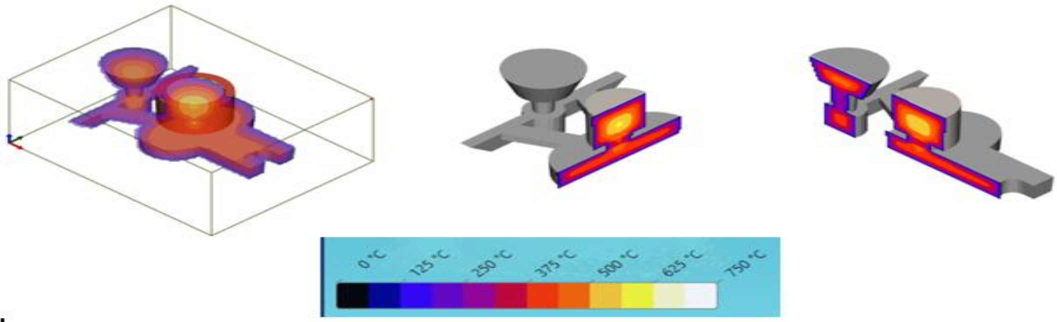

Fig. 9. cooling simulation of casting in 3D

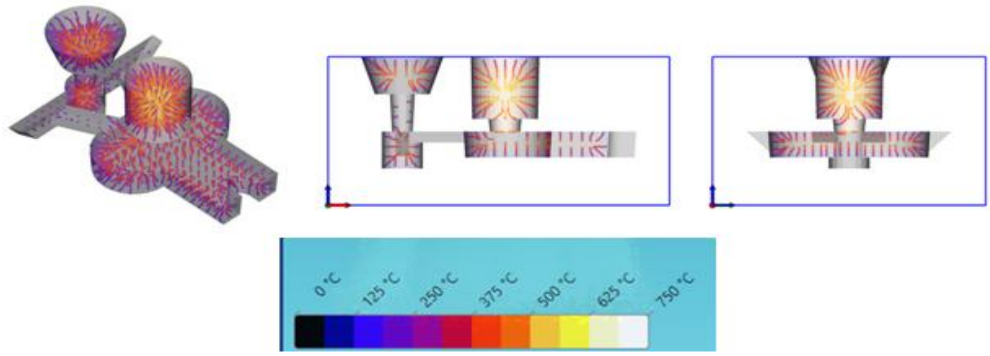

Fig. 10. feed metal paths in 3d and in cross section

Shrinkage porosity was computed from the temperature and gradients using metal-specific process characteristics. The shrinkage porosity is displayed as dots inside the casting red for macro and orange for micro as shown in Fig.11. The simulation gives the value of macro porosity and micro porosity as 3.12 cm3.

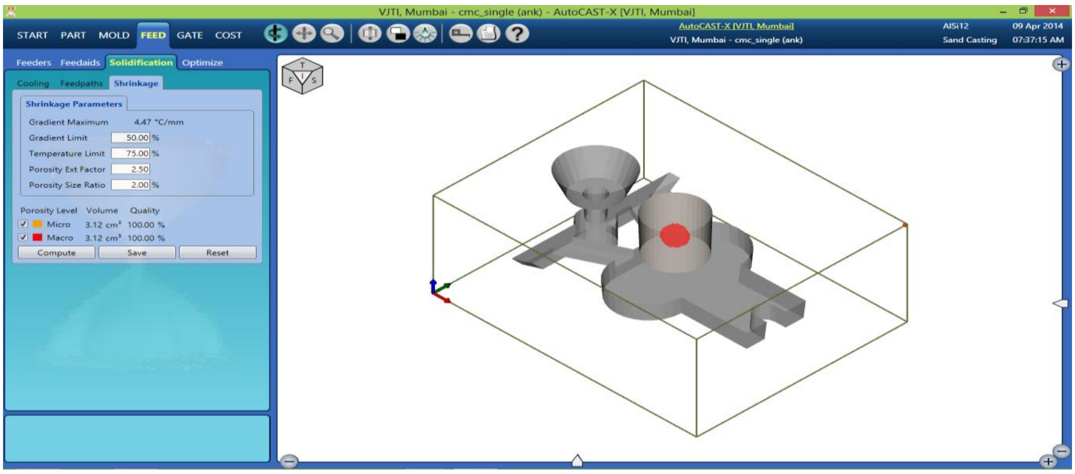

Fig. 11. shrinkage porosity as seen in 3d, side view and front view (macro-red, micro-orange)

The feeding design is evaluated (in terms of feedability index), and automatically optimized in this function. A composite weighted feedability index is computed using the above criteria and their importance (1-10 scale). The index is 100% if all criteria are in the green zone, and 0% if even one criterion is in the red zone.

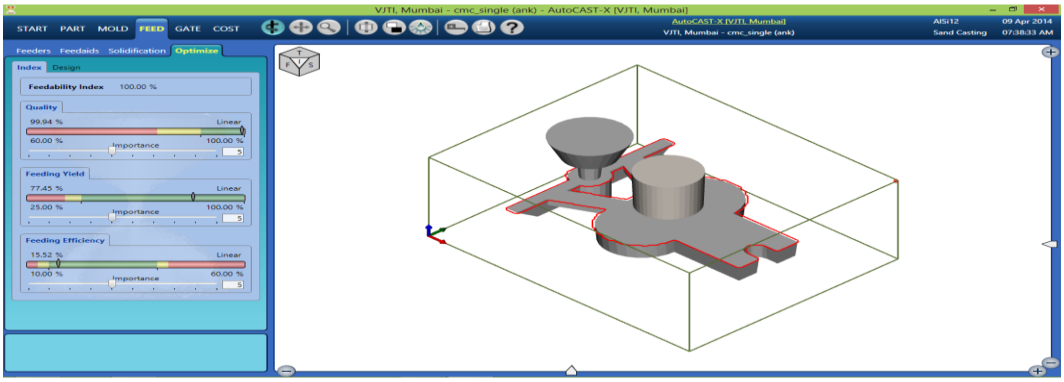

Fig. 12. feedability index

V. EXPERIMENTAL VALIDATION

After making wooden patterns as per design calculations for aluminium casting as shown in Fig. 13. A mould box of size 250 x 200 x 120 was rammed using silica sand and the mould cavity was prepared in two parts, Cope and Drag as shown in Fig. 14.

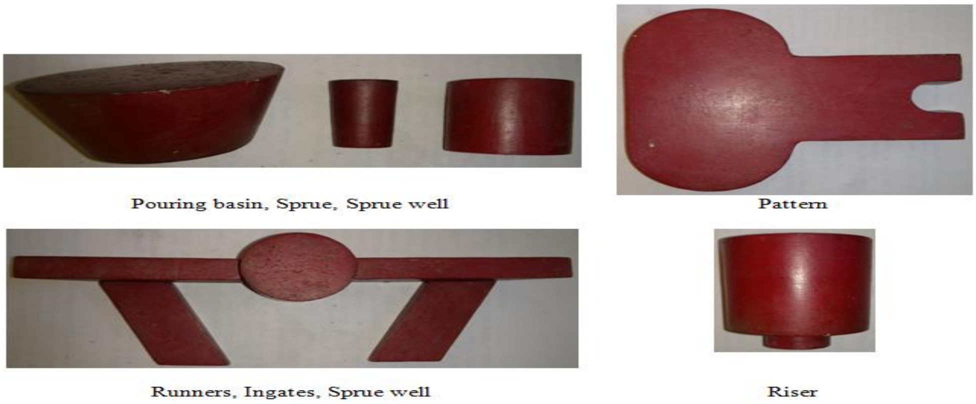

Fig. 13. wooden rigging system with pattern

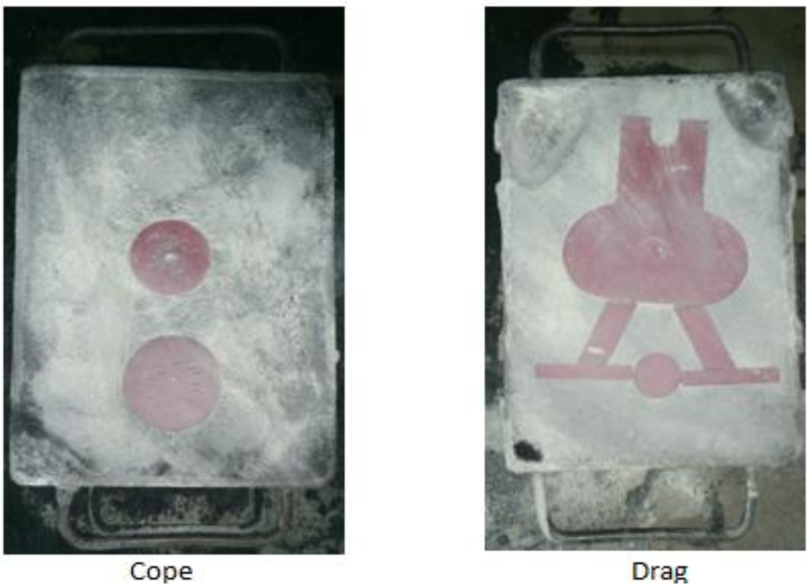

Fig. 14.cope and drag with pattern embedded in mould box

VI. RESULT

Casting trials were carried out without feeder, with feeder and feeder with exothermic sleeve. It can be seen that casting without feeder directly shows shrinkage defect at the centre as shown in Fig.15., when the feeder of 50mm diameter was placed no surface defects were present but when the component was machined shrinkage porosity was found as shown in Fig. 16. but when same feeder was placed with an exothermic sleeve of 10mm thickness no shrinkage related defects were found in the casting after machining as shown in Fig.17.

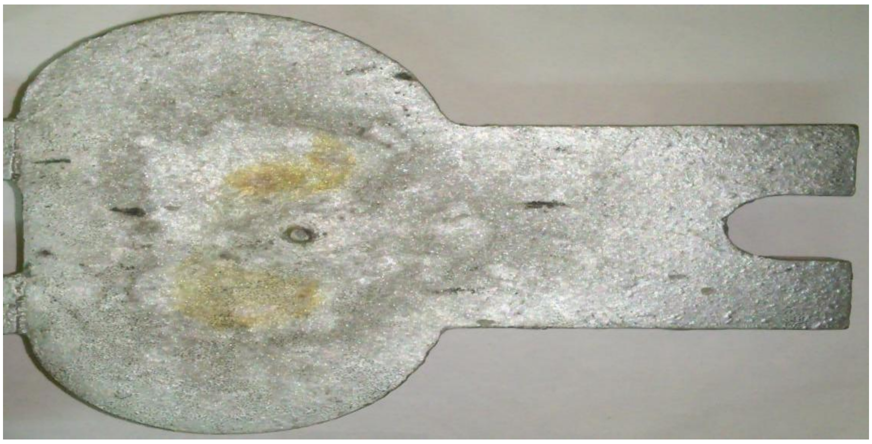

Fig. 15. casting without feeder shows defect

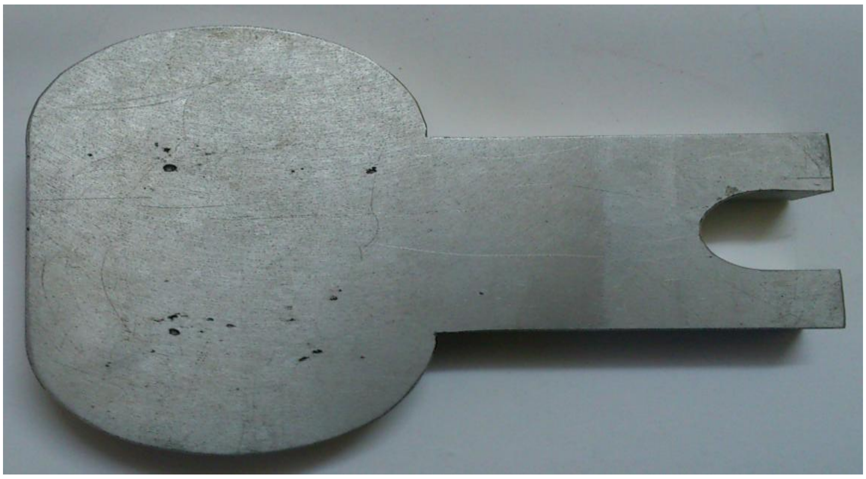

Fig. 16. casting with feeder of diameter 50mm shows defect after machining

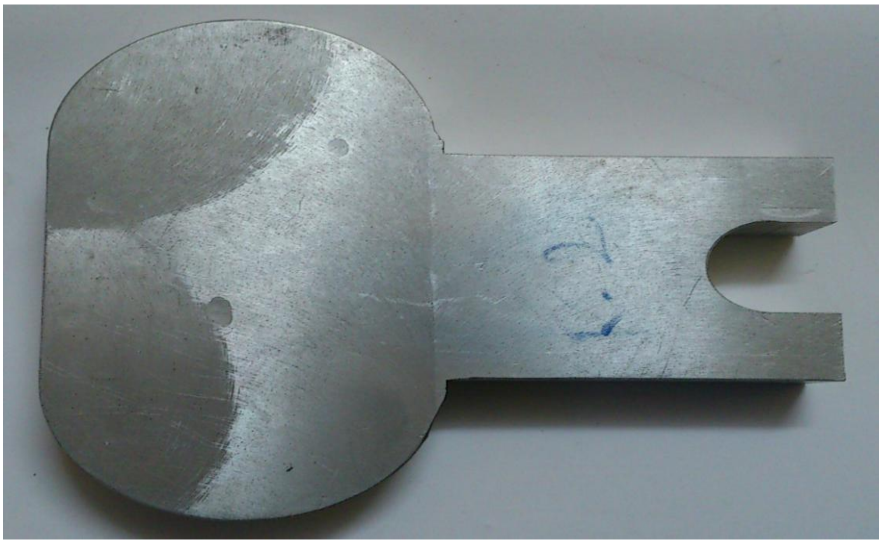

Fig. 16. casting with feeder of diameter 50mm and sleeve thickness 10mm shows no defects after machining

Fig. 17. section cut of casting with feeder of diameter 50mm and sleeve thickness 10mm shows no defects

VII. CONCLUSION

Solidification simulation has been performed in AutoCAST-X environment according to the design dimensions obtained for pattern with allowances, gating system and feeder. Simulation study of castings has provided the temperature contours which has helped in identifying the hot spot locations, solidification time etc. Step wise procedure for method design, internal quality assessment and obtaining the yield of the casting using AutoCAST-X software is outlined in this study.

When insulating sleeve(exothermic) of 10mm thickness was incorporated with the design dimensions of the feeder and simulation was run. The hotspot has got completely shifted in the feeder.

Shrinkage porosity was computed from the temperature and gradients using metal-specific process characteristics. The simulation gives the value of macro porosity and micro porosity as 3.12 cm3. This study has shown that entire shrinkage porosity has been shifted in the feeder when it was designed properly. Therefore more emphasise should be given on design phase of the casting by anticipating the probable occurrence of the defects rather than controlling the process parameters. It save time to develop new casting, wastage of material in carrying number of trials, to develop sound casting, energy and most important is money.

Casting with feeder of diameter 48mm along with the sleeve of thickness 10mm has been validated by performing actual trials in a foundry. Using sleeve as a feed aid helped in increasing casting yield.

REFERENCES

Journal Papers:

[1] Shamsuddin Sulaiman, Lim Ying Pio, Validation Of MAGMAsoft Simulation Of The Sand Casting Process, The Institution of Engineers, Malaysia, September/December 2004, Vol. 65, No. 3/4, 55-64.

[2] Yeh-Liang Hsu, Chia-Chieh Yu, Computer Simulation Of Casting Process Of Aluminium Wheels – A Case Study, J. Engineering Manufacture, 2006, Vol. 220, Part B, 203-211.

[3] Thoguluva Raghavan Vijayaram, Paolo Piccardo, Computers in Foundries, Metallurgical Science and Technology, 2012, Vol. 30-2, 28-38.

[4] P. Prabhakara Rao, G. Chakraverthi, A. C. S. Kumar, G. Srinivasa Rao, Modeling and Simulation of Solidification in Alloy Steel Sand Castings, International Journal of Thermal Technologies, Dec. 2011, Vol.1, No.1, 110-116.

[5] T. Ramu, M. L. S. Deva Kumar, B. K. C. Ganesh, Modeling, Simulation And Analysis In Manufacturing Of A Flywheel Casting By S.G.Iron, International Journal of Materials and Biomaterials Applications, 2012; 2(4): 25-28.
[6] A. Kermanpur, Sh. Mahmoudi, A. Hajipour, Numerical Simulation Of Metal Flow And Solidification In The Multi-Cavity Casting Moulds Of Automotive Components, Journal Of Materials Processing Technology, 2008, 1-7.
[7] T. Nandi, R. Behera, S. Kayal, A. Chanda, G.Sutradhar, Optimization Of Feeder Size Of Aluminium Alloy (LM6) Castings By Using Conventional Method And Computer Simulation Technique, Nov. 2011, International Journal Of Scientific & Engineering Research, Volume 2, Issue 11, 1-6.
[8] El Hassan E. M. Khalafalla, Hashim A. A. El Hashimi, Simulation Of Heat Flow In Aluminum Sand Casting, Shendi University Journal, January 2010, Issue No. 8, 15-48.
[9] AutoCAST information and case studies, Advanced Reasoning Technologies Pvt. Ltd., http://www.adva-reason.com.

Books:
[10] P. N. Rao, Manufacturing Technology (TATA Mc Graw-Hill Education, New Delhi, 2008).
[11] B. Ravi, Metal Casting: Computer Aided Design and Analysis (PHI Learning Pvt. Ltd.2011).